World Academy of Science, Engineering and Technology
International Journal of Architectural and Environmental Engineering
Vol:13, No:8, 2019

Measurement and Evaluation of Outdoor Lighting Environment at Night in Residential Community in China: A Case Study of Hangzhou

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***Abstract*—**With the improvement of living quality and demand for nighttime activities in China, the current situation of outdoor lighting environment at night needs to be assessed. Lighting environment at night plays an important role to guarantee night safety. Two typical residential communities in Hangzhou were selected. A comprehensive test method of outdoor lighting environment at night was established. The road, fitness area, landscape, playground and entrance were included. Field measurements and questionnaires were conducted in these two residential communities. The characteristics of residents' habits and the subjective evaluation on different aspects of outdoor lighting environment at night were collected via questionnaire. A safety evaluation system on the outdoor lighting environment at night in the residential community was established. The results show that there is a big difference in illumination in different areas. The lighting uniformities of roads cannot meet the requirement of lighting standard in China. Residents pay more attention to the lighting environment of the fitness area and road than others. This study can provide guidance for the design and management of outdoor lighting environment at night.

***Keywords*—**Residential community, lighting environment, night, field measurement

I. Introduction

A good lighting environment at night plays a significant role to guarantee night safety. Previous researches in UK and Norway showed that accidents happened at night more often than during the daytime [1]-[3]. Report from Zhejiang Public Security Department Traffic Management Bureau Office of Vehicle Management confirmed that most of the death accidents happened from 5 pm to 8 pm, due to the bad lighting environment [4]. Previous studies showed road lighting at night is an effective measure to reduce the accident rate [5]. International Commission on Illumination (CIE) conducted a series of studies on road lighting, and proposed recommended values for motor and pedestrian traffic [6]. Now they are working on the concept of visibility for road lighting [7].

Many existing researches focus on the road safety; however, lighting environment in residential community is more complicated. There are many kinds of urban environment, such as community entrance, fitness area and landscape. There is still a lack of systematic studies about the current lighting environment at night in residential community. It not clear what kind of lighting is best for lighting at night in residential community. There is a strong demand for nighttime activities in China, such as shopping, walking and square dancing [8]. Therefore, the requirement of outdoor lighting environment at night needs to be assessed.

The purpose of this study is:

(1) to examine the actual lighting environment level at night in residential community.
(2) to establish a simple evaluation model for lighting environment at night, in order to guide the design of lighting in residential community.

II. Methodology

A. Sample Selection

Two residential communities in Hangzhou are selected. One is a high-rise residential community, built in 2006. The highest number of floors is 18. And another one is a low-rise residential community, built in 2003. The photos of these two communities are shown in Fig. 1. The basic information is summarized in Table I.

B. Field Measurement

Field measurements were conducted in two communities in May, 2016. In order to assess the outdoor lighting environment at night in two communities, six kinds of outdoor environments, including road, community entrance, landscape, fitness, plaza and building entrance, were chosen. The measuring areas in two communities are summarized in Fig. 2.

The lighting system, lighting source and layout of communities were investigated. The lamp spacing and height were measured. According to the lighting mode, outdoor environments were divided into two types, roads and others. In community there are two kinds of roads, external and internal roads.

1. External and internal roads: The primary purpose of road lighting is to provide good visibility at night for drivers and pedestrians and to provide a convenient, safe, comfortable environment. Road in residential zone includes motor road, pedestrian road and intersection area. In this study, the illuminances at ground level of the external road and internal road were measured. The evaluation indexes of light environment were selected based on China's road evaluation index system [9] and the actual characteristics of residential roads.

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TABLE I
BACKGROUND INFORMATION OF TWO COMMUNITIES

Community	Built year	Highest number of floors	Occupied area/m^2	Greening rate
A	2006	18	90000	30%
B	2003	6	120000	32%

(a)

(b)

Fig. 1 Photos of (a) community A and (b) community B (Derived from [10])

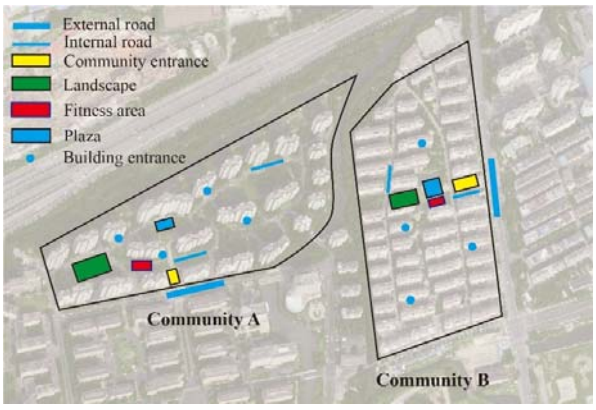


Fig. 2 Measuring area in two communities

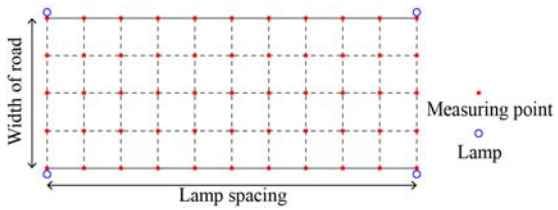


Fig. 3 Layout of measured points for the test of road

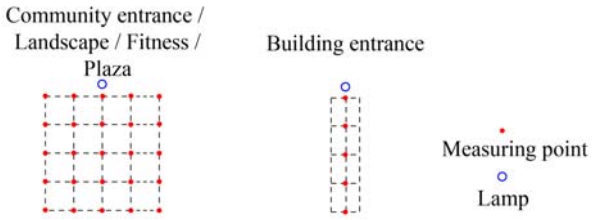


Fig. 4 Layout of measuring points for the test of community

A typical unit of street lamp was selected for measurement, as shown in Fig. 3. All measuring points in roads were at the ground level. The four-point method was adopted. The measuring points were arranged at the four corners of the grid, and the illuminances at the four corners of the grid were measured.

Meanwhile, the average illuminance was obtained according to (1) [11]:

$$E_{av}=\left(\sum E_{\theta}+2\sum E_{0}+4\sum E\right)\Big/\left(4MN\right) \quad (1)$$

where E_{av} (lx) is the average illuminance; M is the number of vertical grids, N is the number of horizontal grids. E_{θ} (lx) is the illuminance at the four corners of measuring area. E_0 (lx) is the illuminance at the outer boundary of measuring area apart from E_{θ}. E (lx) is the illuminance within the measuring area.

Uniformity of illuminance was calculated by using (2):

$$U_0 = E_{min} / E_{av} \quad (2)$$

where U_0 (lx) represents the uniformity of illuminance; E_{min} (lx) is the minimum illuminance;

2. Community entrance, landscape, fitness, plaza and building entrance: The lighting modes for community entrance, landscape, fitness, plaza and building entrance are different from that of roads. In these areas only one or two lamps are set to provide outdoor lighting. The layout of measuring points is shown in Fig. 4. The illuminances at the ground level of community entrance, plaza and building entrance were measured. The illuminances were measured at 0.5 m above the ground area in the tests of landscape and fitness areas. The average illuminance, minimum illuminance, and uniformity of illuminance were obtained according to (1), (2).

C. Questionnaire Survey

A questionnaire survey was conducted in two communities, in order to investigate the activities of residents and residents' concern about light environment at night. The questionnaire survey (See Appendix for an example) contains background information on the residents and lighting environment assessment of different environments. Information on gender, age, working hours, night activity, activity radius and activity schedule were collected as background information. The participants also need to evaluate the importance on different environments in the community. The lighting environment

importance was set as five scales. Meanwhile, the frequency of night activities was investigated by manual count. The flows of pedestrians and vehicles were included. The SPSS 22.0 was used to analyze the data of questionnaire survey. The weighted values of different areas were calculated by (3) and (4):

$$S_j = \sum_{i=1}^{n} W_{i,j} \tag{3}$$

$$w_j = S_j \Big/ \sum_{j=1}^{m} S_j \tag{4}$$

where n is the subject number; m is the total number of lighting areas, $W_{i,j}$ is the score of subject i on lighting area j; S_j is the sum of scores on lighting area j and w_j is the weighted value of lighting area j.

III. Results

A. External and Internal Roads

Based on field measurements, the height and spacing of lamps in different road are summarized in Table II. In two communities, the lighting mode of external road and internal road is the symmetrical arrangement on both sides. And the lighting mode of others is the unilateral arrangement. The results of illuminances are presented in Table III.

According to code for lighting design of urban nightscape JGJ/T 163-2008 [12], the illuminances in external road fail to meet the requirement of 8 lx. However, the illuminances in internal road are much higher than the requirement of 5 lx.

In terms of uniformity of illuminance, only internal road in community A can meet the minimum requirement (0.3) [9]. The uniformities of illuminance in other three roads are much lower than the minimum requirement. There are two main reasons resulting in this problem. One is that, street lamps are usually blocked by trees and vehicles. A second reason is the insufficient maintenance of street lamps. Some are out of work, and there is a lack of regular cleaning and maintenance of lamps.

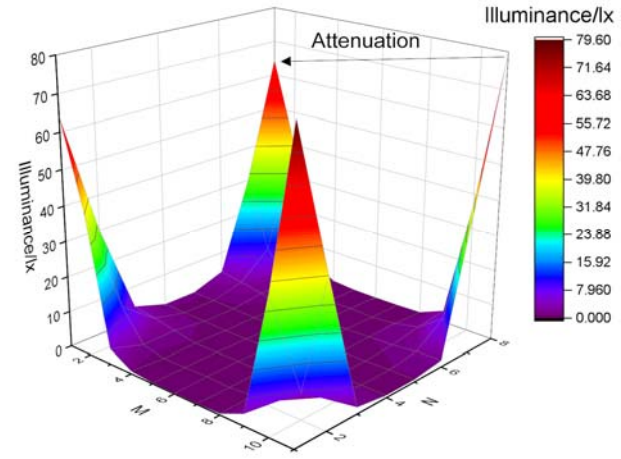
TABLE II
Height and Spacing of Lamps in Different Roads

Lighting area	Community	Height of lamps (m)	Spacing of lamps (m)
External road	A	4.2	26.9
	B	2.7	7.4
Internal road	A	4.2	24.7
	B	2.7	27.4

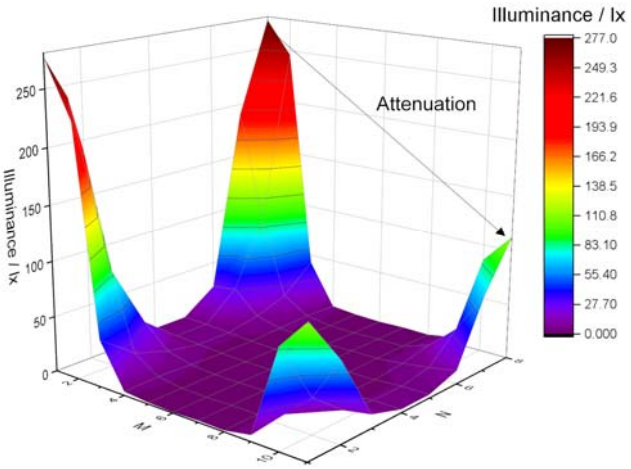
TABLE III
Average, Minimum Illuminance and Uniformity of Illuminance in Different Roads

Lighting area	Community	E_{av} (lx)	E_{min} (lx)	U_0
External road	A	3.0	0.2	0.07
	B	0.6	0.1	0.17
Internal road	A	15.3	0.8	0.05
	B	14.7	7.4	0.50

Typical units of external road and internal road in community A were selected, and the distributions of illuminance in this unit are shown in Fig. 5. Even though the lamps are the same in each unit, the peak difference between the two adjacent lamps is nearly 20% in external road, and in internal road it is 150%.



(a)



(b)

Fig. 5 The distribution of illuminances in community A in a typical unit of (a) external road, (b) internal road

TABLE IV
Average, Minimum Illuminance and Uniformity of Illuminance in Different Areas

Lighting area	Community	E_{av} (lx)	E_{min} (lx)	U_0
Community entrance	A	10.0	5.8	0.58
	B	7.0	3.5	0.50
Landscape	A	0.9	0.4	0.44
	B	0.3	0.2	0.67
Fitness	A	0.6	0.4	0.67
	B	0.5	0.2	0.40
Plaza	A	0.4	0.2	0.50
	B	0.3	0.2	0.67
Building entrance	A	3.6	1.0	0.28
	B	0.6	0.4	0.67

TABLE V
REQUIREMENT OF HORIZONTAL ILLUMINANCE AT THE GROUND LEVEL IN DIFFERENT STANDARDS

	Mainland China	Hongkong, China	CIE	Japan
External road	8.0	10	10	5.0
Internal road	2.0* / 5.0	5.0	7.5	3.0 / 10*
Community entrance	20.0	/	/	/
Landscape	2.0	/	/	/
Fitness	/	/	/	/
Plaza	5.0	/	/	/
Building entrance	/	/	/	/

Note: * represents the special requirement for pedestrians.

B. Community Entrance, Landscape, Fitness, Plaza and Building Entrance

The results of illuminances in community entrance, landscape, fitness, plaza and building entrance are summarized in Table IV. The results show that the illuminances of community entrance are the highest. And lighting environment in landscape, fitness, plaza and building entrance is quite bad. However, illuminance distributions of these areas are more well-distributed than that of road. 90% of lighting areas meet the requirement of uniformity (0.3).

In this study, external road is for motor vehicles and the internal road is for pedestrians. The minimum requirement of sidewalk in China is 2 lx, which is much lower than that in Japan (10 lx). However, only the average illuminances of community entrance in community A and B meet this requirement. Related standards of different environments, including mainland China, Hongkong China [13], CIE [6] and Japan [14], are summarized in Table V. The results show that there is still a lack of requirements for different environments in residential community.

C. Questionnaire Results

A total of 30 questionnaires were sent out and 29 valid questionnaires were collected. Based on the questionnaire analysis, people mainly go out for a walk and shopping between 6 and 8 pm. Residents usually do fitness activities around 10 pm. Based on a one-hour record, there were 6 electric vehicles and 20 residents passing through the main entrance in community A while there are 3 vehicles and 5 residents passing through the main entrance in community B. People in community B go out less frequently than people in community A. The overall satisfaction of light environment in community A is much better than that in community B. It can be concluded that the light environment at night plays an important role on the night activities, and providing a good light environment at night can increase the frequency of people's activities at night and improve the safety of the community.

Based on the results of subjective survey, the distribution of subjective weighted values is obtained, as shown in Table VI. Lighting areas are divided into three levels, degree I, degree II and degree III based on weigh coefficients. It can be concluded that fitness area, internal road and building entrance are the main concern for residents at night, following by external road and community entrance. Residents generally pay less attention to the lighting of the landscape area and plaza area. Special attention needs to be paid to lighting design of fitness areas, roads and entrances.

TABLE VI
WEIGHTED VALUE OF DIFFERENT AREAS

Lighting areas	Weighing coefficient	Importance degree
Fitness area	0.19	I
Internal road	0.18	I
Building entrance	0.18	I
External road	0.14	II
Community entrance	0.13	II
Landscape	0.09	III
Plaza	0.09	III

IV. CONCLUSION

Two residential communities were selected in Hangzhou. Outdoor lighting environments at night were investigated, by adopting the combination of objective measurement and subjective evaluation method. Residential environment is divided into seven aspects, such as external road, internal road, community entrance, landscape, fitness, plaza and building entrance. Corresponding measurement method was proposed. Safety evaluation system of lighting environment at night for residential community was established.

(1) In the field measurement, the overall lighting environments are poor in two communities. In general, lighting environment in community A is much better than that in community B. However, apart from internal roads and community entrance, other areas in two communities fail to meet the minimum requirement of average illuminance in China.
(2) It is found that illuminance distribution of roads is more uneven than that of other areas. In order to avoid the obstruction of trees and cars, trees and cars need to be kept a reasonable distance from lamps. It is suggested to prune the trees regularly.
(3) Light environment at night plays an important role on the night activities. Providing a good light environment at night can increase the frequency of people's activities at night and improve the safety of the community.
(4) From high to low importance, lighting environments in residential community can be divided into three degrees, degree I, degree II and degree III. Fitness area, internal road and building entrance (degree I) are the main concern for residents at night, following by external road and community entrance (degree II). The landscape and plaza area (degree III) are the least important aspects.

There is still no special design standard for residential light environment. In the future, more residential communities in different ages need to be assessed, in order to comprehensively evaluate and analyze the light environment of residential community and put forward the corresponding suggestion to improve the lighting environment at night.

APPENDIX

Questionnaire Survey on Lighting Environment at Night

Please tick in the following table.

1. Background information

Gender:

male □ female □

Age:

0-18 □ 18-30 □ 30-50 □ 50 and above □

Working hours:

morning shift □ nine-to-five □ night shift □

Night activity:

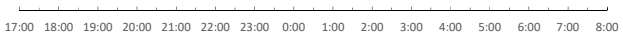
go for a walk □ shopping □ fitness □ others □

Activity radius:

in residential area □ 500-1000 m □ 1000 m and above □

Activity schedule:

Please draw your activity schedule.



2. Light environment assessment

	Satisfaction				
	Very dissatisfied ← Neutral → Very satisfied				
	1	2	3	4	5
Overall light environment	□	□	□	□	□
Lighting area	**Importance Degree**				
	Not essential ← Important → Very important				
	1	2	3	4	5
External road	□	□	□	□	□
Internal road	□	□	□	□	□
Community entrance	□	□	□	□	□
Landscape	□	□	□	□	□
Fitness area	□	□	□	□	□
Plaza	□	□	□	□	□
Building entrance	□	□	□	□	□

ACKNOWLEDGMENT

The study has been supported by the China National Key R&D Program "Functional upgrading and renovation technologies of existing urban residential community" (Grant No. 2018YFC0704802)".

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