

RECOMMENDED ILLUMINANCE LEVELS FOR VISUAL TASKS IN BUILDINGS

Rojarek Seangatith^{1*} and Yingsawad Chaiyakul²

Received: May 15, 2018; Revised: April 26, 2019; Accepted: May 02, 2019

Abstract

Illuminance recommendations in Thailand have been adopted from western standards' documents. Using the adopted illuminance standards for Thai people is questioned. The main objectives of this paper are to compare the visual performances of Thai people and western people under different lighting quantities and to suggest appropriate illuminance levels to perform various visual tasks for Thai people. The final part of the study compares the study's results to the existing lighting recommendations and legislation standards in Thailand. Firstly, the visual performances of 36 subjects of various ages were tested in the lighting laboratory with the same method used in the original research by Weston (1945). The visual task used in this experiment was finding the directions of Landolt rings on different charts under 6 illuminance levels (5, 22, 86, 345, 1,380, and 5,510 lx). Landolt ring sizes of 4.5, 3.0, and 1.5 min of arc and contrasts of 0.97, 0.56, 0.39, and 0.28 were included. In the second part, the obtained illuminance levels were then tested for satisfaction under real situations. The results showed that the average visual performance scores of Thai subjects were lower than those found by Weston. However the recommended illuminance levels obtained from the study were similar to the ones of Weston in every task group. When comparing the recommended illuminance levels with Thai legislation, the illuminance criteria in legislation in Thailand were relatively lower. When considering the satisfaction test, the illuminance levels of the Illuminating Engineering Society of North America were relatively low compared to the test results.

Keywords: Visual performance, illuminance, recommendation, Thailand

¹ Department of Architecture, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima, 30000, Thailand. E-mail: rojarek8000@gmail.com

² Faculty of Architecture, Khon Kaen University, Khon Kaen, 40002, Thailand. E-mail: yingsawad@gmail.com, cyings@kku.ac.th

* Corresponding author

Introduction

The illuminance level standards used in Thailand are adopted from foreign standards. Thai legislation defines the minimum levels of illuminance for some visual tasks. Moreover, the required illuminance levels for the same visual tasks are remarkably different between the different codes. The local lighting organization, the Illuminating Engineering Association of Thailand (TIEA) also has suggested minimum illuminance levels for designers. Examination of the TIEA recommendations (Illuminating Engineering Association of Thailand, 2016) shows that the recommended levels are by reference from the Commission Internationale de l'Eclairage (CIE). Using foreign illuminance level standards for buildings in Thailand may not be appropriate because Thais have different levels of illuminance familiarity from foreigners. To find the appropriate illuminance for various visual tasks for Thai people, 3 steps of study were conducted, as follows. Firstly, since the original work by Weston (1945) was adopted for initiating quantity recommendations in the USA (Perry *et al.*, 1987), we compared the visual performance of Thai people with that of foreigners, searched for the recommended illuminance which is appropriate for Thai people, and compared the recommended illuminance that was obtained from the experiment with the laws and regulations used in Thailand.

In Thailand, the illuminance level standards used mostly follow foreign standards such as those of the Illuminating Engineering Society of North America (IESNA) also known as the Illuminating Engineering Society (IES) used in North America, the Chartered Institution of Building Engineers of England (CIBSE) used in the United Kingdom, and the CIE used in continental Europe. In Thailand, there is the TIEA which provides the recommended illuminance levels and the 1994 Ministry of the Interior Regulation No. 39, and the 2001 Bangkok Ordinance relating to the illuminance in buildings; furthermore, the 2006 Ministry of Labour Regulations set the standards of illuminance levels for working

and industry. This legislation (excluding TIEA) provides the average illuminances for indoor areas of buildings but does not determine the type of tasks. The TIEA provides advice on the minimum illuminance levels to which architects should design to meet the criteria in order to ensure the safety of a building's users in various aspects and provide the appropriate illuminance level for any tasks done in the building.

The recommended illuminance levels, according to the TIEA refer to the illuminance levels of the CIE (TIEA, 2016). The illuminance levels of the CIE refer to European standards which are based on the familiarity to natural light of European people. The light in some parts of Europe is less intense than in Thailand but this standard is used in Thailand with Thai people who are used to different natural light conditions. It is inappropriate to use the same standard of illuminance levels since the familiarity to natural light and sky conditions between Europe and Thailand may be different (Littlefair, 2001; Chirarattananon *et al.*, 2002). Thus, the standard of illuminance for Thai people should be different from the standard for people in Europe. The study of Bergamin *et al.* (1998) shows that the pupil with a different iris color has a different light reflex. Therefore this study was based on the assumption that Europeans with a light iris color should have a different lighting perception from Asians with a darker iris color. The main objectives of this research are to compare the visual performance of Thai people to western people and to identify appropriate illuminance levels of various visual tasks for Thai people.

Research Methodology

Part 1: Visual Performance Test

The first part of the work was the visual performance test. The objectives of this part were to find the visual performance of Thai subjects in order to compare with the visual performance of foreigners and to find the

recommended illuminance levels for Thai people. The performance test which tested a person's ability or behavior was used (Weston, 1945). The main variables affecting the visual performance, as shown in Figure 1, were tested.

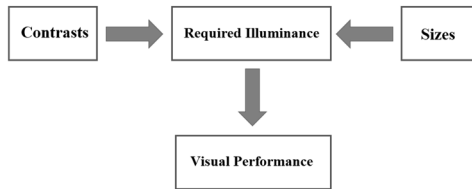


Figure 1. The variables in visual performance experiment

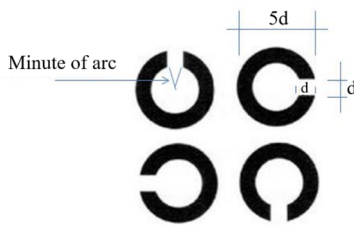


Figure 2. Proportion of Landolt ring, the size of the diameter is 5 times of the gap size. (IES, 2009)

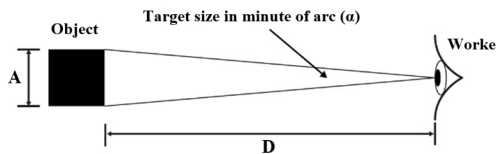


Figure 3. The object size or the target size (α) in min of arc, in this experiment the distance A is the gap size of Landolt rings. (Visual functions committee, 1984)

The visual task in this test was looking to find the directions of Landolt rings and when the direction of a ring was found, it would be crossed out. A Landolt ring is a circle similar to the letter C with a gap, as shown in Figure

2. The edges of the gap must be parallel. The position and direction of the gap are important for the eye test. The Landolt ring is an important standard instrument for the visual performance test. The use of other instruments such as reading texts or numbers requires a more complicated assessment of visual performance because, in reading the texts or numbers, not only the ability to see but also the ability to memorize and interpret is used.

The size of the objects or tasks was determined by the angle that the objects were seen in min of an arc. The task used in this test was the size of the angle that was seen for the gap in the Landolt ring. Three sizes of Landolt ring 1.5, 3.0, and 4.5 min of arc including the contrasts of 0.97, 0.56, 0.39, and 0.28 were used in this test with a 40 cm reading distance. The sizes of the tasks and the contrasts used in the test were the same values as used in Weston's test. The size of the Landolt ring gap was calculated as follows. From Figure 3, the size of the Landolt ring gap was the distance A and the reading distance D was 40 cm. The reading angle α was measured in min of the arc. Distance A was calculated as in Equation (1) and the size of the Landolt ring gaps were calculated as shown in Table 1. The Weston's assessment of the visual performance score was used in the test as shown in Figure 4.

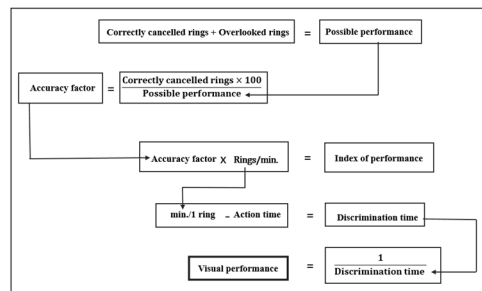


Figure 4. The visual performance assessment diagram

$$\tan \frac{\alpha}{60} = \frac{A}{D} \quad (1)$$

The test in Part 1 was conducted by using a lighting laboratory of the Faculty of

Table 1. The gap sizes of the Landolt rings which are derived from Equation (1)

Visual angle (α) (min of arc)	Visual angle (α) (degree)	Gap size of the Landolt rings (A) at 40 cm. reading distance (D) (mm)	Outer diameter of the Landolt rings (Ax5) (mm)
4.5	0.075	0.50	2.50
3.0	0.05	0.35	1.75
1.5	0.025	0.18	0.90

Architecture, Khon Kaen University. The test subjects were adults who were of a working age. There were 36 people aged between 20-50 years old who were divided into 3 age ranges: 20-30, 31-40, and 41-50 years old. In each group there were 12 subjects who were 6 males and 6 females. Six illuminance levels were used in this test: 5, 22, 86, 345, 1,345, and 5,510 lx. The lamps used in the test were incandescent lamps in order to match Weston's test. The color temperature of the lamps was between 2600-3900 K.

The number of the subjects in Part 1 of the test was obtained by using the subject size estimation method to estimate the population average with the subject average, if the size of the population was large (∞). The following formula was used.

$$n = \frac{Z^2 \sigma^2}{E^2} \quad (2)$$

where n = the number of subjects, Z = the confidence level (95% confidence level is 1.96), σ = the population variance (using the variance = 0.15 from a pilot test), and E = the error (use of the error = 5%).

From the formula, $n = (1.96^2 \times 0.15^2) / 0.05^2$, so $n = 34.57$ (approximately 35 people) (Wanichbancha, 2006).

Part 2: Visual Satisfaction Test

The second part was to test the satisfaction of the recommended illuminance levels, which were derived from the first part, with the actual visual tasks. The visual tasks provided to each group were classified by the IESNA (Harrold and Mennie, 2003) and were divided into 7 groups with respect to both size and contrast. However, groups A, B, and C were

confined to simple tasks where illuminance levels were not significant. The test for investigation of the visual tasks where the size and contrast of the work were crucial and proper illuminance was important were: group D for the large size with high contrast, group E for the small size with high contrast or large size with low contrast, group F for the small size with low contrast, and group G for the very small size with very low contrast.

In Part 2, the tasks used in the test were the tasks that took place in a reading room. The tasks were provided to each group as follows: reading for group D, looking for words on maps for group E, reading texts written with a # 4 lead pencil for group F, and manually craft cutting a detail for group G. Two illuminance levels were used in each group task. One illuminance level was the result obtained from the test in Part 1 which was the average of the group's maximum and minimum illuminance levels. The other was the recommended illuminance level of the IESNA which was equal to the minimum value of the Part 1 test. These 2 illuminance levels were compared to find the visual satisfaction and visual comfort of the subjects.

The tests in Part 2 were aimed to examine whether using the minimum value as a recommended value was enough for the visual tasks occurring in each group or not. The minimum and middle illuminance levels were used to compare the visual satisfaction and visual comfort. Illuminance levels, visual satisfaction, and visual comfort were the main variables.

In Part 2, the tests assessed the feelings of the subjects toward the illuminance levels used in performing the visual tasks. Two illuminance levels were tested for each visual task. The total number of tasks was 4, so the

tests were done using 8 illuminance levels per 1 subject. At each illuminance level, the subject would be asked about the sufficient amount of the illuminance level and visual comfort for the visual task. During testing, the researcher would ask the subject and record the results on the record form with 5 rating scales. There were 5 choices for the answer of the visual satisfaction questionnaire as follows: “cannot see clearly”, “just can see”, “can see quite well”, “can see well”, and “can see very well”. Also, there were 5 choices for the questionnaire on visual comfort as follows: “the light is not enough and it is not comfortable for the eyes”, “the light is too little”, “the light is appropriate and comfortable for the eyes”, “the light is quite bright”, and “the light is too bright and it is not comfortable for the eyes”.

The estimation of the number of subjects for the test in Part 2 used the formula

$$n = \frac{(Z_{1-\frac{\alpha}{2}})^2 \sigma^2}{E^2} \quad (3)$$

At the confidence level of 90%, the value $Z_{1-\frac{\alpha}{2}} = Z_{0.95} = 1.645$, the error E is not greater than 0.2, and the variance $\sigma = 0.75$ (from a pilot test). When substituting the value, it was found that $n = 38$ (Wanichbancha, 2006).

There were 2 groups of subjects with 2 age ranges, 20-35 and 36-50 year old, and with 20 subjects for each group. The total number of the subjects was 40 and all were of working age. In the test, a compacted fluorescence lamp was used. The color temperature of the lamp used in this study was 6500 K (cool daylight) and the color rendering index was 83. The lamp was mounted in a table lamp for reading and the illuminance levels could be adjusted by sliding the table lamp in and out from the task in front of the subject. There was a light meter placed at the task area which measured the required illuminance levels every time before the subject started the task. The test was performed from 10 am to 2 pm during the daytime. Compacted fluorescence was used in this study because fluorescence and compacted fluorescence are commonly used in Thailand. Fluorescence is normally used for general

lighting and compacted fluorescence is used for localized lighting as well as general lighting.

Results and Discussion

Part 1:

Visual Performance Test Results

There was an anomaly in the test at the illuminance level of 345 lx as shown in Figures 5, 6, and 7. The first two lines ($C = 0.97$ and $C = 0.56$) showed that the average visual performance decreased at 345 lx. This may be because the value of 345 lx was the first illuminance level that the subjects started to work on, so they worked slowly. In particular, the graph of the large black ring ($C = 0.97$ size = 4.5 min of arc) showed that the value of the visual performance was rather low as it was the first chart tested by the subjects. For the large and middle tasks with high contrast, the increasing illuminance level did not affect the visual performance much since the size of the tasks was easily seen and the average visual performance of the large and middle tasks were quite similar.

For the highest and middle contrast ($C = 0.97$ and $C = 0.56$) of the large and middle tasks (size = 4.5 and 3.0 min of arc), the visual performances were quite similar as shown in Figures 5 and 6. For small tasks (size = 1.5 min of arc), the illuminance level and contrast affected the visual performance much as the size of the task was difficult to be seen. Therefore, the difficulty of seeing a small task depended on the illuminance level and contrast as shown in Figure 7. When considering the standard deviation values, it was found that the visual performance of the large and middle tasks (easy to be seen) deviated from the average more than the visual performance of the small size tasks (difficult to be seen). The visual performance of the small size task provided little deviation. It was probably because when the task was easy to be seen, some subjects would pay much attention to do the test but some did not, so it could cause several errors.

Visual Performance Comparison between Male and Female

The graphs showed that, in the comparison of the visual performance between males and females, gender did not affect the visual performance. The test results of males and females showed a similar visual

performance as shown in Figures 8, 9, and 10. A t-test was used to compare the difference in the visual performance average between males and females. For each size of the task and contrast, it was found that there were no significant differences at the significance level of $\alpha = 0.05$.

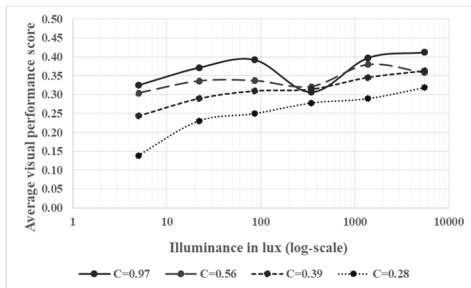


Figure 5. Average visual performance scores of the 4.5 min of arc task size

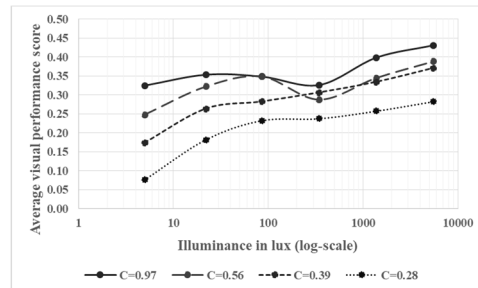


Figure 6. Average visual performance scores of the 3.0 min of arc task size

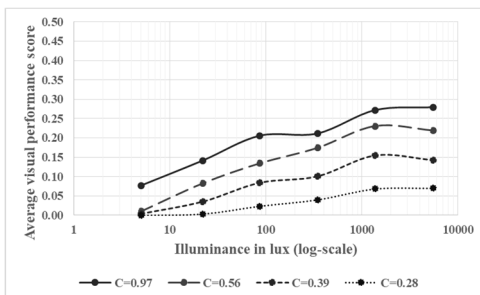


Figure 7. Average visual performance scores of the 1.5 min of arc task size

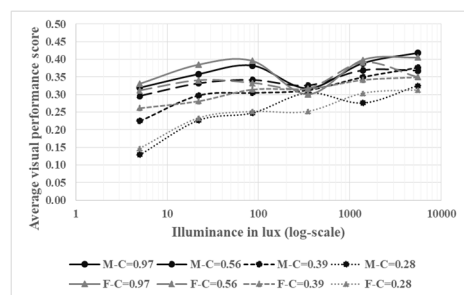


Figure 8. The comparison of 4.5 min of arc average visual performance score between male and female

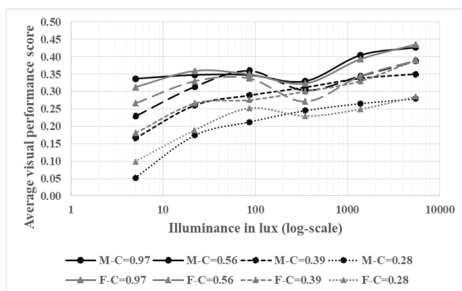


Figure 9. The comparison of 3.0 min. of arc average visual performance score between male and female

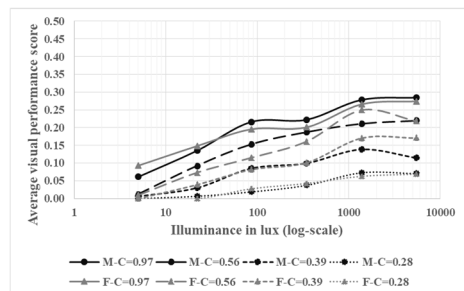


Figure 10. The comparison of 1.5 min. of arc average visual performance score between male and female

Visual Performance Comparison between Young and Old Subject Groups

In a comparison of visual performance between the young and old subject groups as shown in Figures 11, 12, and 13, the subjects would be divided into 2 groups with 18 subjects each at the age of 20-35 years old and 36-50 years old. The visibility threshold was reduced at the age of about 40 years old (Halonen, 1993) and, according to observation during the test, it was found that at the age around 36-40 years old, the visual performance of the subjects was reduced. The comparison of the difference of the visual performance average between the young and old subject groups for each size and contrast was examined by using a t-test at a significance level of $\alpha = 0.05$ and it was found that when the tasks were small and the amount of the illuminance was low, which was the unclear visual condition, young subjects had a better visual performance at the illuminance level of 5 lx and 22 lx. With more than the 86 lx illuminance level, the visual performances of old and young subjects were similar. It was noted that the old subjects were wearing glasses during the test.

Comparison of Test Results to Weston's Test

When comparing the test results to Weston's test results, as shown in Figures 14, 15, and 16, it showed that when the size and the contrast of the task were equal and tested at an equal illuminance level, the average visual performance of the subject group was lower than Weston's. When using the t-test to examine the difference between the average of the visual performance of the test results and Weston's, it was found that in the case that the contrast was 0.97, which was a clear visual condition, the results of all sizes (1.5, 3.0, and 4.5 min of arc) at all illuminance levels (5, 22, 86, 345, 1,380, and 5,510 lx) showed that the average visual performance of the subjects was less than Weston's at a significance level of $\alpha = 0.01$. This meant that the difference was rather high. However, when the contrast was reduced to 0.56, 0.39, and 0.28, the significance level of $\alpha = 0.05$ was applied in

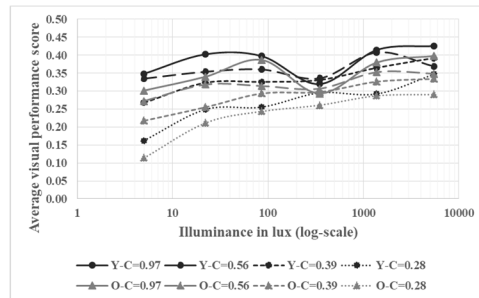


Figure 11. The comparison of 4.5 min. of arc average visual performance score between young and old subject groups

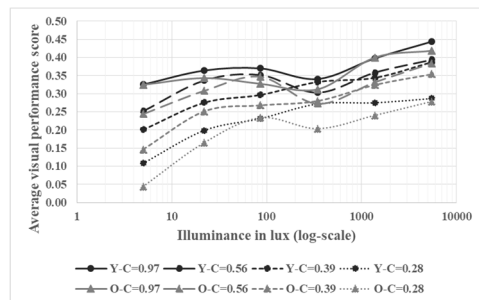


Figure 12. The comparison of 3.0 min. of arc average visual performance score between young and old subject groups

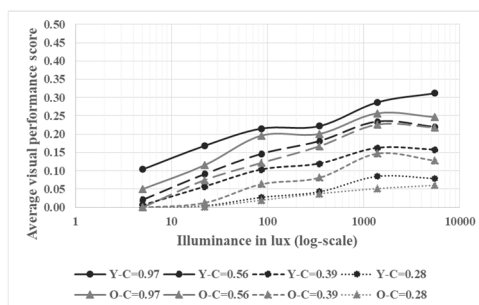


Figure 13. The comparison of 1.5 min. of arc average visual performance score between young and old subject groups

order to accept that the average visual performance of the subjects was lower than the average visual performance in Weston. However, there was an average visual performance of some sizes and contrasts in which the t value showed that there were no significant differences at a significance level of $\alpha = 0.05$ most of which were unclear visible conditions.

The Recommended Illuminance Levels from the Test Results

To find the recommended illuminance levels from the test results, the point where the slope of the graph is approaching 0 was determined to present the suitable illuminance level of each line. When considering the values obtained from the graph, it can be seen that the divided size and contrast in the group caused each group to obtain more than 1 illuminance level which showed the highest and lowest values except in group G, as shown in Table 2. Furthermore, since the IESNA's recommended illuminance levels derived from Weston's graph used the lowest value, then the appropriate illuminance levels obtained from the test would be the minimum values. Therefore the illuminance levels from the test were equivalent to the values obtained from Weston which were equivalent to the IESNA's. Although the average visual performances obtained from the test were lower than Weston's, the minimum recommended illuminance levels found in the graphs were equivalent to the minimum illuminance levels of Weston's graphs which were the same as the IESNA's recommended values.

Part 2:

Visual Satisfaction Test Results

From the average satisfaction graph, in each task group of young and old subjects as shown in Figure 17, it was found that when the minimum illuminance level (L) was used in group D and group E, the young subjects showed better visual satisfaction than the older subjects at the level of 3.4. However, when the middle illuminance level (M) was used, both old and young subjects showed equal visual satisfaction at the level of 4.5. In group F, the old subjects showed better visual satisfaction

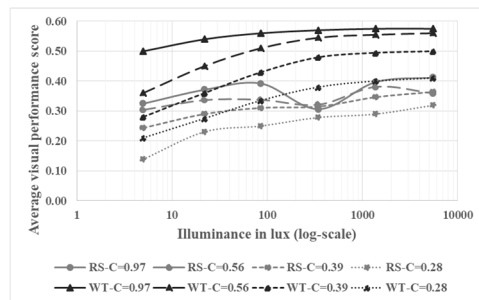


Figure 14. The comparison of 4.5 min. of arc average visual performance score between the ones of Weston (WT) and the results of the experiment (RS)

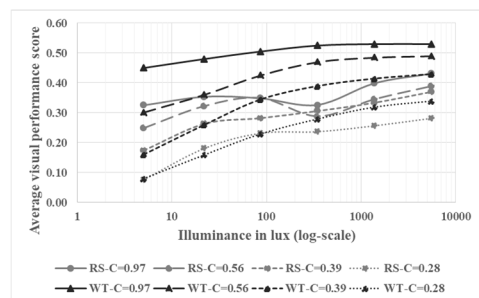


Figure 15. The comparison of 3.0 min. of arc average visual performance score between the ones of Weston (WT) and the results of the experiment (RS)

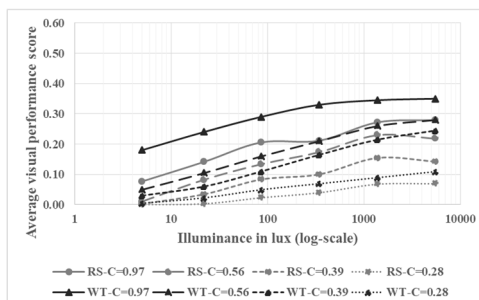


Figure 16. The comparison of 1.5 min. of arc average visual performance score between the ones of Weston (WT) and the results of the experiment (RS)

than the younger subjects in both the minimum and middle illuminance levels. In group G, the old subjects showed better visual satisfaction in the minimum level. There was only the minimum level in group G, without a middle level.

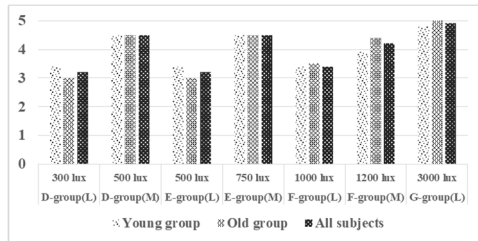


Figure 17. The comparison, between the minimum and the middle values, of average satisfaction in each task group from the young group, the old group and all the subjects

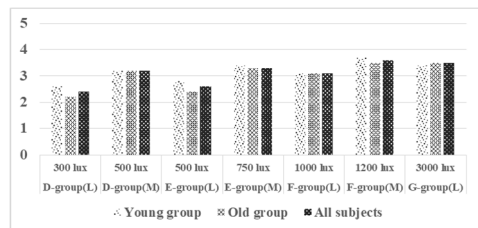


Figure 18. The comparison, between the minimum and the middle values, of average eye comfort satisfaction in each task group from the young group, the old group and all the subjects

However, for the tasks that needed high illuminance levels which were the tasks in group F and group G, most young subjects revealed that these groups have too high illuminance levels and would likely disturb the visual satisfaction. Nevertheless, the old subjects were satisfied with the high illuminance levels and revealed that they improved the vision. When considering the average satisfaction of 40 subjects, it was found that, in groups D, E, and F, the subjects were more satisfied with the middle levels than with the lowest.

Visual Comfort Test Results

From the average visual comfort graph of each group of young and old subjects as shown in Figure 18, it was found that groups D and E showed similar values. When using the minimum illuminance level (L), the subjects in both groups revealed that the illuminance level was relatively low and the value obtained from the test was about 2.5 (3 is the illuminance level of visual comfort). When the illuminance level was increased to the middle level (M) for the tasks of groups D and E, the old and young subjects expressed greater visual comfort. For the task of group F, when using the minimum illuminance level, both old and young subjects revealed that this illuminance level was appropriate and comfortable for the eye but when using the middle illuminance level, both old and young subjects revealed that it was relatively bright at the level of 3.5. The task of group G needed a high illuminance level; therefore, even if the minimum illuminance level was used, both the old and young subjects revealed that it was relatively bright at the level of 3.3.

Table 2 The minimum, the maximum, and the middle value of illuminance levels obtained from the experiment in Part 1

IESNA Groups of recommended illuminance levels		IESNA Recommended illuminance (lx)	Illuminance levels obtained from the experiment (lx)		
			Min.	Mid.	Max.
Group No.2 Common visual tasks	D	300	300	500	700
	E	500	500	750	1000
	F	1,000	1,000	1,200	1400
Group No.3 Special visual tasks	G	3,000	3,000	-	-

When considering the average visual comfort of the 40 subjects as shown in Figure 18, it was found that the results of the groups D and E tasks were similar. When using the minimum illuminance level, the visual comfort was about 2.5 which meant that the illuminance level was relatively low. However, when the illuminance level was increased to the middle level, the visual comfort of both subject groups was about 3.25 which was relatively comfortable but slightly bright. When using the minimum illuminance level in the group F task, the light was relatively comfortable for the eyes, and when using the middle illuminance level, the light was too bright at the level of 3.6. When using the minimum illuminance level in the group G task, the light was too bright at the level of 3.5. According to the results of satisfaction and visual comfort, it can be seen that for the group F task, the subjects were satisfied with the minimum illuminance level. This may be because of the type of the visual task which was reading texts written with a #4 lead pencil. Reading the texts written with pencil using the high illuminance level would cause the reflection of the luster of the pencil. If the selected task was with other types of pencil, there might be a different result.

Conclusions

Based on the test in Part 1, when comparing the visual performances obtained from the test to Weston's results, it showed that

the visual performances were lower than Weston's. On the other hand, when finding the appropriate illuminance levels by using the visual performances from the test, it was found that, at the same illuminance level, the values were similar to Weston's and these values were used as the recommended illuminance levels by the IESNA.

The results of Part 2 showed that the subjects were relatively satisfied with the middle illuminance levels. In the aspect of visual satisfaction, when using the middle illuminance levels for groups D, E and F, the subjects showed more visual satisfaction. The average of visual comfort of the groups D, E and F was over 3 at 3.2, 3.3, and 3.6, respectively (3 = comfortable light for eyes and 4 = quite bright). However, when using the middle illuminance level for the tasks of groups D and E, the amount of illuminance was comfortable to the eyes at 3.2 and 3.3, respectively, but the average visual comfort of group F was at the level of 3.6 which was relatively high.

According to the results, it can be suggested that the current recommended values of the IESNA are relatively low for Thai people's satisfaction to perform visual tasks. If the illuminance was increased to the middle level, the visual satisfaction would be better. When comparing the recommended illuminance levels from the test to Thai legislation as shown in Table 3, it showed that the illuminance levels of the Thai legislation were relatively lower compared to the test results. When considering the satisfaction, the

Table 3. The comparison of recommended illuminance levels obtained from the test, Thai standards, IESNA and CIBSE

Locations and Tasks	1994 Interior Ministerial Regulations No. 39 (lx)	2001 Bangkok Ordinance (lx)	2006 Labor Ministerial Regulations (lx)	IESNA (lx)	CIBSE (lx)	TIEA (lx)	Result's Mid. Levels (lx)
Libraries, Classrooms	300	300	-	300	300	300	500
Reading areas in libraries	-	-	-	500	500	500	750
Lecture halls, Meeting rooms	300	300	300	500	500	500	750
Office's working areas	300	300	400	500	500	500	750
Packaging areas	-	-	-	300	300	300	500
Post offices	-	-	-	500	500	500	750

illuminance levels of the IESNA were relatively low. However, there was only 1 task selected for the test in Part 2 for each group. There should be more various types of tasks tested in each group.

There are some limitations to the study. In order to compare the results of the study to those of Weston, the methodology of Weston's experiment had to be repeated. In the experiment each subject had to find the directions of Landolt rings on a total of 96 charts at 6 illuminance levels. Although there was a break for the subject to rest every time the illuminance level changed, the subject still had eye fatigue because of the number of charts. The time used for 1 subject to perform the experiment was 3 hours including breaks which was quite long. Since the IESNA used Weston's results to initiate a quantity of recommendations (Perry et al., 1987), in this experiment the groups of the IESNA had to be followed to categorize the results and to compare the obtained recommended illuminance levels to the ones of the IESNA.

References

- Bergamin, O., Schoetza, A., Sugimoto, K., and Zulauf, M. (1998). The influence of iris color on the pupillary light reflex. *Graef. Arch. Clin. Exp.*, 236(8):567-570.
- Chirarattananon, S., Chaiwiwatworakul, P., and Pattanasethanon, S. (2002). Daylight availability and models for global and diffuse horizontal illuminance and irradiance for Bangkok. *Renew. Energ.*, 26(1):69-89.
- Halonon, L. (1993). Effects of lighting and task parameters on visual acuity and performance, [Ph.D. thesis]. Helsinki University of Technology, Espoo, Finland, 169p.
- Harrold, R. and Mennie, D. (2003). *IESNA Lighting: Ready Reference*. 4th ed. Illuminating Engineering Society of North America, New York, NY, USA, 205p.
- Illuminating Engineering Society. (2009). *IES Course Fundamentals of Lighting: Instructor's Manual, Module1: Basic Lighting Concepts, Vision and Color*. Illuminating Engineering Society of North America, New York, NY, USA, 167p.
- Illuminating Engineering Society of Thailand (TIEA). (2016). *Guidelines for Indoor Lighting Design*. Illuminating Engineering Association of Thailand, Bangkok, Thailand, 77p.
- International Council of Ophthalmology. (1984). *Visual Acuity Measurement Standard*. International Council of Ophthalmology, San Francisco, CA, USA, 45p.
- Littlefair, P. (2001). Daylight, sunlight and solar gain in the urban environment. *Sol. Energy*, 70(3):177-185.
- Perry, M.J., Campbell, F.W., and Rothwell, S.E. (1987). A physiological phenomenon and its implications for lighting design. *Lighting Res. Technol.*, 19(1):1-5.
- Wanichbancha, K. (2006). *Statistics for Research*. 2nd ed. Faculty of Commerce and Accountancy, Chulalongkorn University, Bangkok, 320p. (in Thai)
- Weston, H.C. (1945). *The Relation between Illumination and Visual Efficiency: the Effect of Brightness Contrast*. His Majesty's Stationery Office, London, UK, 35p.