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Effects of Security Lighting Lamps on Discomfort Glare to Indoor Occupants

Lee, Yoon Jeong* · Kim, Jeong Tai**

* *Graduate School of Kyung Hee University, South Korea (yoonjeonglee@khu.ac.kr)*
** *Corresponding author, Department of Architectural Engineering, Kyung Hee University, South Korea (jtkim@khu.ac.kr)*

ABSTRACT

Purpose: Although security lights are used to secure pedestrian visibility and safety at nighttime, they can generate light trespass in the neighboring residential space. To prevent this, standards for acceptance limits on vertical illuminance and light pollution by the windows of residential buildings are presented. **Method:** This study thus representatively selected three types of lamps and, through an evaluation and analysis of the physical and subjective discomfort glare per lamp, proposed a discomfort glare index for each lamp. The evaluation and analysis according to the lamps were conducted through experiments. The variables were the security lights' lamps (NH 100W, MH 70W, LED 50W), installation angles (0°, 20°), and installation distances (3m, 5m, 7m, 9m). **Result:** According to the results of the discomfort glare evaluation depending on the angles and distances of the security lights, the following minimum standards are proposed: for NH 100W, a discomfort glare index of 30 and an installation distance of 4m; for MH 70W, a discomfort glare index of 32 and an installation distance of 4m; and, for LED 50W, a discomfort glare index of 31 and an installation distance of 6m, respectively. In addition, this paper recommends the use of MH 70W, when the road width is 4m-6m, and LED 50W, when the road width is over 6m, respectively.

KEYWORD

Discomfort glare,
Security lighting,
Lamps

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1. Introduction

1.1. Background and Purpose of Study

It is essential to install security lights along the street in residential areas to ensure night visibility and safety of pedestrians. Seoul has about 225,000 security lights installed [1], and if consider its population of about 10,385,000 [2], one security light is used by about 46 Seoulites. Although security lights have important role and responsibility for night pedestrians as shown in the example, excessive or insufficiently planned lighting may generate light trespass, causing damage to indoor life of residents at night.

Light trespass is defined as all kinds of light which may penetrate into a private property to cause disturbance and discomfort to people [3]. To suppress and prevent the occurrence of this light trespass, 「Artificial Lighting-Caused Light Pollution Prevention Act」 presents vertical illuminance standard of window surface in residential buildings [4]. The standard alone, however, is not sufficient in controlling light coming into direct view. As a result, National Environmental Dispute Resolution Commission announced in February 2014 that it suggests Discomfort Glare Index 36 as the light pollution acceptance limit for calculating light pollution compensations[5].

The UGR index used as a discomfort glare index for light pollution acceptance limit has the maximum of 28. As it is an index targeted for Westerners, however, it needs to be corrected appropriately to apply to Koreans. As optical characteristics such as light flux and light distribution also differ from lamp to lamp, it is judged that light pollution acceptance limits are to be determined for actually used lamps.

Among lamps for used as security lights installed in Seoul, metal lamps (45,564 including CDM) and sodium lamps (171,640) are most used [1]. Recently, study on energy efficiency and optical characteristics of LED lamps [6] and research on residents' recognition of change to LED lamps [7] continue to be performed.

This study aims at suggesting lamp-specific discomfort glare index by evaluating light pollution of security lights for effective light pollution control through the physical and subjective discomfort glare evaluation and analysis of most used metal and sodium lamp and LED lamp which is popular as an alternative lamp.

1.2. Details and Method of Study

This study performs measurements and experiments to suggest lamp-specific discomfort glare index at the light pollution acceptance limit by UGR index analysis and evaluation of discomfort glare of residents according to the lamps of security lights.

First, metal lamp (MH 70W), sodium lamp (NH 100W) and LED

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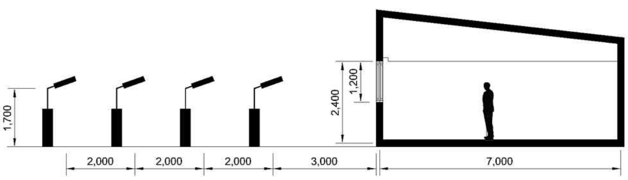
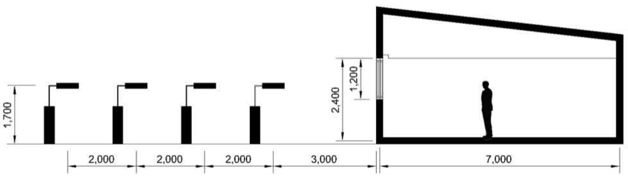
lamp (LED 50W) were selected as the lamps used for experiment, and preliminary experiment has been performed to measure brightness and vertical illuminance on window surface according to the angle and distance of security lights near the Mock-up experiment room installed on the K University Engineering College rooftop.

According to the result of the preliminary experiment, conditions (2 angles and 4 distances) for main experiment have been selected and 24 physical environments were organized to perform the discomfort glare evaluation experiment. For discomfort glare evaluation, subjects checked one of 6 discomfort glare levels (imperceptible-perceptible-acceptable-uncomfortable-hard to bear-unbearable) for glare felt in a given experimental environment.



(a) Luminaire bended upwards at 20° angle



(b) Luminaire bended upwards at 0° angle

Figure 1. Section of luminaire position from the window

Discomfort glare evaluation results obtained by experiments have been compared with UGR index according to experimental environment conditions. At the time, as the tested lamp has no common characteristics in light distribution or luminescent surface illuminance, lamps were classified for analysis. For the verification of significant difference in discomfort glare evaluation according to installation angle and distance, independent sample t-test and variance analysis (ANOVA) of SPSS were used.

Through the comparison of discomfort glare evaluation values and UGR indexes, light pollution impact characteristics of lamps for security light have been found and discomfort glare index applicable as light pollution acceptance limit has been proposed for each lamp.

2. Experiment Method for Evaluating Discomfort Glare of Security Lights

This study has performed discomfort glare evaluation experiments according to the lamp types for security light. Each lamp was connected to the security light luminaire and targeted for discomfort glare evaluation according to the installation angle and distance from the window surface. Discomfort glare evaluation was performed by experiments for subjects.

2.1. Experiment Overview

To evaluate discomfort glare of security light, the following experiment space has been organized by assuming a 2 stories high residential space where a lamp comes into view.

The experiment space is a mock-up which is made with the actual size and one-to-one scale, and installed on rooftop of the K University Engineering College (at 37.17 north latitude, 127.01 east longitude). It faces south, has the shape of 5.2m wide, 7.0m deep and 2.4m high, and the window size is 3.9m (W)×1.2m (H). The plan and elevation of the room are as shown in Fig 1 and 2.

Target lamps are sodium (NH) 100W, metal halide (MH) 70W and LED 50W, and they have the luminaire shape as shown in Fig 3. For basic information of each lamp, measurement data of Korea Institute of Lighting Technology has been referred to. LED 50W shows 62lx of average surface illuminance and 0.6 of uniformity. MH 70W shows 14lx of average surface illuminance and 0.21 of uniformity, and NH 100W shows 78.2lx of average surface illuminance and 0.24 of uniformity. At the time, MH 70W was measured for 16×8(m^2) of application area after installed at 6m of height and LED 50W and NH 100W were measured for 8×4(m^2) of application area after installed at 4m of height.

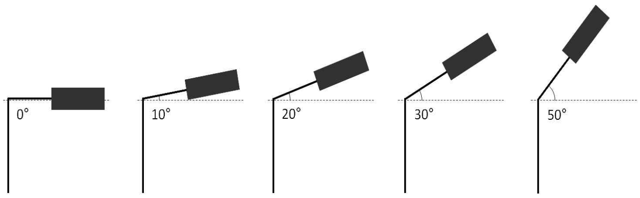
LED 50W, MH 70W and NH 100W show 4,850lm, 4,900lm and 9,200lm of light flux, respectively. While LED 50W and MH 70W show similar flux with the difference of 50lm, NH 100W shows nearly twice higher light flux if compared with the others.

Figure 2. Luminaires with NH 100W, MH 70W(left), and LED 50W(right)

2.2. Setting Experimental Conditions for Security Lights

In the preliminary experiment, security lights have been installed at 5m from the window surface and five angle conditions of 0°, 10°, 20°, 30° and 50° (Fig 3) were set to measure illuminance and compare with the UGR value of each security light (Table 1).

Then, the angle was fixed to 30° and distance-specific illuminance from the point where vertical illuminance of window



(a) 0° (b) 10° (c) 20° (d) 30° (e) 50°

Figure 3. Upward angle of a luminaire from the horizontal

surface is 25lx to 10m was measured and compared with the UGR value (Table 3). UGR index was calculated using illuminance measured by LMK mobile advanced and illuminance measured at the brightest part on the window surface was used for vertical illuminance at window surface.

In the first preliminary experiment, 30° and 50° were excluded from the experiment variables as the security light angle of 30° or higher exceeds 28, the maximum constant of UGR in all lamps. Although NH 100W and MH 70W showed similar UGR values of 10-13 at 0° and 10°, 0° was set as a variable to evaluate discomfort glare when a full cutoff type luminaire (Table 2) was installed. 20° was set as the second angular variable as it shows lower UGR value than 30° and 50° and can explain a semi-cutoff type luminaire (Table 2) while exposing light-emitting part for setting the light pollution acceptance limit.

Table 1. UGR by angle of each luminaire

Lamp	UGR by angle of each luminaire				
	0°	10°	20°	30°	50°
NH 100W	13	13.2	27	31	38.8
MH 70W	10.8	11.4	32	33.8	41.3
LED 50W	26	31	33	34	39

Table 2. Luminaire classification for outdoor luminaires by cutoff

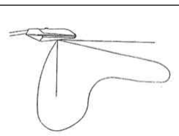
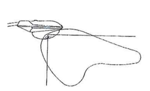
Classification	Full-cutoff	Semi-cutoff
Definition	Illuminate downward ground	Light is able to be exceeded 25% over 90°
Light distribution		
Upward lighting ratio	0%	0~20%

Table 3. UGR by distance of each luminaire

Lamp	UGR by distance of each luminaire					
	5m	6m	7m	8m	9m	10m
NH 100W	-	-	31.3	27.5	28.2	28.3
MH 70W	-	37	30.6	28.8	33.8	28.8
LED 50W	31.7	32.5	29.8	30.7	31.3	28.8

In the second preliminary experiment, the position where each lamp shows maximum 25lx of vertical luminance at window surface was confirmed 7m, 6m and 5m for NH 100W, MH 70W and LED 50W, respectively. According to the analysis of UGR with the interval of 1m, it has been found that it shows less than 3[1)] of difference, which is the difference between two classes of UGR index.

As it is judged that analysis is to be performed on the basis of the same distance although vertical illuminance at window surface shows 25lx or higher, 3m of minimum street length in residential areas was selected as the minimum distance condition. As it is also judged that residents cannot feel the difference in glare if UGR index indicates difference of less than one class, 2m of interval which can show difference of more than one class was selected as the second condition. Therefore, 3m, 5m, 7m and 9m of four distance conditions were set to perform the experiment for this study.

3. Lamp-Specific UGR Index Analysis and Discomfort Glare Evaluation

For each lamp, UGR index was analyzed and discomfort glare was evaluated through illuminance measurements. For each lamp, discomfort glare evaluations were analyzed and compared with the UGR index for each condition according to the installation angle and distance.

Indoor discomfort glare evaluation results were analyzed when the security light is installed at 0° and 20°. As it analyzes impact of angle, angle-specific discomfort glare evaluation values were compared at the fixed positions of 3m, 5m, 7m and 9m, and in the last step, impact of angle when all positions are included was compared together to see overall impact.

3.1. Indoor Discomfort Glare Analysis of NH 100W

3.1.1. Analysis of Discomfort Glare Evaluation Results According to Angles

First, when the security light is installed at 0° at 3m distance, discomfort glare evaluation value is distributed in the range of 0－3.3, showing the average of 1.40. When it is installed at 20°, the evaluation value is distributed in the range of 1.5－5.0, showing the average of 3.25. According to the independent sample T-test, it has been confirmed that there is statistically significant difference[2)] (t=-7.295, p=.000).

1) In CIE, UGR is divided into 6 classes of 13-16-19-22-25-28. The difference of two neighboring classes is equally 3.

2) Statistically significant difference means that there is meaning in the difference of analysis results.

When the security light is installed at 0° at 5m distance, discomfort glare evaluation value is distributed in the range of 0 – 3.0, showing the average of 1.23. When it is installed at 20°, the evaluation value is distributed in the range of 0.3 – 5.0, showing the average of 2.86. According to the independent sample T-test, it has been confirmed that there is statistically significant difference (t=-5.655, p=.000).

When the security light is installed at 0° at 7m distance, discomfort glare evaluation value is distributed in the range of 0 – 3, showing the average of 0.97. When it is installed at 20°, the evaluation value is distributed in the range of 0.3 – 4.5, showing the average of 2.59. According to the independent sample T-test, it has been confirmed that there is statistically significant difference (t=-6.465, p=.000).

Lastly, when the security light is installed at 0° at 9m distance, discomfort glare evaluation value is distributed in the range of 0 – 2.2, showing the average of 0.82. When it is installed at 20°, the evaluation value is distributed in the range of 0 – 4.3, showing the average of 2.23. According to the independent sample T-test, it has been confirmed that there is statistically significant difference (t=-6.066, p=.000).

NH 100W lamp shows statistically significant difference in discomfort glare evaluation values according to angles for all four positions and the difference has a tendency to decrease as the distance from window surface increases (Table 4). It can be analyzed that the range of discomfort glare evaluation values when the angle of the security light is 0° is different from that when the angle is 20°. From this, it can be confirmed that the angle has more impact on indoor discomfort glare as the distance between the window surface and security light decreases.

Table 4. T test on assessment of discomfort glare by angle (NH 100W)

Distance	Angle	Min.	Max.	Avg.	SD	t(p)
3m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
5m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
7m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
9m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	

3.1.2. Analysis of Discomfort Glare Evaluation Results According to Distances

As it analyzes impact of distance, distance-specific discomfort glare evaluation values were compared at the fixed angles of 20° and 0°, and in the last step, impact of distance when all angles are included was compared together to see overall impact.

First, when the security light angle is 0°, averages of discomfort glare evaluation results were 1.40, 1.23, 0.97 and 0.82 at 3m, 5m, 7m and 9m (Table 5), respectively. ANOVA analysis was performed for this and it has been confirmed that there is no significant difference (F=2.317, p=.079).

When the security light angle is 20°, averages of discomfort glare evaluation results were 3.25, 2.86, 2.59 and 2.23 at 3m, 5m, 7m and 9m (Table 5), respectively. ANOVA analysis was performed for this and it has been confirmed that there is significant difference (F=5.198, p=.002). According to multiple comparison by Tukey back testing, it has been confirmed that there is significant difference in discomfort glare evaluation values only when the distances from window surface are 3m and 9m.

Table 5. T test on assessment of discomfort glare by distance (NH 100W)

Distance	Angle	Min.	Max.	Avg.	SD	t(p)
0°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	
20°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	

From the above results, it can be found that there is no significant impact of distance on discomfort glare if a security light with NH 100W is installed at 0° (full cutoff). It can also be found that if it is installed at 20° (semi-cutoff), 4m of distance difference has no significant impact on discomfort glare and more than 6m of difference has significant impact when compared at 3m.

3.2. Indoor Discomfort Glare Analysis of MH 70W

3.2.1. Analysis of Discomfort Glare Evaluation Results According to Angles

First, when the security light is installed at 0° at 3m distance, discomfort glare evaluation value is distributed in the range of 0 – 3.3, showing the average of 1.17. When it is installed at 20°, the evaluation value is distributed in the range of 0.8 – 5, showing the average of 3.15. According to the independent sample T-test, it has been confirmed that there is statistically significant difference (t=-8.063, p=.000).

When the security light is installed at 0° at 5m distance, discomfort glare evaluation value is distributed in the range of 0 – 3, showing the average of 1.03. When it is installed at 20°, the evaluation value is distributed in the range of 0.5 – 4.5, showing the average of 2.73 (Table 6). According to the independent sample T-test for results, it has been confirmed that there is statistically significant difference (t=-6.985, p=.000).

When the security light is installed at 0° at 7m distance, discomfort glare evaluation value is distributed in the range of 0－2, showing the average of 0.69. When it is installed at 20°, the evaluation value is distributed in the range of 0－4, showing the average of 2.33 (Table 6). According to the independent sample T-test for results, it has been confirmed that there is statistically significant difference (t=-7.338, p=.000).

Lastly, when the security light is installed at 0° at 9m distance, discomfort glare evaluation value is distributed in the range of 0－3, showing the average of 0.76. When it is installed at 20°, the evaluation value is distributed in the range of 0－4.3, showing the average of 1.90 (Table 6). According to the independent sample T-test for analysis results, it has been confirmed that there is statistically significant difference (t=-4.471, p=.000).

Table 6. T test on assessment of discomfort glare by angle (MH 70W)

Distance	Angle	Min.	Max.	Avg.	SD	t(p)
3m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
5m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
7m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
9m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	

MH 70W lamp shows statistically significant difference in discomfort glare evaluation values according to angles for all four positions and the difference has a tendency to decrease as the distance from window surface increases. From this, it can be confirmed that the angle has more impact on indoor discomfort glare as the distance between the window surface and security light decreases.

3.2.2. Analysis of Discomfort Glare Evaluation Results According to Distances

First, when the security light angle is 0°, averages of discomfort glare evaluation results were 1.17, 1.03, 0.69 and 0.76 at 3m, 5m, 7m and 9m, respectively. The average decreases as the distance increases up to 7m and increases again at 9m (Table 7). ANOVA analysis was performed for this and it has been confirmed that there is no significant difference.

When the security light angle is 20°, averages of discomfort glare evaluation results were 3.25, 2.86, 2.59 and 2.23 at 3m, 5m, 7m and 9m, respectively (Table 7). ANOVA analysis was performed for this and it has been confirmed that there is significant difference (F=7.728, p=.000).

Table 7. T test on assessment of discomfort glare by distance (MH 70W)

Distance	Angle	Min.	Max.	Avg.	SD	t(p)
0°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	
20°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	

In addition, multiple comparison by Tukey back testing was performed to analyze between which positions discomfort glare evaluations indicate significant difference. According to the results, it has been found that there is significant difference in discomfort glare in three positional relationships and more significant difference exists in the order of 3m:7m < 5m:9m < 3m:9m. From this, it can be found than more than 4m of difference has significant difference in discomfort glare.

From the above results, it can be found that there is no significant impact of distance on discomfort glare if a security light with MH 100W is installed at 0° (full cutoff). It can also be found that if it is installed at 20° (semi-cutoff), more than 4m of distance difference has significant impact on discomfort glare of residents.

3.3. Indoor Discomfort Glare Analysis of LED 50W

3.3.1 Analysis of Discomfort Glare Evaluation Results According to Angles

First, when the security light is installed at 0° at 3m distance, discomfort glare evaluation value is distributed in the range of 0－4, showing the average of 1.84. When it is installed at 20°, the evaluation value is distributed in the range of 1.8－5, showing the average of 3.76 (Table 8). According to the independent sample T-test, it has been confirmed that there is statistically significant difference in discomfort glare evaluations between angles (t=-7.295, p=.000).

Table 8. T test on assessment of discomfort glare by angle (LED 50W)

Distance	Angle	Min.	Max.	Avg.	SD	t(p)
3m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
5m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
7m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	
9m	0°	0	3	0.64	0.78	-11.073 (.000)
	20°	1.6	5	2.98	0.88	

When the security light is installed at 0° at 5m distance, discomfort glare evaluation value is distributed in the range of 0－

4, showing the average of 1.05. When it is installed at 20°, the evaluation value is distributed in the range of 1.7 – 5, showing the average of 3.23 (Table 8). According to the independent sample T-test for analysis results, it has been confirmed that there is statistically significant difference (t=-8.783, p=.000).

When the security light is installed at 0° at 7m distance, discomfort glare evaluation value is distributed in the range of 0 – 3, showing the average of 0.64. When it is installed at 20°, the evaluation value is distributed in the range of 1.6 – 5, showing the average of 2.98 (Table 8). According to the independent sample T-test for analysis results, it has been confirmed that there is statistically significant difference (t=-11.073, p=.000).

When the security light is installed at 0° at 9m distance, discomfort glare evaluation value is distributed in the range of 0 – 2, showing the average of 0.21. When it is installed at 20°, the evaluation value is distributed in the range of 1.3 – 4, showing the average of 2.84 (Table 8). According to the independent sample T-test for analysis results, it has been confirmed that there is statistically significant difference (t=-15.161, p=.000).

LED 50W lamp shows statistically significant difference in discomfort glare evaluation values according to angles for all four positions and the difference has a tendency to decrease as the distance from window surface increases. From this, it can be confirmed that the angle has more impact on indoor discomfort glare as the distance between the window surface and security light decreases.

3.3.2 Analysis of Discomfort Glare Evaluation Results According to Distances

First, when the security light angle is 0°, averages of discomfort glare evaluation results were 1.84, 1.05, 0.64 and 0.21 at 3m, 5m, 7m and 9m, respectively (Table 9). ANOVA analysis was performed for this and it has been confirmed that there is significant difference (F=19.984, p=.000). In addition, according to multiple comparison by Tukey back testing, it has been found that there is more significant difference in the order of 3m:5m < 5m:9m < 3m:7m < 3m:9m. From this, it can be found that more than 4m of distance difference has significant difference in discomfort glare when LED 50W is installed at 0°(full cutoff).

Table 9. T test on assessment of discomfort glare by distance (LED 50W)

Angle	Distance	Min.	Max.	Avg.	SD	t(p)
0°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	
20°	3m	0	3	0.64	0.78	-11.073 (.000)
	5m	1.6	5	2.98	0.88	
	7m	0	3	0.64	0.78	-11.073 (.000)
	9m	1.6	5	2.98	0.88	

When the security light angle is 20°, averages of discomfort glare evaluation results were 3.76, 3.23, 2.98 and 2.84 at 3m, 5m, 7m and 9m, respectively (Table 9). ANOVA analysis was performed for this and it has been confirmed that there is significant difference (F=6.294, p=.001). In addition, according to multiple comparison by Tukey back testing, it has been found that there is more significant difference in the order of 3m:7m < 3m:9m. Although it can be found that more than 4m of distance difference has significant difference in discomfort glare, but it only applies to the reference position of 3m. From this, it is judged that difference in discomfort glare according to distance decreases as the distance from window surface increases.

4. Comparison of UGR Index and Discomfort Glare Evaluation Values

4.1. Analysis of UGR Index and Discomfort Glare Evaluations for NH 100W

Discomfort glare evaluation values in analyzed in chapter 3 were compared with the UGR index to suggest light pollution acceptance limits in the form of UGR index by applying discomfort glare felt by residents. At the time, discomfort glare evaluation values are divided into three ranges and the frequency and percentages are additionally analyzed. Three ranges were indicated by a number of 0, 1 and 2. 0 only includes discomfort glare evaluation value 0 and 1 includes discomfort glare evaluation values 0.1-2.9. And the range 2 includes discomfort glare evaluation values 3-5. Here, range 2 was defined as discomfort glare which causes discomfort to residents. It is because discomfort glare evaluation value 3 is a point at which glaring light starts to be felt uncomfortable.

First, as shown in Table 10, UGR index and discomfort glare evaluation values were compared for NH 100W. When the security light angle is 0°(full cutoff), it is judged that residents felt almost no discomfort glare as UGR indexes indicated less than 13(minimum value) at all positions and frequency of discomfort glare evaluation

Table 10. UGR and discomfort glare by distance (NH 100W)

Angle	Distance	UGR	Frequency by range (Ratio,%)		
			0	1	2
0°	3m	11.6	2(6.5%)	26(83.9%)	3(9.7%)
	5m	9.4	5(16.1%)	23(74.2%)	3(9.7%)
	7m	7.6	8(25.8%)	22(71.0%)	1(3.2%)
	9m	5.1	7(22.6%)	24(77.4%)	0(0%)
	Total	-	22(17.7%)	95(76.6%)	7(5.6%)
20°	3m	32.2	0	12(38.7%)	19(61.3%)
	5m	26.9	0	15(48.4%)	16(51.6%)
	7m	23.8	0	19(61.3%)	12(38.7%)
	9m	21.8	1(3.2%)	19(61.3%)	11(35.5%)
	Total	-	1(0.8%)	65(52.4%)	58(46.8%)

range 2 has the average of 5.6%. When the security light angle is 20°(semi-cutoff), on the contrary, the frequency of discomfort glare range 2 were 61.3% and 51.6% at 3m and 5m, respectively, exceeding 50% of occurrence frequency.

For this, simple regression analysis was performed to expect the position of the security light and UGR index at which discomfort glare may occur (Table 11). According to the result, minimum distance with no discomfort glare was 4m (discomfort glare 2.94) and UGR index was 30 (discomfort glare 2.9) (however, residual normality is not met). Therefore, if NH 100W is used as the lamp(semi-cutoff), we propose 4m of minimum installation distance and discomfort glare index 40 of light pollution acceptance limit.

Table 11. Simple regression analysis of NH 100W (20°)

	Division	B	β	t(p)	F(p)	R^2
Discomfort glare to occupants	(Constant)	3.631		13.257* (.000)	17.491 (.000)*	0.14
	Distance	-.179	-.376	-4.182* (.000)		
UGR	(Constant)	-.078		-.121 (.904)	17.004 (.000)*	0.14
	UGR	.101	.372	4.124* (.000)		

*p<.01

4.2. Analysis of UGR Index and Discomfort Glare Evaluations for MH 70W

For MH 70W, the analysis result is as shown in Table 12. When the security light angle is 0°(full cutoff), it is judged that residents felt almost no discomfort glare as UGR indexes indicated less than 13(minimum value) at all positions and frequency of discomfort glare evaluation range 2 has the average of 3.2%. When the security light angle is 20°(semi-cutoff), on the contrary, the frequency of discomfort glare range 2 were 64.5% and 48.4% at 3m and 5m, respectively.

Table 12. UGR and discomfort glare by distance (MH 70W)

Angle	Distance	UGR	Frequency by range (Ratio,%)		
			0	1	2
0°	3m	11	2(6.5%)	28(90.3%)	1(3.2%)
	5m	8	7(22.6%)	22(71.0%)	2(6.5%)
	7m	6.7	9(29.0%)	22(71.0%)	0(0%)
	9m	5.6	9(29.0%)	21(67.7%)	1(3.2%)
	Total	-	27(21.8%)	93(75.0%)	4(3.2%)
20°	3m	31.2	0	11(35.5%)	20(64.5%)
	5m	29	0	16(51.6%)	15(48.4%)
	7m	20	1(3.2%)	19(61.3%)	11(35.5%)
	9m	18.8	2(6.5%)	20(64.5%)	9(29.0%)
	Total	-	3(2.4%)	66(53.2%)	55(44.4%)

For this, simple regression analysis was performed to expect the position of the security light and UGR index at which discomfort glare may occur (Table 13). At the time, abnormal data was excluded to improve normality of data and the standard for discomfort glare occurrence was set to discomfort glare evaluation value 3. According to the result, minimum distance with no discomfort glare was 4m (discomfort glare 2.94)[3] and UGR index was 32 (discomfort glare 2.97) (however, residual normality is not met). Therefore, if MH 70W is used as the lamp(semi-cutoff), we propose 4m of minimum installation distance and discomfort glare index 32 of light pollution acceptance limit.

Table 13. Simple regression analysis of MH 70W (20°)

	Division	B	β	t(p)	F(p)	R^2
Discomfort glare to occupants	(Constant)	3.767		13.800* (.000)	23.567 (.000)*	0.16
	Distance	-.207	-.402	-4.855* (.000)		
UGR	(Constant)	.519		1.155 (.250)	20.860 (.000)*	0.15
	UGR	.081	.382	4.567* (.000)		

*p<.01

4.3. Analysis of UGR Index and Discomfort Glare Evaluations for LED 50W

For LED 50W, the analysis result is as shown in Table 14. When the security light angle is 0°(full cutoff), it is judged that residents felt almost no discomfort glare as UGR indexes indicated 19.7－29.6 at all positions and frequency of discomfort glare evaluation range 2 has the average of 6.5%. When the security light angle is 20°(semi-cutoff), on the contrary, the frequency of discomfort glare range 2 were 74.2%, 71.0% and 58.1% at 3m, 5m and 7m, respectively.

Table 14. UGR and discomfort glare by distance (LED 50W)

Angle	Distance	UGR	Frequency by range (Ratio,%)		
			0	1	2
0°	3m	29.6	3(9.7%)	23(74.2%)	5(16.1%)
	5m	27.1	9(29.0%)	20(64.5%)	2(6.5%)
	7m	25.2	11(35.5%)	19(61.3%)	1(3.2%)
	9m	19.7	22(71.0%)	9(29.0%)	0(0%)
	Total	-	45(36.3%)	71(57.3%)	8(6.5%)
20°	3m	37.7	-	8(25.8%)	23(74.2%)
	5m	33	-	9(29.0%)	22(71.0%)
	7m	30.6	-	13(41.9%)	18(58.1%)
	9m	29.4	-	19(61.3%)	12(38.7%)
	Total	-	0(0%)	45(39.5%)	75(60.5%)

Simple regression analysis was performed to expect the position of the security light and UGR index at which discomfort glare may occur (Table 15). At the time, four abnormal data were excluded to improve normality of data and the standard for discomfort glare occurrence was set to discomfort glare class 3. According to the result, minimum distance with no discomfort glare was 7m

3) It is a value represented by simple regression analysis by using SPSS.

(discomfort glare 3.08) and UGR index was 31 (discomfort glare 3.04) (however, residual normality is not met). Therefore, if LED 50W is used for the semi-cutoff type security light, we propose 7m of minimum installation distance and discomfort glare index 31 of light pollution acceptance limit.

Table 15. Simple regression analysis of LED 50W (20°)

	Division	B	β	t(p)	F(p)	R2
Discomfort glare to occupants	(Constant)	4.190		18.653* (.000)	20.417 (.000)*	0.16
	Distance	-.159	-.402	-4.519* (.000)		
UGR	(Constant)	-.552		-.687 (.494)	22.443 (.000)*	0.18
	UGR	.116	.418	4.737* (.000)		

*p<.01

5. Conclusion

This study has performed physical and subjective evaluation of discomfort glare for three lamps of security lights. For this study, experiments were performed with the variables of the installation angle and distance from window surface of the security light and impact of the installation angle and distance on discomfort glare of occupants was analyzed.

For NH 100W lamp, it has been analyzed that the installation angle of the security light has more impact on indoor discomfort glare as the distance from window surface decreases. It has been found that installation distance has no significant impact on discomfort glare when the light is installed at 0°(full cutoff). But, it has been found that more than 6m of distance difference has significant impact on discomfort glare if it is installed at 20°(semi-cutoff).

For MH 70W lamp, it has been analyzed that the installation angle of the security light has more impact on indoor discomfort glare as the distance from window surface decreases. It has been found that installation distance has no significant impact on discomfort glare when the light is installed at 0°. But, it has been found that more than 4m of distance difference has significant impact on discomfort glare if it is installed at 20°.

For LED 50W, it has been analyzed that the installation angle of the security light has more impact on indoor discomfort glare as the distance from window surface decreases. When the installation angle is 0° and distance difference is more than 4m, discomfort glare has significant difference. Also for 20°, more than 4m of installation distance has significant difference in discomfort glare but it is judged that difference in discomfort glare according to distance decreases as installation distance increases because this only applies to 3m of reference position.

According to the above analysis, we propose the use of LED 50W with highest energy efficiency for full cutoff type security lights as all the three lamps have been analyzed not to cause discomfort glare. For semi-cutoff type security lights, we propose discomfort glare index 30 and installation distance 4m for NH 100W, discomfort glare index 32 and installation distance 4m for MH 70W and discomfort glare index 31 and installation distance 6m for LED 50W on the basis of the comparison of discomfort glare evaluation results, UGR indexes and distance conditions.

By applying this, we recommend the use of MH 70W with smaller range of light distribution than NH 100W and less possibility of light trespass and discomfort glare when the road width is 4-6m. When the road width is longer than 6m, we recommend the use of LED 50W which is highly energy efficient and where discomfort glare greatly decreases as distance increases.

In the experiments for this study, conditions for security light installation distance were limited and height change of security lights according to the increase of road width has not been applied. Therefore, it is judged that future study will have to increase accuracy and applicability of study results through experiments by setting various security light installation distances and applying height change of security lights according to the increase of installation distance.

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