

EFFECT OF LIGHTING LEVELS AND LAMP TYPES FOR CRIME PREVENTION IN THAI PEDESTRIAN WALKWAYS

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Abstract

The effects of illuminance level and lamp type were investigated for crime prevention in Thai pedestrian walkways aimed to examine the effects of illuminance on perceived safety, pedestrian behaviour, and criminal identification as part of crime prevention. Laboratory tests were carried out at the Faculty of Architecture, Kasetsart University. Five levels of illuminance: 10, 20, 50, 100, and 200 lux, and the types of lamps-HPS, LED Daylight and LED Warm White were investigated. Experimental tests were performed using a 3D model with DIALux simulation. Results showed that each lamp type required a different illuminance to optimize crime prevention. The HPS lamp with an illuminance of 200 lux was found to be the most suitable level for perceived safety, while 10 lux was suitable for pedestrian behaviour and was suitable for criminal identification. For the LED Daylight lamp, the illuminance of 200 lux was the most appropriate level for perceived safety, while 20 lux was suitable for pedestrian behaviour and 10-20 lux was enough for criminal identification. For the LED Warm-white lamp, the illuminance of 10 lux was the most appropriate level for perceived safety, with 20 lux for pedestrian behaviour, and 10-20 lux for criminal identification.

Keywords: Criminal identification, Lighting, Pedestrian behaviour, Perceived safety

Introduction

In the past, it has been studied in light to reduce the fear of crime and the number of crimes. From the 1960s to the 2000s, there was a growing awareness of crime prevention in public spaces. In this time, several projects by the government have been initiated involving the improvement of streetlighting to increase illumination in public areas with high crime rates. For example, in the UK and USA, lighting studies were conducted (Painter,

1988; Painter, 1989; Painter, 1991; Painter, 1996; Painter and Farrington, 1997; Painter and Farrington, 1999; Painter and Farrington, 2001). The findings of these studies have shown that street lighting affects people's behavior, reducing crime and fear of crime. Moreover, the lighting improvement could lead to an increase in the use of nighttime pedestrian areas and increase as effective crime prevention.

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In the following decades, in the study of lighting and crime prevention in pedestrian environments in the past research, perceived safety (or fear of crime) was the most important factor in terms of the influence of street lighting quality instead of the actual crime rate. (Evans and Fletcher, 2000; Van, 2010; Fotios and Unwin, 2013; Boomsma and Steg, 2014; Wu and Kim, 2016). This is due to uncontrollable factors that affect the number of crimes to be measured, such as weather conditions and the relocation of officers at checkpoints (Day *et al.*, 2007).

From gathering literature reviews, it has been shown that lighting was one of the important factors that affect people's perceived safety in pedestrian areas. And, the most cited factor consisted of illuminance, uniformity, and the CCT (Boyce *et al.*, 2000; Boyce *et al.*, 2009; Knight, 2009). The use of lighting affects human night vision. The more light there is, the more visible we are and the greater the sense of security (Haans and Kort, 2012). At present, there are several standards and recommendations for street and pedestrian lighting, IESNA (2003) indicated that the minimum horizontal illuminance for pedestrian lighting is 6 lux, and a minimum vertical illuminance is 5-8 lux. (IESNA, 2013) Moreover, the recommended illumination for a pedestrian average of 15 lux, a minimum of 5 lux. (CIE, 2010)

In addition to the sense of security of crime that affects crime prevention, there were also other factors that should be considered, such as pedestrian behavior, both in terms of obstacle detection and face recognition (Caminada and Bommel, 1980; Fujiyama *et al.*, 2005)

In addition, crime prevention also includes criminal identification. From the part studies, the most cited factors for criminal identification factors are gender, clothing, attire, and hair color (Davis *et al.*, 2015). Criminal identification has been used in many studies in terms of criminal identification in the past (Wells, 1978).

Adequate lighting affects pedestrian crime prevention, and the appropriate values were indicated in other countries. But how much light will be enough for Thai people? The main objective of this study was to investigate appropriate lighting conditions to enhance crime prevention for Thai pedestrians. Findings from this study can be used as design guidelines for street and pedestrian lighting to reduce crime during the nighttime in Thailand.

Materials and Methods

Participants

Fifty people participated in the experiment with mean age of 20.62 (SD $\frac{1}{4}$ 2.72). All the

participants were Thai nationals and had no color blindness or other eye problems. The test road image was regarded as relatively safe. All participants received 100 Baht as compensation.

Study variables

1. Independent variables

Two independent variables were investigated as illuminance level and lamp type. Five levels of illuminance were explored including 10, 20, 50, 100, and 200 lux. These levels were chosen because they were used in other studies and recommendations in terms of street and pedestrian lighting (IESNA, 2003; Fujiyama *et al.*, 2005). Three types of lamps were explored as 2,600 K High-Pressure Sodium Lamp (HPS), 6,500 K Daylight White Light-Emitting Diode (LED), and 3,000 K Warm-White Light-Emitting Diode (LED). All these lamps are normally used for street lighting (see Figure 1).

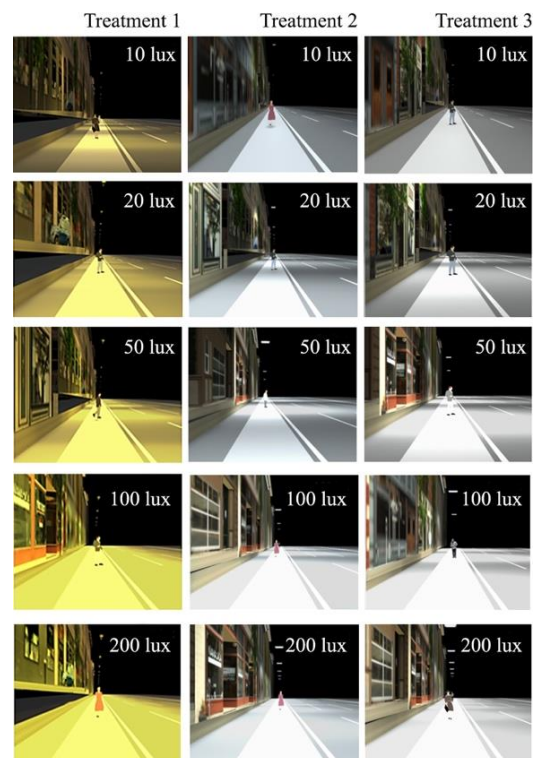


Figure 1. The fifteen simulated videos investigated in this study. Treatment 1 is HPS, Treatment 2 is Daylight LED, and Treatment 3 is Warm-white LED

2. Dependent variable

The dependent study variable was crime prevention of pedestrians, consisting of three sub-

variables as perceived safety, pedestrian behaviour, and criminal identification.

Perceived safety was defined as a person's immediate sense of security and an absence of anxiety of becoming victimized when travelling through a street environment (Haans and Kort, 2012), like perceived personal danger (Blöbaum and Hunecke, 2005) and fear of crime (Fisher and Nasar, 1992; Nasar and Fisher, 1993; Nasar, 2000). An adapted version of the perceived personal danger scale developed by Blöbaum and Hunecke (2005) was used to measure the perceived safety of Thai pedestrians in this study with the three self-report items: "I have a pleasant feeling with the idea of having to walk into this street", "I feel easy at this street" and "I feel safe in this street" (Blöbaum and Hunecke, 2005; Boomsma and Steg, 2014). Participants rated items on a 7-point scale, ranging from 1 (strongly disagree) to 7 (strongly agree). Mean scores were computed for each setting; higher scores reflected higher feelings of safety. Cronbach's alpha was tested and averaged 0.78.

Pedestrian behaviour in this study was defined as four behaviours of pedestrians when walking through a particular street environment. These behaviours were collision avoidance distance, obstacle avoidance distance, facial recognition distance, and minimum comfortable distance. These behaviours were adapted from pedestrian behaviours previously explored on the effects of lighting levels in several studies (Fujiyama *et al.*, 2005). In this study, collision avoidance distance was the distance between pedestrians when walking in the same direction. Obstacle avoidance distance was the distance between the pedestrian when confronted with an obstacle before taking avoidance. The minimum comfortable distance was the distance between other people for pedestrian comfort. Facial recognition distance was the distance at which the pedestrian had the "FIRST" thought that he/she could be "SURE" to identify other people (Fujiyama *et al.*, 2005).

Criminal identification in this study was defined as the ability of the pedestrian to identify criminal characteristics such as sex, race, cloth, and hair color (Davis *et al.*, 2015).

Experimental setting and equipment

The experiment began in November 2020. Fifty subjects aged 18-60 years old participated in a completely dark experimental room (Boomsma and Steg, 2014) on the 4th floor, Faculty of Architecture Building, Kasetsart University.

Fifteen virtual environment VDO clips generated by DIALux 14.3 were shown to the participants in random order. The simulated environment can control extraneous variables.

Based on a comprehensive review of scholarly sources, many studies also showed that the results from simulated environment are not different from real environment. (Tlauka and Wilson, 1996; Bishop and Rohrmann, 2003; Nasar and Cubukcu, 2011). The study also explored the correlation between the subject perceptions from the image screen and those of the real-world scene. The results was a highly significant correlation of these two data ($r=0.744$, $p<0.01$). The DIALux 14.3 VDO clips were identical except for lighting levels and lamp types. In total, Fifteen VDO clips were used in this experiment.

Experimental design and testing procedure

A repeated measures Balanced Latin Square design was used. The subjects experienced all fifteen treatments presented in systematic random orders. In this design, each treatment condition appeared an equal number of times in each position and was preceded and followed by every other condition. Thus, carry-over and sequence effects were eliminated.

When the participant reached the laboratory, he/she first signed a consent form. Then, the experimenter described the purpose and experiment procedure. After that, the participant had a 5-minute visual acuity test (Fujiyama *et al.*, 2005) and then relaxed for 5 minutes (Wang and Luo, 2016).

When the experiment started, participants were seated alone in a dark room 60 cm in front of a screen and fixed their eyes on the center of the screen (with solid angle size of 5.55 steradians). They viewed full-screen virtual environment movie clips of different settings, in which the levels of lighting and lamp types were systematically varied. The luminance of the test vdo images were range from 100 cd/m² to 150 cd/m². (see Figure 2).

Participants were asked to imagine walking in a real place. After each movie clip, participants rated three dependent variables as 1) perceived safety, 2) pedestrian behaviour from the street shown on the screen and 3) criminal identification. After the experiment, the subject will be grateful for the cooperation of the participants.

Measurements

The first dependent variable as perceived safety was measured using an adapted version of the perceived personal danger scale developed by Blöbaum and Hunecke (2005).

The second dependent variable was pedestrian behaviour. Four pedestrian sub-behaviors were measured as collision avoidance distance, obstacle avoidance distance, minimum comfortable distance, and facial recognition distance. The factors were measured as follows (Fujiyama *et al.*, 2005):

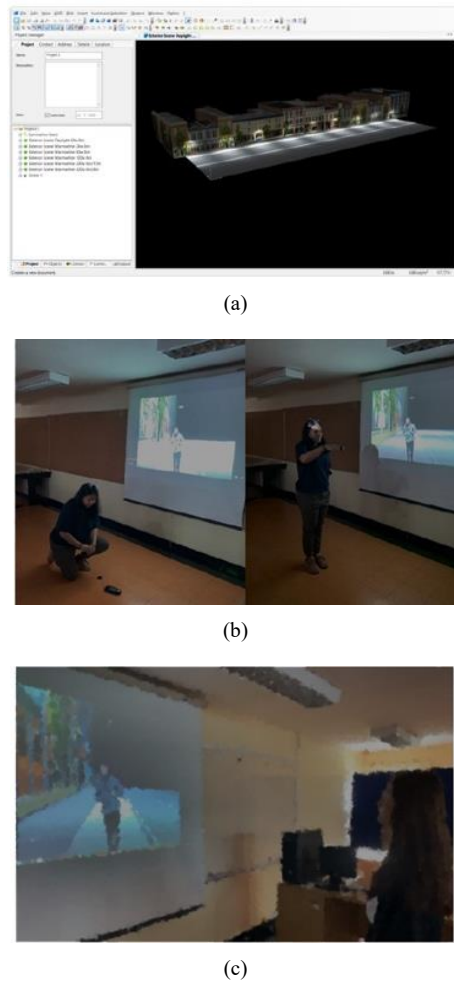


Figure 2. (A) 3D video simulations, (B) Experimental area metering for optical accuracy, and (C) Explanation and experimentation

1. Distance to avoid collisions. Participants were asked to watch a video clip projected onto the screen. Participants had to press 'stop playing' when he/she wanted to avoid a collision with other people on the walkway.

2. Obstacle avoidance distance. Participants were asked to watch a video clip projected onto the screen. Participants had to press 'stop playing' when he/she wanted to avoid a collision from an object 1.50 m high and 0.51 m wide on the walkway in the VDO.

3. Minimum comfortable distance. Participants had to press 'stop playing' when he/she became uncomfortable because of the close distance between the participant and others on the walkway in the VDO.

4. Facial recognition distance. Participants were required to stop when he/she FIRST thought

that they could identify the people on the walkway in the VDO (first recognition). After that, the participants were asked to walk again and stop when this time he/she SURELY recognized the face of the person (sure recognition).

After recording the 'stop' seconds, distances on the walkway for each person were obtained using the following formula (Fujiyama *et al.*, 2005):

$$\text{Distance} = A - (V \times (S \times 100))$$

where,

A = distance from the origin to the object (m)

V = walking speed of the trial participants (m/s)

S = Time stopped in the video (s)

Finally, the results of overall pedestrian behaviour were came from the averaged values from five factors, which are 1) distance to avoid collisions, 2) obstacle avoidance distance, 3) minimum comfortable distance, 4) first recognition, and 5) sure recognition.

The third dependent variable was the criminal identification performance of the pedestrian. This was measured by three aspects of hair color, cloth color, and sex. In the experiment, participants were required to press 'stop' and identify hair color, cloth color, and sex of the person on the walkway in the VDO.

After collection, the data for perceived safety and pedestrian behaviour were analyzed using mean value and standard deviation and one-way ANOVA as well as the Sidak t-test for multiple comparison. Results of criminal identification performance were analyzed as percentages.

Results and Discussion

Results of perceived safety

The perceived safety scores for each of the fifteen lighting conditions are summarized in Table 1. A repeated-measures ANOVA was used to analyze the results of perceived personal safety as the dependent variable. Significant effect of illuminance was shown for all lamp types. For the HPS lamp, an increase in illuminance led to a significant increase in perceived safety ($p < 0.01$). Further post-hoc comparisons (Sidak t-test) revealed that illuminances of 200 lux, 100 lux, 50 lux, and 20 lux were rated highly significant in terms of perceived safety and higher than 10 lux at $p < 0.01$. There was no significant difference between any pair for illuminance values.

For Daylight LED, ANOVA showed that an increase in illuminance can highly significantly led to an increase in perceived safety ($p < 0.01$). The Sidak t-test) revealed that illuminance of 200 lux was rated highly significant in terms of perceived

safety and higher than 20 lux and 10 lux at $p < 0.01$, while illuminance of 200 lux was rated significantly higher in terms of perceived safety than 50 lux. There was no significant difference between 100 lux and 200 lux in terms of perceived safety, while the illuminance of 10 lux was rated significantly lower than the other illuminances (20 lux, 50 lux, 100 lux, and 200 lux) at $p < 0.01$.

For Warm-white LED, the result was interesting. An increase in illuminance led to a significant decrease in perceived safety ($p < 0.01$). Illuminance of 10 lux led to a feeling of safety that was significantly higher than all other tested illuminance levels at $p < 0.01$, while illuminance of 200 lux led to a feeling of safety that was significantly higher than all other tested illuminance levels at $p < 0.01$, except for 100 lux.

Table 1. Mean, standard deviation, and significant level of perceived safety at different illuminances for each lamp type

Illuminance	Perceived safety		
	Mean	Standard Deviation	p-value
HPS lamp			
10 lux	2.57	0.93	0.00**
20 lux	4.65	1.40	
50 lux	4.91	1.24	
100 lux	4.85	1.63	
200 lux	4.95	1.92	
Daylight LED			
10 lux	3.57	1.59	0.00**
20 lux	3.95	1.38	
50 lux	4.36	1.39	
100 lux	4.54	1.51	
200 lux	4.78	1.80	
Warm white LED			
10 lux	4.32	1.29	0.00**
20 lux	3.75	1.37	
50 lux	3.58	1.37	
100 lux	2.39	1.21	
200 lux	2.55	1.79	

** Highly significant ($p < 0.01$); * Significant ($p < 0.05$)

Results of pedestrian behaviour

1. HPS lamp

Table 2 shows mean, standard deviation, and significance levels of pedestrian behaviour at different illuminances for HPS lamp. An increase in illuminance significantly increased obstacle avoidance distance, sure recognition ($p < 0.01$), and first recognition ($p < 0.05$). Results of overall pedestrian behaviour also showed a highly significant difference, with an increase in illuminance levels at $p < 0.01$.

Table 2. Mean, standard deviation, and significance levels of pedestrian behaviour at different illuminances for HPS lamp

Illuminance	Mean	Standard Deviation	p-value
Distance to avoid collisions			
10 lux	4.00	2.87	0.149
20 lux	3.46	1.90	
50 lux	3.23	2.16	
100 lux	3.27	1.36	
200 lux	3.05	1.11	
Obstacle avoidance distance			
10 lux	5.93	4.24	0.00**
20 lux	3.85	1.63	
50 lux	4.41	0.63	
100 lux	3.82	2.12	
200 lux	3.01	1.93	
Minimum comfortable distance			
10 lux	6.25	2.26	0.225
20 lux	5.10	3.25	
50 lux	5.79	2.96	
100 lux	5.36	3.10	
200 lux	5.14	2.67	
First recognition			
10 lux	8.71	2.80	0.042*
20 lux	9.10	3.88	
50 lux	7.88	3.72	
100 lux	7.69	2.70	
200 lux	7.33	3.18	
Sure recognition			
10 lux	3.61	1.81	0.00**
20 lux	2.35	1.10	
50 lux	4.49	1.86	
100 lux	2.42	2.17	
200 lux	1.84	2.18	
Overall pedestrian behaviour			
10 lux	5.70	3.42	0.00**
20 lux	4.77	3.46	
50 lux	5.16	2.94	
100 lux	4.51	2.99	
200 lux	4.07	3.02	

** Highly significant ($p < 0.01$); * Significant ($p < 0.05$)

Results showed that for HPS lamp, an illuminance of 10 lux created a significant greater obstacle avoidance distance than the other illuminance levels (20 lux, 50 lux, 100 lux, and 200 lux) at $p < 0.01$, while an illuminance of 20 lux created greater distance of first recognition than 100 lux ($p < 0.05$) and 200 lux ($p < 0.01$). However, no significant differences in first recognition scores were recorded between 20 lux and 10 lux and 20 lux and 50 lux. An illuminance of 50 lux led to a sure recognition distance significantly greater than 10 lux, 20 lux, 100 lux, and 200 lux. Moreover, for overall pedestrian behaviour, an illuminance of 10 lux gave significantly improved behaviour over other illuminance levels (20, 50, 100, and 200 lux) at $p < 0.01$.

Table 2 Mean, standard deviation, and significance levels of pedestrian behaviour at different illuminances for HPS lamp

2. Daylight LED lamp

Table 3 shows mean, standard deviation and significance level of pedestrian behaviour at different illuminances for Daylight LED lamp. Under Daylight LED lamp, an increase in illuminance significantly led to an increase in distance to avoid collisions, obstacle avoidance distance, first recognition, sure recognition ($p<0.01$), and minimum comfortable distance ($p<0.05$). Results of overall pedestrian behaviour also showed highly significant difference with an increase in illuminance levels at $p<0.01$.

Table 3. Mean, standard deviation, and significance levels of pedestrian behaviour at different illuminances for Daylight LED lamp

Illuminance	Mean	Standard Deviation	p-value
Distance to avoid collisions			
10 lux	5.49	1.25	0.00**
20 lux	5.80	3.93	
50 lux	7.04	0.57	
100 lux	7.20	0.00	
200 lux	6.05	3.07	
Obstacle avoidance distance			
10 lux	5.07	2.11	0.00**
20 lux	11.08	4.44	
50 lux	7.20	4.25	
100 lux	4.51	3.27	
200 lux	4.77	2.77	
Minimum comfortable distance			
10 lux	4.85	3.49	0.026*
20 lux	8.54	4.72	
50 lux	7.37	4.88	
100 lux	6.74	4.75	
200 lux	5.63	3.25	
First recognition			
10 lux	7.89	3.06	0.00**
20 lux	7.75	3.02	
50 lux	9.15	2.30	
100 lux	8.19	2.26	
200 lux	7.37	3.36	
Sure recognition			
10 lux	1.11	0.74	0.00**
20 lux	1.57	2.24	
50 lux	3.84	1.10	
100 lux	3.28	1.58	
200 lux	1.42	1.66	
Overall pedestrian behaviour			
10 lux	4.88	3.20	0.00**
20 lux	6.94	4.92	
50 lux	6.92	3.54	
100 lux	5.99	3.37	
200 lux	5.05	3.50	

** Highly significant ($p<0.01$); * Significant ($p<0.05$)

For Daylight LED lamp, an illuminance of 100 lux created a significantly greater distance to avoid collisions than illuminance levels of 10 lux, 20 lux ($p<0.05$), and 200 lux ($p<0.01$). However, no significant difference of distance to avoid collisions was recorded between 100 lux and 50 lux.

An illuminance of 20 lux created a greater obstacle avoidance distance than illuminance levels of 10 lux, 50 lux, 100 lux, and 200 lux ($p<0.01$), while an illuminance level of 10 lux led to significantly reduced minimum comfortable distance compared with 20 lux, 50 lux, and 100 lux.

No difference in minimum comfortable distance was recorded between 10 lux and 200 lux and between minimum comfortable distances of all other illuminance levels. The Sidak t-test also showed that illuminance level of 50 lux gave significantly higher first recognition distance than other illuminance levels (10 lux, 20 lux, 100 lux, and 200 lux). The Sidak t-test showed that an illuminance of 50 lux ensured a significantly higher recognition distance than other illuminance levels of 10 lux, 20 lux and 200 lux ($p<0.01$), and 100 lux ($p<0.05$). For overall pedestrian behaviour, an illuminance of 20 lux created a better overall pedestrian behaviour than other illuminance levels of 10 and 20 lux ($p<0.01$) and 50 and 100 lux ($p<0.05$).

3. Warm-white LED lamp

Table 4 shows mean, standard deviation, and significance level of pedestrian behaviour at different illuminances for Warm-white LED lamp. An increase in illuminance led to a significant increase in distance to avoid collisions, obstacle avoidance distance, sure recognition ($p<0.01$), minimum comfortable distance, and first recognition ($p<0.05$). Results of overall pedestrian behaviour also showed a highly significant difference, with an increase in illuminance levels at $p<0.01$.

Warm-white LED lamp showed that an illuminance of 10 lux created significantly greater distance to avoid collisions than illuminance levels of 20 lux, 50 lux, 100 lux, and 200 lux ($p<0.01$). An illuminance of 20 lux also created greater obstacle avoidance distance than illuminance levels of 100 lux and 200 lux ($p<0.01$), 10 lux, and 50 lux ($p<0.05$).

An illuminance of 20 lux led to a significantly reduced minimum comfortable distance than 100 lux and 200 lux ($p<0.05$) but no difference in minimum comfortable distance was recorded between 10 lux, 20 lux, and 50 lux. The Sidak t-test

showed that illuminance of 100 lux significantly reduced first recognition distance than other illuminance levels of 10 lux ($p<0.05$), 20 lux, and 50 lux ($p<0.01$). The Sidak t-test also showed that an illuminance of 50 lux gave significantly greater sure recognition distance than other illuminance levels of 10 lux, 20 lux, 100 lux, and 200 lux ($p<0.01$). For overall pedestrian behaviour, illuminance levels of 10 lux, 20 lux, and 50 lux significantly improved overall pedestrian behaviour over illuminance levels of 100 and 200 lux ($p<0.01$), with no significant difference of overall pedestrian behaviour found between 10 lux, 20 lux, and 50 lux.

Table 4. Mean, standard deviation, and significance levels of pedestrian behaviour at different illuminances for Warm-white LED lamp

Illuminance	Mean	Standard Deviation	p-value
Distance to avoid collisions			
10 lux	6.84	2.78	0.00**
20 lux	5.58	2.79	
50 lux	3.08	1.77	
100 lux	3.85	1.86	
200 lux	3.70	1.66	
Obstacle avoidance distance			
10 lux	7.65	6.45	0.00**
20 lux	8.28	4.27	
50 lux	6.60	4.19	
100 lux	4.56	2.51	
200 lux	5.33	2.19	
Minimum comfortable distance			
10 lux	9.10	5.17	0.032*
20 lux	10.12	5.00	
50 lux	9.29	4.99	
100 lux	7.10	4.78	
200 lux	7.08	4.00	
First recognition			
10 lux	8.39	2.46	0.019*
20 lux	8.90	2.97	
50 lux	8.89	3.54	
100 lux	7.22	2.73	
200 lux	8.82	2.83	
Sure recognition			
10 lux	2.22	1.80	0.00**
20 lux	1.91	1.41	
50 lux	4.08	1.59	
100 lux	1.70	2.12	
200 lux	2.97	1.53	
Overall pedestrian behaviour			
10 lux	6.84	4.77	0.00**
20 lux	6.92	4.46	
50 lux	6.39	4.26	
100 lux	4.88	3.62	
200 lux	5.58	3.37	

** Highly significant ($p<0.01$); * Significant ($p<0.05$)

Table 5 shows the results of specifying gender, hair color, and clothing color of the criminal under different illuminance levels and lamp types. For HPS lamp, Daylight LED lamp and Warm-white

LED lamp all subjects correctly identified the gender of the criminal under all illuminance levels. For HPS lamp, the highest percentage of subjects (94%) identified the criminal hair color under 10 lux, while for Daylight LED lamp and Warm-white LED lamp, highest percentage of subjects (98% and 88% respectively) identified criminal hair color correctly under 20 lux. Moreover, for all investigated lamp types of the highest percentage of subjects (90% for HPS lamp, 88% for Daylight LED lamp, and 100% for Warm-white LED lamp) identified criminal dress color correctly under 10 lux.

Table 5. Percentage accuracy of criminal identification under different illuminance levels and lamp types

Variable	Percentage Accuracy				
	10 lux	20 lux	50 lux	100 lux	200 lux
HPS lamp					
Gender	100 for all illuminance levels				
Hair color	94	92	84	72	58
Dress color	90	56	38	4	4
Daylight LED lamp					
Gender	100 for all illuminance levels				
Hair color	94	98	78	92	88
Dress color	88	78	52	52	6
Warm-white LED lamp					
Gender	100 for all illuminance levels				
Hair color	86	88	30	18	8
Dress color	100	90	30	14	12

Discussion

The main objective of this research was to investigate the effects of illuminance level and lamp type on crime prevention in Thai pedestrian walkways. Laboratory tests were conducted at the Laboratory Room, Faculty of Architecture, Kasetsart University. The most suitable illuminance levels for walkways are presented in Table 6.

Findings, standards, and recommendations differed from previous studies. IESNA (2003) illustrated that the appropriate illuminance for walkways between public spaces is 6 lux, with sidewalks at 10 lux.

Results found in this study were higher than those in IESNA (2003). There might be two possible reasons. First of all, it might be that the influence of cultural factors yielded different results and conclusions. Thai people may require lighter to feel safe, see other people, avoid obstacles, and identify and recognize criminal behaviour than people in the United States. The second reason might be the fact that there is a difference of methodology in this

study and the previous researches to obtain the illuminance data in the IESNA. However, these two assumptions need to be tested in further study to see what is the actual cause of the situation. There is also a limitation in this study in terms of using simulated scene instead of real environment. Therefore, there should be further study to be tested again to make a comprehensive conclusion.

Table 6. Most suitable illuminance levels to reduce crime in walkways for Thai people

Variable	Illuminance (lux)		
	HPS	LED Daylight	LED Warm white
Perceived safety			
Overall	200	200	10
perceived safety			
Pedestrian behaviour			
Overall			
pedestrian	10	20	20
behaviour			
Criminal identification			
Gender	All tested illuminances (10-200)		
Hair color	10	20	20
Dress color	10	10	10

Moreover, it is important to note that high levels of illuminance that found in this study may contribute to a heightened sense of safety. However, there is also the potential effects that the large amount of blue spectrum emitted by the light source. This situation may emerge health problems and the sky glow.

These conclusions should be seriously considered by lighting engineers, urban planners, and city administrators when making decisions about the design of lighting installations that involve the choice of lamps with higher or lower levels of illumination.

In this study, the trial participants were pedestrians of the Bangkok Metropolitan Area only. Therefore, to reach a more comprehensive conclusion, further research is needed on pedestrians in other areas. Future analyses could also consider differences based on age groups and gender.

Conclusions

In this study, the effects of illuminance level and lamp type were investigated for crime prevention in Thai pedestrian walkways. Laboratory tests were carried out at the Faculty of Architecture, Kasetsart University. Results showed most suitable

illuminance levels to reduce crime in walkways for Thai people for each lamp type. This finding could be used as design guidelines for street and pedestrian lighting to reduce crime during the nighttime in Thailand.

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Ethic approval

Ethic approval of this study was obtained from the Kasetsart University Research Ethics Committee (COE No. COE63/196).

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