Case Study for Lighting Performance Enhancing for Multi - Purpose Sport Hall Lighting Analysis

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Abstract: ***Lighting plays a crucial role in indoor environments, significantly affecting human comfort and activity performance. In the context of sports halls, effective lighting design is essential not only for player performance and safety but also for minimizing CO2 emissions. This study examines the lighting design of a multipurpose sports hall, focusing on enhancing the existing setup by replacing traditional metal halide fixtures with energy - efficient LED lights. The hall, designed for handball, basketball, and volleyball, must meet various illumination standards for both televised and non - televised events. Using simulation software, the study compares the current lighting strategy with a proposed LED - based approach. The findings indicate that the LED design significantly reduces power consumption while meeting or exceeding illumination standards, thereby enhancing both energy efficiency and lighting quality.***

Keywords: lighting design, energy efficiency, sports hall, LED lights, illumination standards

1. Introduction

Lighting is one of the critical factors affecting indoor quality and human comfort. Nowadays, designing sufficient lighting is not enough, as the demand for minimising CO2 emissions has become a priority. To achieve sustainable lighting design, some variables need to be taken into consideration, such as illumination level, uniformity, and power consumption. Meeting the illumines demands of the standard requirements for sport halls helps players speed up ball recognition, lengthen visual durability, improve sporting quality, and prevent injuries and accidents during exercises or competitions. In this research, a multi - purpose sport hall lighting design has been studied and analysed to enhance the existing design and replace the current light fixture with a power - saving type (LED). The project consists of three buildings (administration buildings, a stadium (multi - purpose hall), and a service block). It's has a capacity of 2500 people. The study will focus on one part of the stadium building, which is the multipurpose hall. The multi - purpose design is designed for three different sports (handball, basketball, and volleyball). The dimensions of the stadium are 62.18 m by 80 m, and the play floor area is 18 m by 9 m, with an area of 162 square metres and a height of almost 30 meters. The playing area dimensions vary depending on the type of sport. Multipurpose hall lighting system design based on EN 12193 Sports Lighting standard, GAISF (General Association of International Sport Federation European Broadcasting Union). The lighting design took into consideration two types of lighting load calculation criteria (lighting specifications for televised events and lighting specifications for non - televised events). In addition, all luminance levels for sport fields are as per Olympic standards for both national and international activities. The hall is a closed venue that depends totally on artificial lighting.

Figure 1: Project Layout

Figure 2: Outside view

Figure 3: Inside multipurpose hall

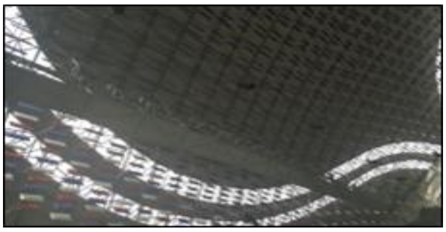

Figure 4: lighting fixture distribution

2. Problem Statement

The aim of this research is to enhance the existing lighting design by using LED lighting fixtures and find an optimal distribution strategy for the multipurpose hall, which helps save power. Since it is a multi - purpose sports hall, the lighting requirements of each sport must be fully understood at the beginning of the project (handball, basketball, and volleyball). In addition, lighting design factors such as illumination level, uniformity, and light temperature should be taken into consideration. In this research,, two lighting distribution strategies will be studied. The first strategy as it is available at the project, is to have the lighting located on two sides of the multipurpose hall with asymmetric light output and metal halide. The proposed strategy is to replace metal halide lights with LED lights and find the best distribution strategy that achieves the highest illuminance levels for both horizontal and vertical services. Then, the results from both strategies will be compared according to the best strategy for saving energy. In both strategies, the design requirements mentioned in the IESNA standard should be followed for both televised and non - televised events. In television coverage, the vertical illuminance needs to be calculated. Although with new television camera technology, the levels of light required to produce a high - quality image are lower, there is still a chance of an inconsistent image. So, factors such as colour rendering and colour temperature need to be coordinated with light levels.

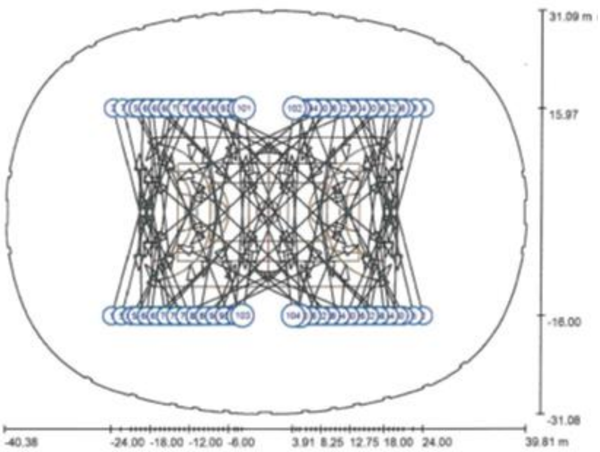

Figure 6: Existing Lighting distribution

Objectives

a) Find the best strategy for lighting design that reduce the power consumption.
b) Enhance the current design by using LED lighting instead of Metal halide.

3. Literature Review

3.1 British standard BS EN 12193: 2007 (Light and lighting – sport lighting)

According to British standard BS EN 12193: 2007 (Light and lighting—sport lighting), there are specific requirements for color television and film recording. The illuminance on a vertical plane forms the basis of the lighting requirements for CTV and film systems. The vertical plane is the point at 1 m above the playing surface. The level of vertical illuminance depends mainly on the speed of action, the shooting distance, and the lens angle. Moreover, the uniformity of vertical illuminance, defined as the minimum vertical illuminance divided by the maximum vertical illumination, should be greater than 0.3, as shown in the following equation at a single grid point over the four planes facing the sides of the playing area:

$$\frac{E_{min}}{E_{max}} \geq 0.3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq (1)}$$

The illuminance is the most important factor for camera recording. So, adequate horizontal illuminance must be achieved, and sufficiently good balance between the horizontal and vertical lighting levels is obtained when the average horizontal illuminance to the average vertical illuminance (relative to main camera positions) is such that:

$$0.5 \leq \frac{E_{h\,ave}}{E_{v\,ave}} \leq 2 \ldots\ldots\ldots\ldots\ldots \text{eq (2)}$$

In addition to the other requirements the uniformity of horizontal illuminance on the playing field should be:

$$\frac{E_{h\,min}}{E_{h\,max}} \geq 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq (3)}$$

In the case of outdoor installations or indoor installations with a significant daylight contribution, the color temperature of the artificial lighting shall be between 4000 K and 6500 K where floodlighting is used during daylight and evening. If there is no significant daylight contribution, then the range can be extended to between 3000 K and 6500 K. In general, the color rendering index lighting shall always be better than 65, with a preferred value of at least 80.

Table 1: Lighting requirements according to each sport based on British standard:

Indoor (sport type)	class	$\bar{E}_m$ lx Horizontal illuminance	$E_{min}/\bar{E}_m$ Horizontal illuminance	CRI
Basketball, Handball, Volleyball	I	750	0.7	>60
	II	500	0.7	>60
	III	200	0.5	>20

3.2 IESNA – Sports lighting standard

According to the IESNA Sports Lighting Standard, there is an acceleration between the size of the facility and the level of the player; a player with a higher level of skill attacks more spectators. A larger number of spectators means a larger size of the playing field, and the distance between the fields and audience increased, which increased the need for more illuminance on the playing field to see players and tasks. In large sports facilities, activities and events are either broadcast or recorded for television. Higher illuminance required for televisions because it helps with high - speed shutters and small apertures that increase image sharpness and depth of field. More light is good for slow motion, stop action, and special effects created with telephoto lenses. HDTV replaced standard color TV, and it is recommended to use Lamps stroboscopic effect associated with low frequency ballast on the HID system. The most important thing for broadcasting is to provide sufficient illuminance.

Table 2: Lighting requirements according to each sport based on IESNA - Sport lighting standard

Indoor (sport type)	**class**	**E_h** horizontal target Ages of observers (25 - 65)	**E_v** vertical target Ages of observers (25 - 65)	Uniformity target (playing area) CV	Uniformity target (playing area) Max: Min
Basketball, Volleyball, Handball	I	1000	300	0.13	1.7: 1
	II	750	200	0.21	2.5: 1
	III	500	150	0.25	3: 1
	IV	300	100	0.3	4: 1

The uniformity target is measured by two criteria, as shown in the table. The first one is CV, which stands for coefficient value, which is the ratio of the standard deviation for all illuminance values to the mean illuminance value. The second is the ratio of maximum illuminance to minimum illuminance found for the area of the playing field.

The recommended color temperature of a light source, according to the IESNA, typically varies from 3000 K to 6000 K. In addition, the color quality is defined as CRI, which should not be less than 65.

3.3 Chin - Hsien Hsu studied the effect of lighting quality on visual perception.

Chin - Hsien Hsu studied the effect of lighting quality on spectator's visual perception at sporting events by developing a spectator visual perception model. The author stated the importance of designing good lighting for both the safety of spectators and the athletics and reputation of the place when hosting international events. Well - designed lighting can relieve strain on the eyes, speed up the recognition of objects, lengthen visual durability, improve sporting quality, and prevent injuries and accidents during exercises or competitions. This study aims to investigate the quality of lighting at a specific sports event and test its impact on the visual perceptions of spectators at the event. The study was conducted on the World Games in - line hockey competition in two stages. The first stage was a physical investigation at the site to test the lighting parameters, which were in compliance with the standard. The methodology followed to measure lighting quality at the site was to experimentally test and measure the lighting at several spots. The lights survey followed the international illuminance standard for the in - line hockey method. The results showed that both illuminance levels and lighting uniformity did not meet the standard requirements, which may affect the players' and spectators' vision in locating the ball as well as determining its speed. In the second stage of the research, it was conducted by applying a survey to spectators. The survey concentrated on three key areas: illumination, illuminance variance, and visual clarity. From the survey, a mathematical model was generated based on the statistical data collected. The model measured the visual perception and psychological impact of the lighting on spectators. The aim of the structural model was to investigate whether spectators visual perceptions were affected by them as hockey players or not, and to find out how this could impact their view of the lighting provided at the hockey game. The results showed that the spectators who were players had higher sensitivity to the lighting than general spectators or the audience. However, it should be noted that whether or not spectators used to hockey players have a positive impact on the visual perception of lighting, its 'influential power' only reached 16%.

3.4 Why Invest in Energy Efficiency? The Example of Lighting

In this article, a different approach to evaluating the benefits and risks of energy efficiency investments have been taken in consideration. The selection of optimal technology always depends on the intensity of use and the expected rate of return. In this research, different types of lighting have been studied (halogen light bulb, compact fluorescent, and LED light source). The comparison between the lighting held depends on several factors, such as investment need in AED, discounted payback time in years (r = 7%), lifespan, cost savings compared to incandescent light bulbs in USD/year (r = 7%), cost savings compared to incandescent light bulb percent (r = 7%), and energy savings compared to incandescent light bulbs. The comparison was between the indicators of the different light sources relative to the incandescent light bulb. The duration of working hours ranged from 1 hour per day up to 6 hours per day. The findings were that the selection of the technology depends on the intensity of use; the higher, the better and more feasible. To invest in technologies with a higher initial cost is feasible only when the benefits of future cost savings can be used. The financial risk of the new technology can be avoided by the time limitations of the manufacturing warranty period. The other important result is that LED and compact fluorescent lamps compared to incandescent bulbs, depending on their daily use, can save up to 24–74% on the total cost on an annual average.

4. Methodology

In this research, a different lighting distribution strategy will be tested using a simulation Software (DIAlux evo). The Software offers a variety of lighting fixture options with different illuminances. The design will follow the IENA sport lighting standard. The aim is to find a better distribution strategy that helps reduce power consumption with better lighting uniformity. The proposed strategy is to distribute the lighting perpendicular to and at the sides of the playing area (PA) and use LED lights instead of metal halide. DIAlux Evo helps model the new lighting distribution strategy and gives information related to the lighting fixture needed to be fixed and the power consumption of it. Then, both the proposed strategy and the existing one will be compared according to the best strategy in conserving energy and satisfying the design requirements. The comparison will not be limited to the power consumption but also some other variables such as (average working hours of the lighting, horizontal illuminance, vertical illuminance, uniformity, and color rendering index. The best strategy will be recommended for the new sports complex in RAS - Alkema. Different scenarios will be tested for each sport and for both televised and non - televised events.

4.1 Design requirements

The following table shows the recommended minimum average horizontal illuminance level for each class of play and the minimum or average level of uniformity. The minimum colour rendering index is included.

Table 3: Non - Televised indoor lighting recommendations:

Play	class	Horizontal illuminance	Uniformity Min/average	Color rendering Index
Basketball, Volleyball, Handball	I	750	0.7	>60
	II	500	0.7	>60
	III	200	0.5	>60

Defining the class of play:

- Class I: top - level competition, both national and international. There are a large number of spectators and a long viewing distance.
- Class II: medium - level competitions. Matches at a regional or local club with a medium number of spectators and an average viewing distance.
- Class III: low - level competition or training. It usually involves a small number of spectators and a short viewing distance.

On the other hand, there are different recommendations regarding televised competition. In televised events, both vertical and horizontal illuminance levels should be taken into consideration. Although new televised cameras nowadays are more advanced, the level of light required to produce high - quality images is still high. In addition, there is a chance of inconsistency in image quality. Hence, the quality of light needs to be coordinated with many other factors, such as color rendering and color temperature. The recommended color temperature for sports facilities is usually between 4200 K and 5600 K. The color rendering index should not be less than 80, and it is preferred to be 90.

Table 4: Televised indoor lighting recommendations:

	Horizontal Illuminance	Uniformity Min/ave	Uniformity Min/Max	Vertical Illuminance	Uniformity Min/ave	Uniformity Min/Max	Color Rendering	Glare rating
HDTV	1500 - 3000	0.8	0.7	2200	0.7	0.6	>90	<50
Slow motion Camera	1500 - 3000	0.8	0.6	1800	0.7	0.5	>80	<50
Fixed Camera	1500 - 3000	0.8	0.6	1400	0.7	0.5	>80	<50
Mobil Camera	1500 - 3000	0.8	0.6	1200	0.5	0.3	>80	<50

According to the standard, the recommended average horizontal - to - vertical ratio for the playing field is between (0.75 and 1.5)

The specific requirements for the multi - purpose hall under study are:

Table 5: Specific lighting specifications for the multi - purpose hall for televised events

		Vertical illuminance			Horizontal illuminance			Properties of Lamps	
Class	Calculation to words	Ev cam ave	Uniformity		Ev cam ave	Uniformity		Color Temperature	Color Rendering Index
		Lux	U1	U2	Lux	U1	U2	K	Ra
Class V International	Fixed camera	2000	0.6	0.7	2500	0.7	0.8	>4000	>66
	Fixed camera at pitch level	1800	0.4	0.6					
Class IV National	Fixed camera	2200	0.6	0.7	3000	0.7	0.8	>4000	>66
	Fixed camera at pitch level	2000	0.5	0.6					

Table 6: Specific lighting specifications for the multi - purpose hall for non - televised events

Activity Level	Horizontal illuminance	Uniformity	Lamp color Temperature	Lamp color Rendering
Class I national games	750	0.7	>4000	>66
Class II	550	0.7	>4000	>66
Class I	250	0.5	>4000	>66

- Maintenance factor: 0.7
- Height of the utilization plane: 0 m (horizontal illuminance)
- Height of the reference plane: 1.5 m (vertical illuminance)
- Aiming angle of flood lights < 65 degree (glare reduction)
- Vertical illuminance facing fixed Camera (x= 0.00, y= - 22.00, height z= 7.50 m)

4.2 Calculation and Results

4.2.1 Existing design results

Table 7: Current Design Results

Switching Level	Number of lights ON	Vertical illuminance (lux) required	Horizontal illuminance (lux) required	Area	E average horizontal	E min	E max	E_{min}/E_{av}	E_{min}/E_{min}
Switching Level 1	100	2000	3000	Total Area	2267	1081	3470	0.477	0.311
				Playing area	2834	1931	3416	0.68	0.57
Switching Level 2	36	N/A	700 - 800	Total Area	553	317	778	0.573	0.407
				Playing area	662	490	775	0.74	0.63
Switching Level 3	24	N/A	500 - 600	Total Area	393	185	634	0.470	0.291
				Playing area	487	319	623	0.66	0.51
Switching Level 4	12	N/A	300 - 400	Total Area	184	111	269	0.603	0.413
				Playing area	220	166	268	0.76	0.62

The existing design didn't include vertical illuminance in calculation.

Table 8: Light fixture specifications in existing Design.

Model	brand	Number of Units	Luminous Flux (L_m)	Wattage	CRI	Temperature K	Working hours
Metal halide LLF 120072.00121.3.921	LMG	48	106943	2000	60	4300	12000 hr 50% loss
Metal halide ZM.022.2/3	LMG	52	52512	1000	57	4300	12000 hr 50% loss

From the above results, it shows that the current design does not totally satisfy the requirements. That is why the need for enhancement is essential. Many factors need to be enhanced, such as color rendering index of the lamp and the study of the vertical illuminance level at 1.5 m from the surface. Moreover, the uniformity of the lighting needs to be improved in the proposed design.

The existing design distribution is on the two sides of the playing area with asymmetric light fittings. The specifications of the light are IP65, with an Osram metal - halide lamp 2000W 400V E40 - HQI - T 2000W/D/I built - in internal starter and three types of asymmetrical optics used for indoor and outdoor sporting events, for installation on masts and structures of up to 30–40 m in height above and around the illuminated area.

4.2.2 Proposed Design

The proposed design enhances not only the illumination and uniformity but also reduces power consumption. The design suggests using LED light fixtures instead of metal halide, which consumes more power and has a lower maintenance factor and working hours. There are two proposed designs that satisfy design requirements and achieve standard requirements. The first one focuses on uniformity as a priority, and the second one focuses on vertical illuminate as a priority. Actually, trying to achieve both is not cost - effective, and it increases the illumination above the required limits. The optimum strategy is to distribute lighting fixtures on the two sides of the playing area. But not to distribute the lighting at the side of the goal to prevent light blindness that may occur to the players. The proposed design suggests using different lighting numbers distributed in two lines with different mounting heights and angles for the reach line. The upper lighting group has an 18 - metre height and a 30 - degree angle. The lower group has a 16 - metre height and a 40 - degree angle. For non - televised events, there is more than one classification depending on activity level. In all non - televised events, the vertical illuminance is neglected. In this case, there are three main classes (Class I, Class II, and Class III). According to the standard each class has, there are requirements regarding horizontal illuminance and uniformity. In this project, the lighting dimming process was used to achieve the illuminance requirement for each class. In fact, using the dimming process is better than switching on the right number of lights. Because it can maintain higher uniformity and be better seen as a consequence. The following table compares the results of the existing design to the proposed design.

Table 9: Light fixture specifications in existing Design.

Model	brand	Number of Units	Luminous Flux (Lm)	Wattage	CRI	Temperature K	Working hours
Endo Lighting Corp. ERG5299S HIGH - BAY Series	Endo Lighting	114	30647	305.7	82	4000	40, 000
Traxon Technologies Limited - Washer Quattro AC XB4.18 DW 13 Full ON Washer Quattro AC XB4.18 DW 13 Full ON	Traxon Technologies	48	4975	80.1	100	3000	40, 000

Table 10: Proposed Design Results

Switching Level	Number of lights ON	Vertical illuminance (lux) required	E avr vertical (lux) design	Emin/ E av	Emin/ Emin	Horizontal illuminance (lux) required	Area	E average horizontal	E min	E max	Emin/ E av	Emin/ Emin
Switching Level 1	162	2000	2115	0.81	0.75	3000	Total Area	3188	0	5120	0	0
							Playing area	4501	3171	5120	0.70	0.62
Switching Level 2 Class I	162 dimming 17%	N/A	N/A			750	Total Area	542	0	871	0	0
							Playing area	765	539	871	0.7	0.62
		N/A	N/A			550	Total Area	383	0	615	0	0

Switching Level 3 Class II	162 dimming 12%				Playing area	540	381	615	0.71	0.62
Switching Level 4 Class III	162 dimming 6%	N/A	N/A	250	Total Area	191	0	308	0	0
					Playing area	270	190	307	0.7	0.62

Table 11: Lighting Fixture Schedule

Light Fixture Schedule								
Light No.	Descriptions	illuminance (lux)	watt	K	CRI	Mounting Hight m	Distance form middel m	Rotatio Angel
L1 - L29	LED Endo Lighting ERG5299S high Bay	30647	305.7	4000	82	16	11.2	y= -40
L30- L57	LED Endo Lighting ERG5299S high Bay	30647	305.7	4000	82	18	11.2	y= - 30
L58- L86	LED Endo Lighting ERG5299S high Bay	30647	305.7	4000	82	16	11.2	y= 40
L87- L114	LED Endo Lighting ERG5299S high Bay	30647	305.7	4000	82	18	11.2	y= 30
L115- L138	Traxon Technologies Limited - Washer Quattro AC XB4.18 DW 13 Full ON Washer Quattro AC XB4.18 DW	4975	80.1	3000	100	18	9.7	x= 20
L139- L162	Traxon Technologies Limited - Washer Quattro AC XB4.18 DW 13 Full ON Washer Quattro AC XB4.18 DW	4975	80.1	3000	100	18	9.7	x= -20

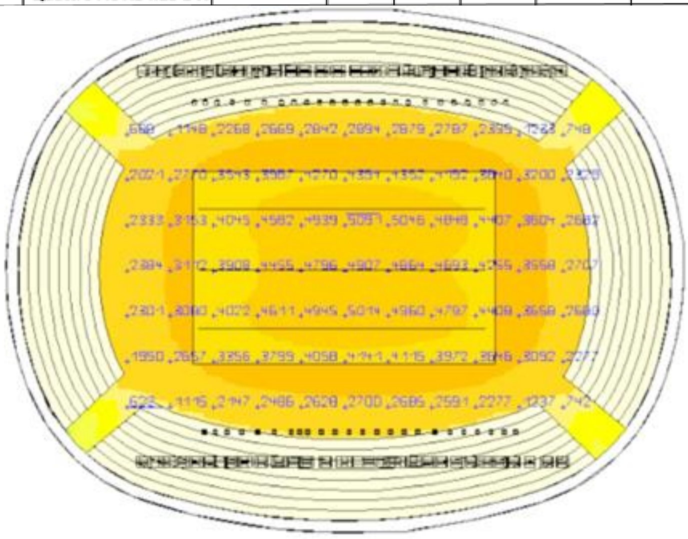

Figure 6: Proposed lighting distribution for televised event

Table 12: Comparison between proposed design and existing design for the playing area.

Parameters	Existing Design	Proposed Design
Number of lights	100	162
Horizontal Illuminance televised events	2834	4501
Vertical Illuminance televised events	Not specify	2115
Uniformity E_{min}/E_{av}	0.68	0.70
Uniformity E_{min}/E_{min}	0.57	0.62
Temperature	4300	4000
CRI	60	82
Total Power consumption W/h	149, 000	38, 694.6
Average Working hours	12000	40000

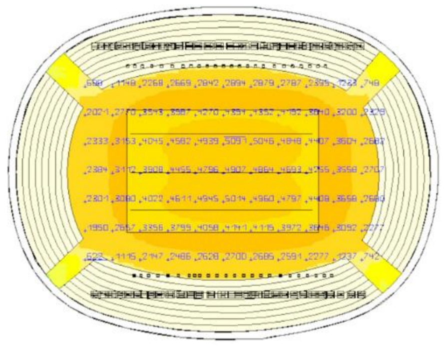

Figure 7: Televised events

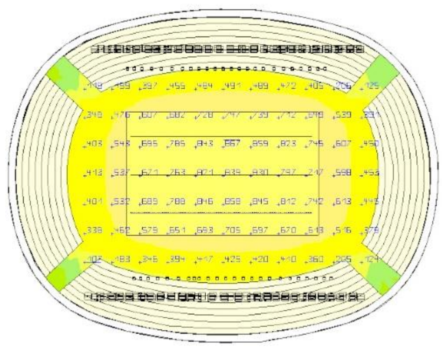

Figure 8: Non- Televised events (class I)

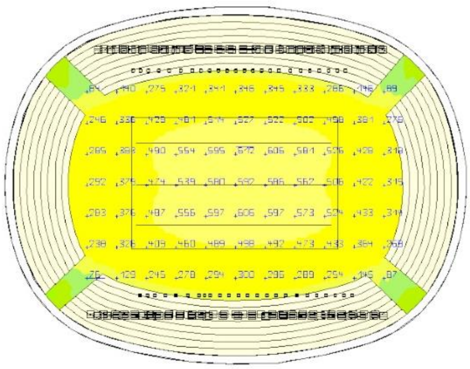

Figure 9: Non- Televised events (class II)

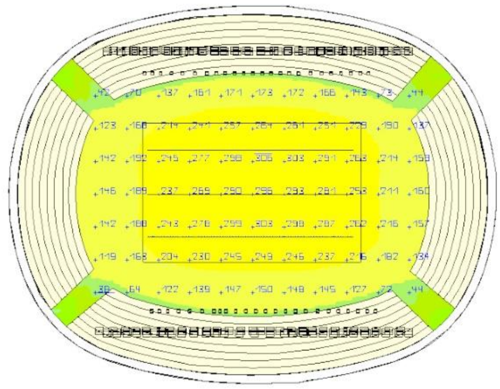

Figure 10: Non - Televised events (class III)

5. Discussion

In this project, the lighting design has been improved by using LED lights instead of metal halide lights. Even the distribution of the lighting and the lighting positioning changed in order to achieve better illuminance and better uniformity. The most important part was achieving the standard requirements while still having a low - power lighting system. Table 10 shows the results of the proposed design. All the parameters have been improved and satisfy the requirements mentioned in the standard. As the results show, the horizontal illuminance improved from 2834 lux to 4501 lux, and the required illuminance as per standard is 3000 lux. For the vertical illuminance in the existing design, it is not specified, but in the proposed design, it satisfies the required illuminance which is 2000 lux. In the proposed design, the light fitting number will increase from 100 units to 162 units. But the power consumption of the LED units specified in the proposed design is less. The power consumption for a televised event in the existing design is 149, 000 watts per hour, and the power consumption for the same event in the proposed design is 38, 694.6 watts per hour. The reduction in power consumption is 25.9%. In addition to that, the uniformity slightly increased from 0.68 to 0.7. The value of uniformity increases due to the use of a lighting fixture with a wide beam (Endo Lighting Corp. ERG5299S HIGH - BAY). But with a wide - beam light fixture, the vertical illuminance can't be maintained. That is why a combination of two types of LED light fixtures has been used. The first type of light fixture with a wide light beam helps achieve better uniformity for the horizontal surface, and the second type of light fixture with a narrow light beam is used to achieve higher vertical illuminance without a high increase in horizontal illuminance. The other important light specification is the color rendering index; the higher the index, the better. In comparing the specifications of the light fixtures used in the existing design with the proposed one, the CRI is better for all the light fixtures in the proposed design (82 and 100). The CRI indicates the ability of light to show the real color of the objects, and it is a very important parameter for camera recording in order to get a clear image.

More over, LED light working hours are longer than metal - halide, which means less maintenance and replacements. As a matter of fact, all kinds of lights decrease over time. The rate of decrease varies from type to type. The lifetime of a LED is defined as the time it takes until its light output, or lumen maintenance, reaches 70% of the initial output. That means the LED does not die at once, but it slowly dims over time. In the case of metal Hailed used for the existing design, 50% of it is light after 12000 working hours.

In the case of non - televised events, the results for the existing design are less than the required levels of horizontal illuminance for almost all the classes mentioned. In comparison with the results of the proposed design, all the classes in the non - televised event meet the required levels of horizontal illuminance and uniformity. The non - televised event illuminance levels for all classes were achieved by dimming the LED lights to the required levels. This is mainly used to maintain the level of uniformity.

6. Conclusion

In this research a study of enhancing lighting system has been conducted. All the calculated results of the proposed system compared with results of the existing design. The main goal of the proposed design not only enhance the lighting system to meet the standard requirements but also to reduce the power consumption. As a results, LED lights proposed to be used instead of metal hailed. More over. A new lighting distribution strategy has been proposed. The new lighting design has been studied by using Dialux Evo software. It is a specialized software used to design lighting and overs using variety of lighting fixtures form different manufacturers. From the results, it have been found that the best lighting distribution strategy is to place the lighting at the two sides of the playing area but not on the sides of goals. In addition, it is useful to use two types lighting fixtures wide beam type and narrow beam type. The wide beam type enhance the uniformity of the lighting and the narrow beam enhance the vertical illuminance. The other suggestion is to use LED to minimize power consumption and to have longer working hours. From the results using LED light Fixture instead of Metal - hailed decrease the power consumption up to 25.9 %. In case of non - televised events dimming strategy for each class have been proposed. In each class there are a different requirements of horizontal illuminance and uniformity. Dimming strategy is better to achieve the required uniformity than switching on some of the lighting.

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