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RESEARCH ON LIGHTING POWER DENSITY AND ENERGY-SAVING TECHNIQUES OFSPORTS LIGHTING

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RESEARCH ON LIGHTING POWER DENSITY AND ENERGY-SAVING TECHNIQUES OF SPORTS LIGHTING

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Abstract

Lighting power density (LPD) is one of the most important evaluation index for energy-savings, which has been used as standard in USA, China, Singapore and so on. According to the practice, the standard in China helped reduce LPD by 20 percent, contributing a lot to China's energy-saving goals. The sports lighting is characterized by high-power, much energy consumption and great potential in energy-saving as well. In this study, LPD limits for different sports venues have been determinated according to the requirements of sports lighting, the fundamental of sports lighting design, which is important to the saving of lighting energy consumption. Also the technique of computer simulation, the data accumulation of vast engineering practice, the analysis of key points of lighting energy-saving and the improving method of utilization factor of luminaire are essential in the determination of LPD limits.

Keywords: lighting power density (LPD); sports lighting; high-power; energy-saving

1 Background

Lighting power density (LPD) is an important index for the evaluation of lighting energy saving. At present, LPD has been used in USA, China, Singapore and some other countries to evaluate the energy efficient of lighting. According to the practice of LPD limit in China since 2004, the LPD has reduced by twenty percent, which means an obvious effect of energy saving.

LPD of sport venues had never been limited before all over the world. However, the illumination of field of play often reach up to 2000~3000 lux and high power luminaires are usually used in these venues, which can cost lots of electric energy. However, the determination of LPD limits is different because of the complexity of architectural structure, the diversification of competitive events, and the high requirements of lighting performance. In this study, we have determined the LPD limit of sport venues by analyzing the relationship between LPD and mounting position of luminaires, and the factors affecting lighting energy saving based on computer analog technology, accumulated data of testing and designing in the past years, the lighting requirements of sports venues and the fundamental of lighting design. The results are significant to lighting energy saving.

2 Analog computation and analysis of lighting design parameters

In the application of sports lighting, light distribution and mounting position of luminaires can affect not only the lighting performance, but also the lighting installation power and the number of luminaires. In addition, sports lighting system is highly comprehensive, which has influence on both the final application and the implementation of other relevant systems. In this study, we hope to raise a solution to guide the design, construction and energy saving of sports lighting.

Parameters such as Illumination, uniformity, color temperature, color rendering index, glare rating, luminaire efficiency and maintenance factor have to be under consideration in the design of sports lighting. Control variable method has been used in this part to guarantee the accurate correlation of different parameters.

2.1 Relationship between mounting position and utilization efficiency of luminaires

In the control group, the aim angle and illuminance were variable, and the projection distance, efficiency and maintenance factor of luminaires were fixed while calculating the glare rating(GR) of lighting. GR of four points (fig.2-1) were calculated with the boundary conditions of 20m×20m calculation area, distance of 50m between the luminaire and the center of area and distance of 60m between the camera and the center of area.

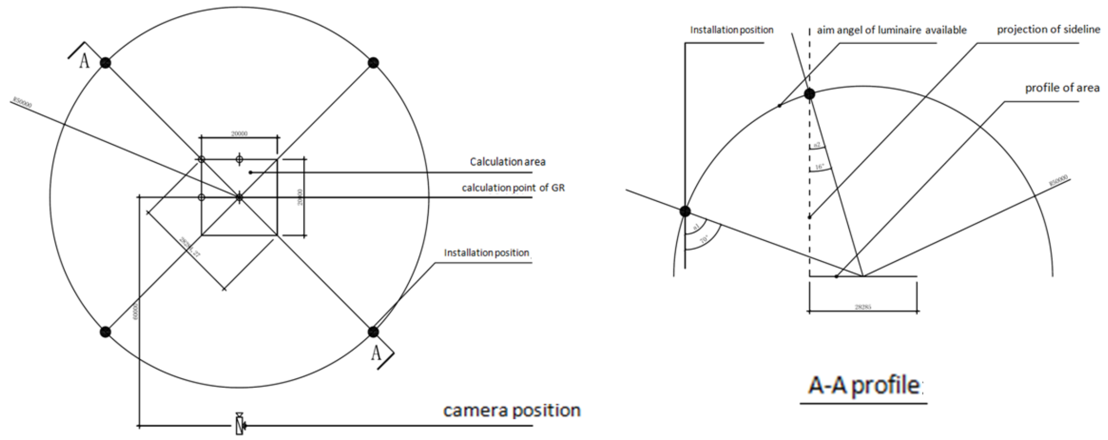


Figure 1 – Diagram of calculation principles

According to the calculation results and analysis of the data (fig. 2-2), we found that:

- The horizontal and vertical illumination increased while reducing the aim angle of luminaire. However, the increase amplitude of horizontal illumination is smaller than that of vertical illumination.
- The vertical illumination decreased significantly when the aim angle changing from 70° to 40°. And the rate of descent became slower with the further reduction of the aim angle.
- The calculation result of GR cannot compliance with the requirements of CIE standard with the aim angle above 70° in stadium and that above 65° in gymnasium. Thus, the aim angle of luminaires shall be limited.

It can be concluded that the aim angle of luminaires shall be limited to reduce lighting energy consumption and the number of luminaires. However, it need the support of building structure.

2.2 Relationship between luminous intensity distribution of luminaire and utilization efficiency

In the control group, the projection distance (20m, 30m, 50m, 75m, 100m) and luminous intensity distribution of luminaires were variable, and the aim angle, efficiency and maintenance factor of luminaires were fixed while calculating the illumination and uniformity. GR of four points (fig.2-2) were calculated with the boundary conditions of 20m×20m calculation area, distance of 50m between the luminaire and the center of area, distance of 60m between the camera (10mabove the ground) and the center of area and aim angle of 45°.

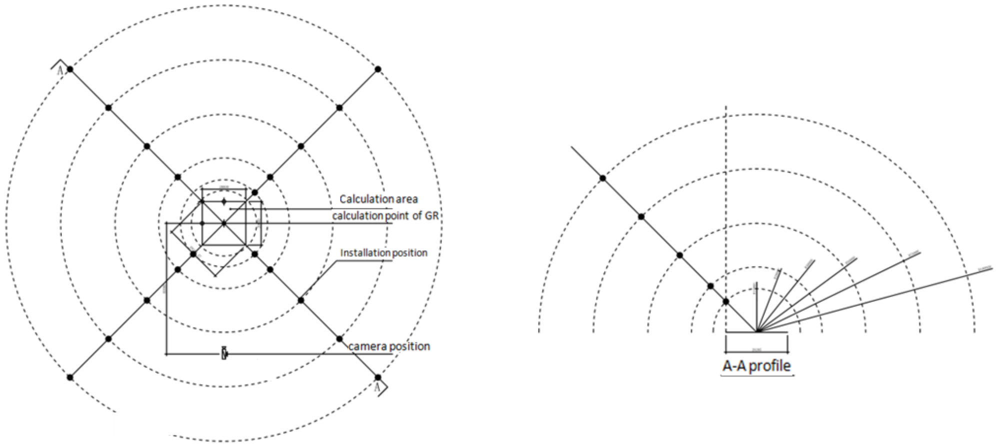


Figure 2 – Diagram of calculation principles

According to the calculation results and analysis of the data, we found that:

- The luminous intensity distribution of luminaires can be chosen according to the requirements of illumination, uniformity and projection distance.
- Luminaires with narrow beam angle should be used in the condition that the projection distance is long. However, it should be considered that the use of narrow beam angle may result in low uniformity.
- Luminaires with wide beam angel should be used in the condition that the projection distance is short. However, it should be considered that the use of wide beam angle can affect the average illumination of the field.

The luminous intensity distribution can affect the number of luminaires used and the installed power of the whole venue. We can achieve the goals of both energy-saving and improvement of lighting quality while using the luminaires with proper luminous intensity distribution. And the used of more kinds of luminous intensity distribution can be helpful for energy-saving and reduction of luminaires needed.

2.3 Summary

In this part, we can conclude that:

- The optimal solution of installation position of luminaires can be determined according to comprehensive cost, other than mounting the luminaires arbitrarily.
- The luminous intensity distribution of luminaires will affect the lighting result. Designation should be proceeded according to actual installation height, determining the final power, luminous intensity distribution, number and specific position of luminaires.

3 Research on catwalk positioning in venues lighting

3.1 Background

Lighting system is one of the most important facilities in sports venues, which can affect the justice of competition, broadcasting, safety of athletes, atmosphere of spectator and so on. And the design of catwalk is very important to the lighting quality and energy consumption.

However, in the practice of venues construction, we found that the design of lighting is not put in an important place, resulting in the phenomenon that the design of catwalk cannot meet the requirement of lighting in a lot of cases. For example, the position of catwalk is so close to the sideline of field of play that the vertical illumination of these points is too low. And another example is that the some catwalk not high enough made the glare very serious, or the catwalk not long enough made the vertical illumination of baseline too low. In the other hand, the LPD of some venues is many times higher than that with the same requirements of lighting because of the unreasonable design of catwalk. In this paper, the set method of catwalk has been studied to guide the design practice for architects.

3.2 the design method of catwalk position

In the design of catwalk, the following factors should be considered:

- Lighting for the athletes and coach;
- Lighting for referee;
- Lighting for spectators;
- Lighting for broadcasting;
- Lighting for emergency escape and competition.

The effect of catwalk position to the lighting quality is of the most important. Thus, the study of it has been proceeded.

The aim angle of luminaires affect the horizontal and vertical illumination, uniformity, GR and so on. Thus, attention should be paid in the design.

In the sports lighting, the horizontal illumination and vertical illumination both have the requirements of uniformity, however, the uniformity requirement of the vertical illumination is more complicated. The aiming angle to the close sideline(θ) and far sideline(φ) is very important to the lighting quality. And the value of θ affect the vertical illumination, uniformity and illumination ratio near the close sideline.

In sports lighting, the GR values should be limited strict (GR＜50 in stadium and GR<30 in gymnasium). We can predict the GR value simply according to the value of φ, which has been limited to meet the requirement of GR.

Thus, the position of catwalk should be set to meet the requirements of both θ and φ, which is one of the most important factors.

3.3 The determination of parameters of catwalk position

The parameters of catwalk position include the horizontal distance from the catwalk to the close sideline (d), the height of catwalk (h), the horizontal distance from the catwalk to the center of field of play (s), etc.

According to related standard, design experience and calculation result, the requirements of installation position of luminaires are as follows:

(1) Requirements of FIFA for class V and IV

- The installation height geometry for sideline head frames and poles is 25degrees to the bottom of the lowest light source above the horizon, starting from the middle of the pitch and looking back towards the stadium seating bowl. The head frame and light structure may exceed this 25-degree minimum guideline but it may not exceed 45 degrees.
- Luminaire tilt angles should not exceed 70 degrees from the nadir (straight down) to the center of the beam.
- Lighting equipment shall not be placed below 25 degrees above the centre point of the pitch and below 75degrees above the horizontal of the goal area.

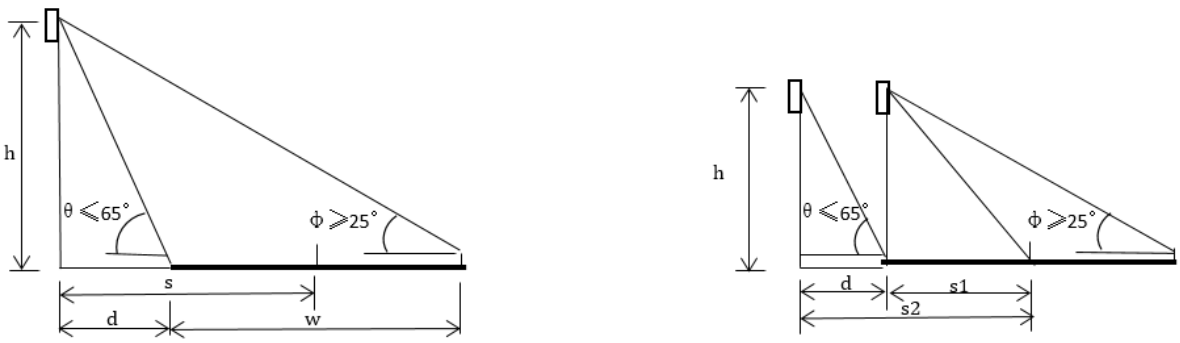
(2) Result according to design experience and calculation

- In this part, the position of catwalk has been studied considering the horizontal illumination, vertical illumination, uniformity, illumination ratio, glare limit, etc.

For the stadium, the luminaire elevation above the far touchline shall not be less than 25°.The luminaire elevation above the near touchline should not be larger than 65°.

For the gymnasium, the luminaire elevation above the far touchline shall not be less than 30°.The luminaire elevation above the near touchline should not be larger than 65° or 60°.

Luminaires installation height for single catwalk and dual catwalks shall meet the requirements of figure 3-1.



where

w the width of competition area;

d the distance from the horizontal projection of catwalk to the near touchline(refers to the rear catwalk when double catwalk;

h the height of the catwalk (luminaires) to the ground;

s the distance from the horizontal projection to catwalk to the center of competition area;

s1,s2 the distance from the horizontal projection of double rows luminaires of double catwalk to the center of competition area.

Figure 3 – The luminaires installation position of catwalk

The parameters d and h can be calculated by the following formulas:

For single catwalk:

$$d = \frac{w \times tg\varphi}{tg\theta - tg\varphi} \tag{1}$$

$$h = d \times tg\theta \tag{2}$$

For dual catwalks:

$$h = w \times tg\varphi \tag{3}$$

$$d = \frac{h}{tg\theta} \tag{4}$$

According to the result in table 1 to table 6, we can find that the value in these tables can meet the requirements of lighting design.

Table 1 – luminaires Installation height and Position when Single Catwalk for stadium

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	$s1$ (m)
Athletics (football)	25	70	93	19.1	52.5	65.6
		65		25.8	55.4	72.3
		60		34.2	59.3	80.7
		55		45.1	64.4	91.6
	30	70		24.7	68.0	71.2

Table 2 – luminaires Installation height and Position when Dual Catwalks for stadium

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	$s1$ (m)	$s2$ (m)
Athletics (football)	25	70	93	15.8	43.3	46.5	62.3
		65		20.2	43.3	46.5	66.7
		60		25.0	43.3	46.5	71.5
		55		30.3	43.3	46.5	76.8
		50		36.3	43.3	46.5	82.9
	30	70		19.5	53.7	46.5	66.0
		65		25.0	53.7	46.5	71.5

Table 3 – luminaires installation height and Position when single catwalk for football pitch

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	s (m)
Football	25	70	68	13.9	38.2	47.9
		65		18.9	40.5	52.9
		60		25.0	43.4	59.0
		55		32.9	47.1	66.9
	30	65		25.1	53.7	59.1

Table4 – luminaires installation height and Position when dual catwalks for football pitch

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	$s1$ (m)	$s2$ (m)
Football	25	70	68	11.5	31.7	34	45.5
		65		14.8	31.7	34	48.8
		60		18.3	31.7	34	52.3
		55		22.2	31.7	34	56.2
		50		26.6	31.7	34	60.6
	30	65		18.3	39.2	34	52.3
		60		22.7	39.2	34	56.7

Table 5 – luminaires Installation height and Position when Single Catwalk for gymnasiums

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	s (m)
Gymnastics	30	65	28	10.3	22.1	24.3
		60		14.0	24.2	28.0
		55		19.0	27.1	33.0
		50		26.3	31.3	40.3
	35	65		13.5	29.0	27.5
		60		19.0	32.9	33.0
		55		26.9	38.4	40.9
	40	65		18.0	38.6	32.0

Table 6 – luminaires Installation height and Position when Dual Catwalks for gymnasiums

Category	φ (°)	θ (°)	w (m)	d (m)	h (m)	$s1$ (m)	$s2$ (m)
Gymnastics	30	65	28	7.6	16.2	14	21.6
		60		9.3	16.2	14	23.3
		55		11.3	16.2	14	25.3
		50		13.6	16.2	14	27.6
	35	65		9.1	19.6	14	23.1
		60		11.3	19.6	14	25.3
		55		13.7	19.6	14	27.7
	40	65		11.0	23.5	14	25.0
		60		13.6	23.5	14	27.6

As for stadiums, the elevation of luminaires at the end of catwalks above the center line of the court shall not be less than 25°. As for gymnasiums, the elevation of luminaires at the end of catwalks above the center line of the court shall not be less than 30°.

3.4 The shape and quantity of catwalk

The aesthetics of architecture are always taken into consideration in the design of catwalk, which may need more luminaires and increase the energy consumption to support. Desirable catwalk should be in line with the field of play, for example, oval field with oval catwalk.

In the design of catwalk, we need to determine the shape and quantity of catwalk according to the lighting requirements above.

3.5 Summary

The position of catwalk is very important to sports lighting. And the lack of solution make it difficult to design the lighting. The position of catwalk affect both the lighting performance and the energy consumption. The result of this study will support the standardization of catwalk design, the improvement of lighting quality and the energy-savings.

4 Field survey and data analysis

The survey data of more than 300 competition venues came from field testing and lighting design of different venues, such as stadium, gymnasium, tennis court, swim palaestra and so on. The parameters of LPD, installation height, illumination, uniformity, lighting rate, CRI, color temperature and GR had been included in the survey.

According to the statistical data, we can conclude that the percent of venues with installation height of luminaires between 40m to 50m is nearly half as for stadium, and the percent of venues with installation height of luminaires between 15m to 25m is more than 60% as for gymnasium. Classification of sports lighting can be found in table 7.

Table 7 – Classification of Sports Lighting

Class	Function	Class	Function
I	Fitness and amateur training	IV	National and international televised
II	Amateur competition and professional training	V	Major national and international televised
III	Professional competition	VI	Major national and international HD televised

The relationship between LPD, installation height of luminaires and classification of sports lighting can be found in figure 4 to figure 6.

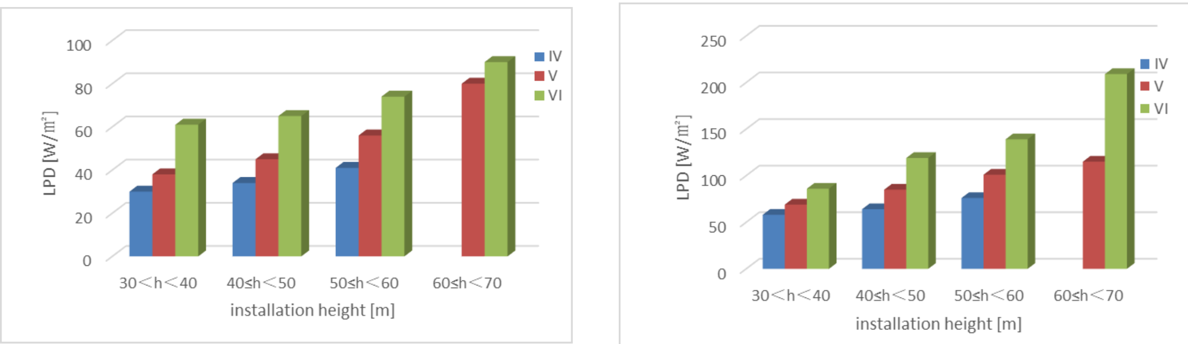


Figure 4 – Relation between LPD, installation height of luminaires and sports lighting classification for athletics(left) and football(right)

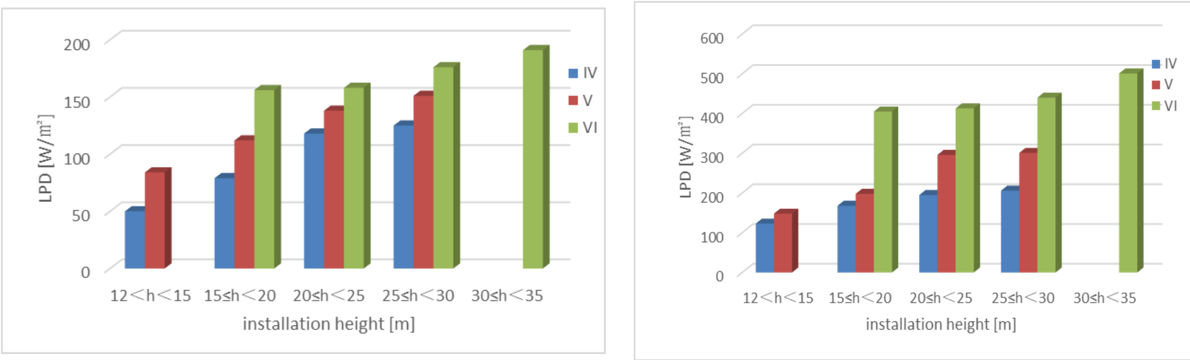


Figure 5 – Relation between LPD, installation height of luminaires and sports lighting classification for gymnastics(left) , Basketball and volleyball(right)

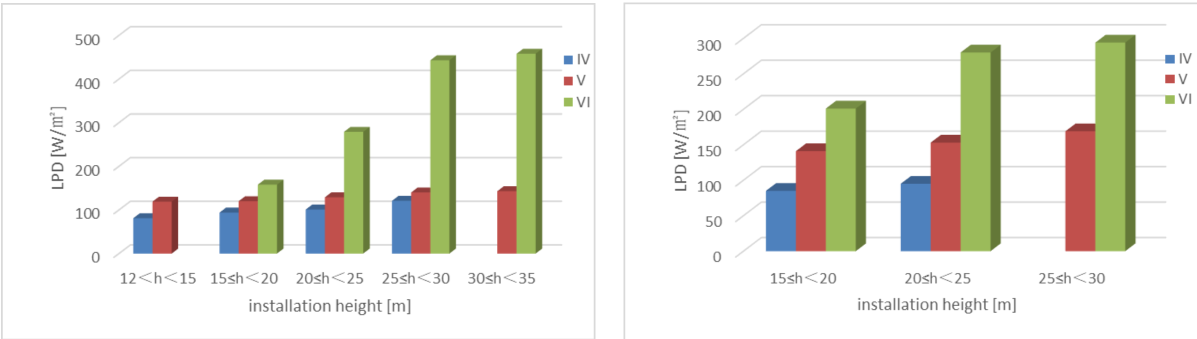


Figure 6 – Relation between LPD, installation height of luminaires and sports lighting classification for tennis(left) and swimming(right)

We can conclude that:

- the LPD increased with increasing the installation height of luminaires;
- the LPD of venues with high sports lighting classification is larger than that of low sports lighting classification;
- Different on/off modes of lighting shall be designed for stadium with comprehensive functions (both football and athletic).

5 Simulating computation

Some basic laws can be concluded according to the field survey. However, we need the work of simulating computation to verify it because of the complexity of sports lighting.

We calculated the lighting parameters and LPD values in different boundary conditions. The relation between LPD, installation height of luminaires and sports lighting classification can be found in figure 7 and figure 8.

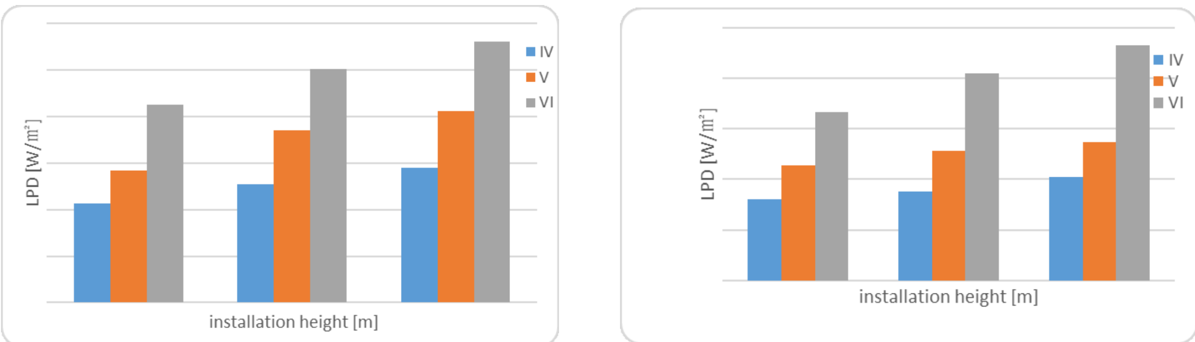


Figure7 – Relation between LPD, installation height of luminaires and sports lighting classification for athletics(left) and football(right)

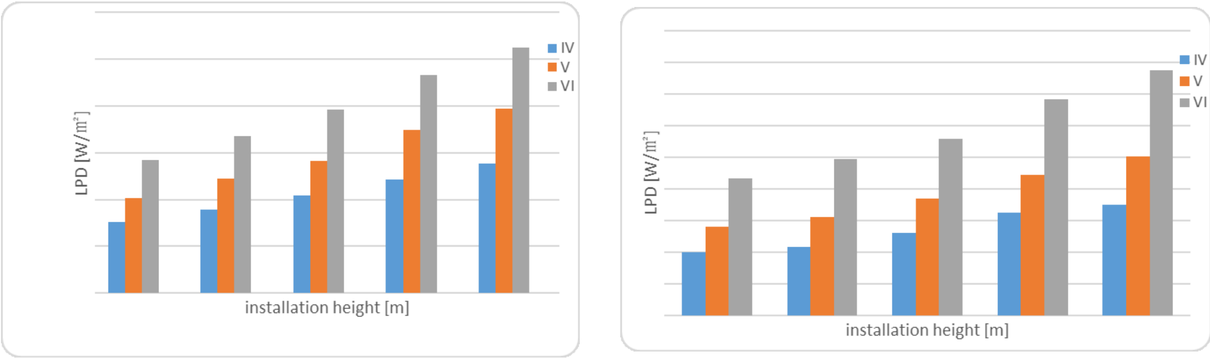


Figure 8 – Relation between LPD, installation height of luminaires and sports lighting classification for gymnastics(left), basketball and volleyball(right)

According to the calculation, we can conclude that lighting performance and energy-saving shall be considered in the design of catwalk, not just the structure and shape.

6 Determination of LPD limits

In this study, we has given the advice of LPD limits of sports venues according to field survey, lighting design practice and simulating computation. Table 8 to table 11 showed the suggestion of LPD limits of stadium and gymnasium.

Table 8 – LPD limits of stadium for training

Classification	Horizontal illumination (lx)	Mounting height *h* (m)	Lighting power density limit values (W/m^2)
I	200	12-20	4
		20-30	7
II	300	15-20	7
		20-30	11
		30-35	14
III	500	20-25	18
		25-35	21
		35-40	23

Table 9 – LPD limits of gymnasium for training

Classification	Horizontal illumination (lx)	Mounting height *h* (m)	Lighting power density limit values (W/m^2)
I	300	5-10	21
		10-15	25
		15-20	32
II	500	5-10	34
		10-15	44
		15-20	46
III	750	5-10	40
		10-15	48
		15-20	64
		20-30	72

Table 10 – LPD limits of stadium for competition

Category	Classification	Mounting height *h* (m)	Lighting power density limit values (W/m^2)	
			Athletics	Football
Athletics Football	IV	30≤h < 40	40	70
		40≤h < 50	45	80
		50≤h≤60	55	90
		60≤h≤70	65	100
	V	30≤h < 40	55	90
		40≤h < 50	65	100
		50≤h≤60	75	120
		60≤h≤70	90	140
	VI	30≤h < 40	80	110
		40≤h < 50	90	140
		50≤h≤60	100	170
		60≤h≤70	120	210

Table 11 – LPD limits of gymnasium for competition

Category	Classification	Mounting height *h* (m)	Lighting power density limit values (W/m^2)	
			gymnastics	Basketball, Volleyball
gymnastics Basketball, Volleyball	IV	12≤h < 15	60	130
		15≤h < 20	80	180
		20≤h < 25	110	210
		25≤h≤30	120	240
		30≤h≤35	130	330
	V	12≤h < 15	90	150
		15≤h < 20	110	240
		20≤h < 25	140	310
		25≤h≤30	160	340
		30≤h≤35	180	440
	VI	12≤h < 15	—	—
		15≤h < 20	160	420
		20≤h < 25	180	460
		25≤h≤30	200	500
		30≤h≤35	220	590

The determination of LPD limits follows the principles below:

- LPD of sports venues have significant correlation with installation height of luminaires and classification of lighting, and
- LPD limits of gymnasium are higher than that of stadium.
- The deviation of LPD limits should be within 15%.

7 Conclusion

The design method of catwalk in sports venues suggested in this paper is scientific and provides the basic law for designer and constructer, which make it more convenient to design catwalk and support the energy-savings of sports lighting.

The LPD limits proposed in this paper is based on a lot of field survey, scientific simulating computation, verification and numerical analysis. And the statistical bias is acceptable. This study filled the gap of LPD limits in the process of standardization and an energy-saving rate of 20% to 30% can be done by following the LPD limits in this study.

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