Green Lighting Design for Outdoor Basketball Court Based on Illuminance Model

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Abstract
Green lighting has become one of mainstream design concepts in architectural lighting field. Especially for sports halls with high requirements for lamplight, how to achieve green lighting has great significance. This paper takes outdoor basketball court for example and applies illuminance model to propose layout method and example verification which can realize lighting demand of basketball courts as per lighting criteria of sports buildings based on considering illuminance and space distance, uniformity ratio of illuminance, the positional relationship between basketball court area and light source, color temperature and color rendering index. Then, LED light source design scheme of outdoor basketball courts is proposed in combination of green lighting principle, and the advantage over traditional method is compared. Finally, this paper indicates green lighting can be achieved only through improving illuminance uniformity of basketball courts and reducing energy consumption, and offers design reference for construction of similar stadiums.
Key words: OUTDOOR BASKETBALL COURT, ILLUMINANCE MODEL, GREEN LIGHTING

1. Introduction

With the popularization of environmental protection and energy-saving awareness, building energy conservation also becomes one of the focuses in energy conservation field. Lighting facility as main energy consumption becomes the key point of energy conservation and emission reduction. Hence, the idea of “green lighting” which advocates energy conservation and rational use of lighting is also praised highly [1]. Some researchers conducted energy conservation system experiments for two classrooms of Engineering Faculty of the University of Rome Sapienza under different lighting control and drew such conclusion that, the classroom with energy conservation system under lighting control more contributes to environmental protection in terms of cost analysis, energy consumption and comfort [2]. Marco Aiello and Tuan Anh Nguyen also indicated the most valuable indexes to measure whether a building is energy-saving included HVAC (heating, ventilating and air conditioning), illuminating system and plug load, and stressed the key to environmentally-frequently intelligent building was energy saving concept and behavior of every user [3].

Researchers carried out continuous detection of illuminating systems of four offices in Korea and gained such conclusion that: It has been found that the application of automatic dimming control for lighting with a design illuminance of 500 lx demands to the field studied offices can reduce lighting energy consumption by up to 43%.

The study also shows that a change in occupancy patterns observed in this study leads to an increase in lighting energy use by up to 50% [1]. The sports venue as a major client for building energy consumption undertakes greater energy conservation responsibility. Especially how to achieve energy conservation from lighting approach has direct realistic significance for effective reduction of energy consumption. At present, the researches on lighting of sports venues mainly focus on measurement of lighting energy conservation, lighting design scheme and system maintenance. Rytel and Tena investigated energy consumption of gymnasium in Duke University and suggested the sports department of Duke University should take into account of LED application indoors. Hence, Cameron room became the first indoor court. Additionally, he recommends that Duke Facilities apply window solar films and implement other lighting changes that will improve occupancy comfort in the Krzyzewski Center [4]. Zhao Kai et al. combined actual conditions of interior and outdoor stadiums and applied illuminance calculation software to compare and calculate the influence of single-packway and dual-packway of venue lighting on lighting indexes. Based on the calculation result, energy consumption minimization method satisfying lighting index demand was proposed [5]. Hu Liangyong et al. took a tennis court for example, proposed and verified lighting measurement method of such stadiums and provided basis for detection of relevant standards. Wang Donghua et al. introduced lamp light source design, installation and scheduling mode according to sports events of stadiums in order to effectively ensure lighting demand of stadiums [6]. Lei Peng et al. took basketball court for example and proposed application of greedy algorithm to design permutation and combination of light sources so as to reach the purpose of improving illumination uniformity of the court [7].

It thus can be seen that lighting system of sports venues has strong comprehensiveness and involves various aspects. It is necessary to consider illuminance uniformity, color rendering index, color temperature and light source efficiency etc. Once green and environmental protection concept is introduced, the complexity will increase, and relevant researches are few. Thus, based on predecessors' researches, this plans to innovatively start from lighting design of outdoor basketball court, blend in green lighting concept and quantify location distribution and quantity of lamps from such aspects as illuminance uniformity and energy conservation by combining illuminance model. Meanwhile, this paper puts forward the design scheme which meets lighting demand and environmental protection requirement and hopes to offer certain reference for green lighting design of such venues.

2. Concepts

2.1 Modeling factors

Lighting of sports venues as a system project involves numerous disciplines. The power and position of light sources as well as whole structural design of buildings should be considered. In particular, after green lighting concept is introduced, environmental protection function should be valued. Hence, before green lighting design, it is required to clarify relevant concepts and master the analysis direction. First of all, lighting brightness of outdoor basketball stadium should satisfy certain national standards and be subject to related architectural lighting design criteria. Secondly, illuminance measurement should be based on scientific computing method. In other words, measurement should be subject to illuminance model. Finally, in lighting design process, it is required to stick to green lighting principle and plan a set of lighting design scheme with low energy consumption and high efficiency.

The illuminance model is a measurement model which is often used to calculate lighting effects of buildings, takes into account of illumination rate, luminous flux, illumination area and the number of lamps and comprehensively reflects lighting quality of certain area in the buildings, including horizontal illuminance and vertical illuminance, with the unit of LX [8]. Generally, good lighting quality can ensure illumination uniformity and the comfortable degree of human body. The calculation formula is as follows:

$$\mathrm{E} = \frac{F \times U \times M \times N}{A} \quad (1)$$

Where, E is illuminance; F represents luminous flux (i.e. luminous efficiency of lamps); U represents illumination rate and reflects the proportion of effective luminous flux of lighted area and total luminous flux of lamps; M reflects the proportion of theoretical illuminance and initial illuminance; N is the number of lamps; A is lighted area. For the convenience of calculation, this formula can be further evolved. We suppose the power of each lamp is 1 watt and the lighting duration is T.

$$\frac{\mathrm{E} \times \mathrm{A}}{W \times T} = \frac{F \times U \times M}{T} \quad (2)$$

Thus, mathematic model of illuminance electricity consumption can be gained. Thus, the number of lamps of unit power, illuminance and other illumination indexes. Accordingly, the calculation formula of horizontal illuminance is:

$$\mathrm{E}_k = \frac{1}{M \times N} \sum E_{ki} \quad (3)$$

Where, $\mathrm{E_k}$ is average horizontal illuminance of light source position, LX; M is the number of longitudinal observation points; N is the number of horizontal observation points. This formula reflects athletes' visual perception for objects on the site observed horizontally. Similarly, computational formula of vertical illuminance which reflects athletes' 3D stereoscopic vision for obejcts is:

$$E_v = \frac{1}{M \times N} \sum E_{vi} \quad (4)$$

Where, E_v is average vertical illuminance of light source position, LX; M is the number of longitudinal observation points; N is the number of horizontal observation points. Similarly, to reflect illumination uniformity degree and ensure lighting comfort, corresponding illuminance uniformity model is:

$$G_i = \frac{E_{min}}{E_{max}} \quad (5)$$

Where, G_i reflects illuminance uniformity; E_{min} reflects minimum illuminance of observation points; E_{max} reflects maximum illuminance of observation points.

Green lighting concept means to effectively and rationally use energy, improve energy efficiency and achieve environmental protection and energy conservation based on guaranteeing lighting demand and comfort [9]. At present, a common hot point is to study how to combine natural light and artificial lighting and form comfortable constant illuminance environment (i.e. active green lighting).

3. Illuminance index measurement and calculation of outdoor basketball court

3.1 Basic parameters

As per architectural lighting design standard in China, the illuminance of sports venues should meet requirements of training and competitions in different periods as shown in Table 1.

Table 1. Illuminance standard values of sports venues

Sports event	Reference plane and height	Illuminance standard value (lx)					
		Training			Competition		
		Low	Middle	High	Low	Middle	High
Basketball, tennis	Ground	150	200	300	300	500	750
Bowling	Ground	150	200	300	200	300	500
Weight lifting	Ground	100	150	200	300	500	750
Ping-pong	Table surface	300	500	750	500	750	1000
Swimming	Water surface	150	200	300	300	500	750

It can be known from the table that, standard illuminance value scope of basketball court is 150-750LX. According to the interval of minimal illuminance and maximum illuminance, we can know that more quantities of lamps can gain better lighting effect, but power consumption is more[10]. Thus, illuminance uniformity also should be considered to make sure lighting non-uniformity reaches the minimum within the lighting range. According to the specific value of the maximum illuminance and minimum illuminance of observation point in the basketball court and the structure of basketball court, Formula (5) is introduced to calculate this index and then rationally plan the position of lamps. Hence, basic parameters are proposed. (1) The area of basketball court is 28×15m rectangle. (2) Illuminance calculation formula of multiple point light sources away from rm with the region is:

$$L = \sum_{i=1}^{m} kw_i / r^2 \quad (6)$$

Where, k is a constant, assumed to be 1; w_i represents the power of the ith light source; r represents the distance between light source and illumination area; m represents the number of light sources. (3) Basic structure of basketball court is shown in Figure.1.

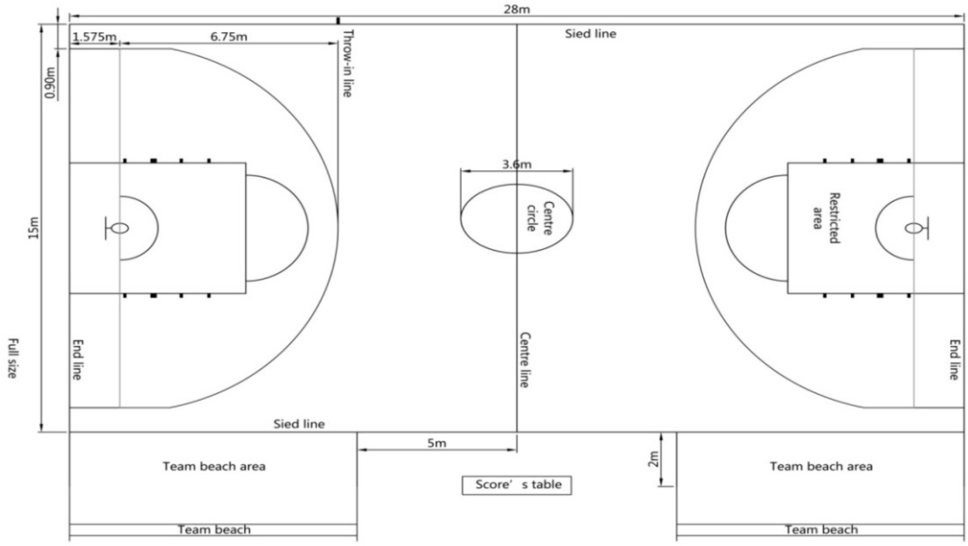

Figure 1. Basic structure diagram of basketball court

For the convenience of calculating horizontal illuminance and vertical illuminance, the whole basketball court is divided into 28×15=420 squares to calculate illuminance at each intersection point. In accordance with the sequence from the left to the right and from the top to the bottom, the interaction points are marked. Each intersection point is the position where light source may be set. In view of the edge of the court, there are 29×16=464 intersection points. The r between light source position and ground is 6m, as shown in Fig.2. The schematic diagram of light source and court can be gained.

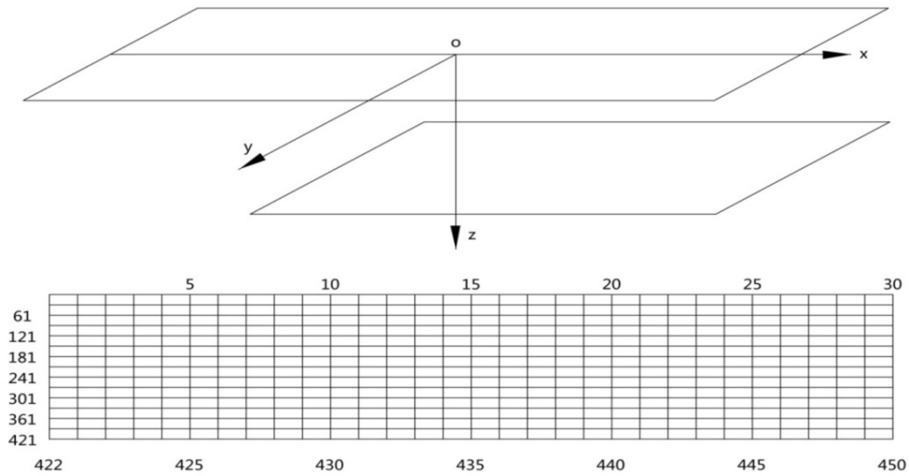

Figure 2. Space schematic diagram of light source and basketball court

In the figure, O is the central point of light source position. The positions with the number of 1-464 are the positions where lamps may be installed. As for the design of specific position and quantity, it is required to regard reduction of illumination non-uniformity as the goal and confirm them after further calculation.

3.2 Example calculation

In this experimental study, AUS, average ranking score (RS) and precision are used to evaluate the effect of user-level personalized recommendation algorithm. These three evaluation indicators are very common and representative in bipartite graph network recommendation.

First of all, according to the relationship between light source and distance, the influence of light sources in different positions on lighting on the court is calculated. According to Formula (6), it is known that the changes in light source and illuminance of the court are only related to the distance r. In combination of space coordinates system in Fig.2, the coordinate value of light source of reference point is (x0, y0, 0). Coordinate parameter of any point i of basketball court ground corresponding to light source i is (xi, yi, 10). In combination of space geometry theory, the distance between light source and this point can be gained.

$$r = \sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2 + 6^2} \quad (7)$$

It is gained from Formula (6) and Formula (7) that, when r is the minimum, illuminance is the largest, i.e. when $x_0 = x_i$ and $y_0 = y_i$; when r is the maximum, illuminance is the smallest. The two present an inverse relation. Supposing the light sources set up in the venue are single independent light sources, 464 intersection points can be placed in proper order. According to symmetric relation between illuminance and distance r reflected in Formula (6), there are 464 same illuminance values, and only illuminance values of 4 positions are the minimum. This is because when light sources are located at four vertex corner ends, the value of $(x_0 - x_i)^2, (y_0 - y_i)^2$ is the largest, i.e. r is the largest, and corresponding illuminance is the minimum. Hence, when light source is located at the top left corner, illuminance of No.464 position (i.e. lower right corner) is the minimum. Similarly, when point light source is at the top right corner, the corresponding position is No.435 position of the basketball court; when the light source is located at lower left corner, the corresponding position is No.44 position of the basketball court; when the light source is located at lower right corner, the corresponding position is No.1 position of the basketball court. These positions belong to the regions with the minimum illuminance.

Secondly, illumination uniformity of basketball court is calculated as per illuminance uniformity model to ensure illumination comfort. According to Formula (5), only when illuminance minimum value of point light source is the maximum, illuminance uniformity can keep largest. According to calculation result mentioned above, the points with the minimum illuminance of basketball court are in the four vertex corners. Thus, the light sources with the maximum power should be placed in the positions with the minimum illuminance. The light sources with the secondarily largest power are placed at the positions with the secondarily smallest to ensure illumination uniformity of basketball court. In combination of illuminance calculation formula, the lam bulbs are placed according to the same principle so that the minimum becomes the maximum until all lamps are placed. To be more specific, the arrangement steps are as follows: (1) sort as per power of lamps in descending order; (2) calculate illuminance of each position of basketball court according to illuminance model and sort in ascending order, and calculate the maximum illuminance value and the minimum illuminance value; (3) place the lamps with the largest power at the positions with the minimum illuminance; if the minimum value is same, the minimum value should become the maximum value; the lamps are placed in such principle until the venue is arranged well. For example, according to Formula (7), when the lamp with the maximum luminance is placed at top left corner (No.1) of the basketball court (-14,-7.5,0), the luminance is maximum. At this moment, the luminance of lower right corner (14,7.5,6) is minimum, so the lamps with secondarily largest luminance should be placed.

Finally, in accordance with illuminance standard and actual conditions of venues, lighting design scheme of basketball court is gained through calculation. Standard size and lighting requirements of basketball court, 464 equidistant lamp mounting points can be gained. If the strength range of 36 lamps is 1000-650cd and 10cd decreases successively, the arrangement mode of lamps can be gained according to Formula (6), Formula (7), the algorithm in this paper and number in Fig.2, as shown in Table 2.

Table 2. Lamp position of basketball court with high illuminance uniformity

Lamp intensity (cd)	1000	990	980	970	960	950	940	930	920
Lamp position	1	464	44	418	440	45	300	25	410
Lamp intensity (cd)	910	900	890	880	870	860	850	840	830
Lamp position	50	36	450	400	80	5	420	425	55
Lamp intensity (cd)	820	810	800	790	780	770	760	750	740
Lamp position	350	80	2	65	40	415	66	180	240
Lamp intensity (cd)	730	720	710	700	690	680	670	660	650
Lamp position	85	19	364	295	162	233	348	190	75

Compared with traditional random lamp arrangement method, this method can significantly improve illuminance uniformity. In addition, as per indoor illumination criteria of CBA basketball stadium, the minimum horizontal illuminance of basket court should be 300lx under entertainment training status; the uniformity should be 0.3; color rendering index should not be less than 65; glare index should not be greater than 35; color temperature range should be 3000-6500K [11]. The threshold limit value of these indexes should be met in actual lighting design.

4. Green lighting design scheme of outdoor basketball court

Under the guidance of green lighting principle and research result of this paper, specific design scheme is proposed by taking outdoor basketball court for example.

Firstly, appropriate lamps should be chose as per various index data measured and calculated. To meet green lighting idea and achieve energy conservation and emission reduction, it is planned to adopt LED floodlight as the light source to replace traditional metal halide lamps. The power of LED lamps is 160w. The shell consists of high-purity die-cast aluminum + 5MM tempered glass surface cover, and American BridgeLux chips are used. The size is L450*W315*H225. Built-in lamp beads are 2 80W integrated beads. The lighting parameters are as follows: AC85~265V; power factor: greater than 9.5; color temperature range: 2700-6500K; luminous flux: 10800-11400LM. In general conditions, the service life is more than 50000h. In view of the relationship between illuminance and distance, lamp post height is set to 6m hot-galvanized post. Meanwhile, to guarantee stability of posts and reduce material wastage, variable diameter design is adopted: the lower diameter of lamp post is 140mm, and the upper diameter is 70mm, with the thickness of 3mm. In accordance with illuminance model, average illuminance of such types of lamps is 323.5Lx. In the competition area where lamps are arranged densely, illuminance of single light source is more than 400lx, which completely reaches lighting requirements of basketball court (150-750lx).

Secondly, the position and quantity of light sources should be confirmed according to the site conditions. According to area and lighting standard of basketball court, it is planned to adopt 4 sets of 2*160wLED floodlights which can completely replace traditional 400W metal halide lamps. The illuminance can reach competition and recreation requirements. The layout is shown in Fig.3 according to site features.

It is known from the figure that in combination of lighting criteria of basketball court JGJ153-2007, 4 sets of 160W LED floodlights are symmetrically distributed at both sides of the court. The detailed positions are shown in the figure. Under such layout, main exposure range of lamps is basketball stand area of the court to ensure lighting demand of offensive area. Such layout can meet requirements of general competitions, training and entertainment.

Figure 3. Layout diagram of LED lamps in outdoor basketball court

Compared with traditional scheme, green in this scheme is mainly reflected in lamp selection. LED lamps have energy conservation function. The performance parameters are superior to metal halide lamps. Under the same site conditions, lighting effect of 160W LED lamps is equal to 400W metal halide lamps. The comparison of basic parameters is shown in Table 3 [12].

Table 3. Performance parameters of 160W LED lamp and 400W metal halide lamp

Product	160WLED lamp	400W metal halide lamp
Self-loss power	10W	85W
Total power	170W	485W
Power consumption per hour	0.17KW	0.485KW
Working current	0.75A	3.11A

Starting performance	The lamp is lit immediately when it is turned on	5min
Noise	No	Yes
Stroboflash	2.64M times/s	50 times/s
Service life	50000h	6000-10000h
Color rendering index	> 90%	<60%
Power factor	> 0.98	<0.8

In line with the table, LED lamps are not just green and energy-saving, but also the lighting performance is also stronger than metal halide lamps. The service life is long. Currently, guarantee period of metal halide lamps is about one year, while guarantee period of LED lamps is about 3 years. Moreover, self-loss power of LED lamps is 0.1 times of metal halide lamps, which greatly reduces energy consumption. These properties become key factors of main green lighting lamps. Comprehensively, the green property is mainly reflected in low energy consumption, electric charge saving and low maintenance cost. For instance, supposing the site will consume electricity for 5h every day, the electric charge of per Kw/h is 0.5 Yuan and there are 365 days in one year, the electric charge expenditure of 4 sets of double-head 160W LED floodlights is $0.17 \times 5 \times 0.5 \times 365 \times 8 = 1241$Yuan; under the same lighting standard, annual electric charge expenditure of 400 metal halide lamps is$0.485 \times 5 \times 0.5 \times 365 \times 8 = 3540.5$Yuan. LED lamps will save 2299.5 Yuan, and the power saving range reaches 64.95%. In terms of maintenance cost, average service life of light source of metal halide lamps is 1 year, and electric appliance maintenance frequency is 2 and a half years. At present, the price of light source of 400W lamps is 100 Yuan, and electric appliance price is 150 Yuan. The maintenance cost of 400W metal halide lamps is 16200 Yuan in three years, while maintenance cost of 160W LED floodlights is 0 Yuan in three years. Hence, LED lamp is the best choice of green lighting design.

4 Conclusions

Lighting design of sports venue concerns whether a contest and recreation item can proceed smoothly and whether athletes can give play to their skills normally. A set of design scheme with advanced concept and mature operation can exert the functions of venues to the largest extent. This paper takes lighting design of outdoor basketball court for example and proposes green lighting concept in order to achieve the win-win of "energy conservation, emission reduction and energy efficiency improvement". Through referring to lighting criteria of basketball stadium, this paper proposes a set of lamp setup and arrangement method as per illuminance model. Such method effectively boosts illumination uniformity and meets basic lighting demand of venues. On this basis, according to green lighting principle, a set of lighting design scheme in which LED lamps serve as the main light source, and the quantity and layout of lamps are confirmed. Meanwhile, performance differences between LED lamps and metal halide lamps are analyzed and compared. Researches show that with regard to green lighting design of sports venue, on the one hand, illumination uniformity should be considered from the aspect of lamp arrangement; on the other hand, it is necessary to take into account of the proportion of energy consumption and cost from such aspects as lamp type and quantity. Only when the factors of the two aspects are overall considered can green lighting be really achieved.

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