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IN THE TASK AND BACKGROUND AREA OF OPEN-OFFICE
LIGHTING**

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EXPERIMENTAL STUDY ON ILLUMINANCE DISTRIBUTION IN THE TASK AND BACKGROUND AREA OF OPEN-OFFICE LIGHTING

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Abstract

In recent years, both the quality of the light environment and the reduction of lighting energy are required in offices. To realize these requirements, it is effective to reduce the illumination of background area where occupants are absent while keeping the brightness of the task area where occupants are present. In this study, we conducted a subjective evaluation of spatial brightness in a non-uniform lighting environment based on the European standard and in a uniform lighting environment. In the experiment, the satisfaction of the whole lighting environment was taken as a superordinate concept, and the absolute level of brightness, visibility, the appropriateness of brightness, and non-uniformity were evaluated as factors explaining the satisfaction. As a result, in the non-uniform lighting environment in conformity of the European standard, while visibility and absolute brightness levels around desktops were highly evaluated, the level of satisfaction with light environment was low.

Keywords: Brightness, Illuminance, European Standard, Task area, Background area

1 Backgrounds and Purposes

Lighting control systems using human detection sensors are effective for saving energy consumption in open offices as shown in Figure 1. However, the illuminance level in ambient areas around task spaces is not clearly recommended in Japanese lighting standards, and the design method of non-uniform environments has not been established yet. When the illuminance level of background areas is kept low for energy-saving, occupants sometimes feel dissatisfied about the spatial brightness of the whole space, although the illuminance on their desk is kept at the optimum level for workability. On the other hand, if the illuminance of the background area is set to be too high, the reduction of the energy consumption would not be achieved. The current European lighting standard (EN 12464-1:2011) represents the recommended levels of illumination on task areas, immediate surrounding areas and background areas. If this standard is referenced for the lighting design in countries outside Europe under the coming international guideline, it would be necessary that various cultural and historical backgrounds should be taken into account, where occupants have different tastes for appropriate balance of brightness. In this paper, we will report the occupants' evaluation on lighting environment where horizontal illuminances were closely set to the recommended values prescribed in EN 12464-1: 2011 at an open-office in Japan.

Figure 1 – Lighting control system using human detection sensors

2 Experiment Methods

A subjective experiment was carried out at the office whose LED lightings on the ceiling were dimmable individually. In addition to the satisfaction of the whole space in uniform and non-uniform lighting environment, we evaluated the absolute evaluation of the brightness, visibility around desktops, the appropriateness of the brightness, and non-uniformity as factors to explain the satisfaction with the lighting environment.

2.1 Experiment space

As shown in Figure 2, the office space was about 18.6 meters in wide, 13.3 meters in depth and 2.8 meters in height. There were windows on the northwest and southwest side. As shown in Figure 3, the office was equipped with desks, chairs and cabinets in general interior layout for open offices. Low partitions and a PC monitor were set on each desk. 600mm-square LED panel lights were installed on the ceiling at intervals of 1.8 meters in the lateral direction and of 2.4 meters in the longitudinal direction. For each experimental condition, the dimming ratio of the luminaires was fixed at the same value in each area.

Figure 2 – Layout of the experimental room

Figure 3 – Experimental situation

2.2 Experimental cases

We divided the office space into three areas: a task area (W: 1.8 × D: 2.4 [m]), an immediate surrounding area (W: 5.4 × D: 7.2 [m]) and a background area (W: 18.6 × D: 13.3 [m]), according to the EN 12464-1:2011. The target levels of average illuminance on the task area was set to be 750, 500, 300 lx. Three uniform conditions were prepared under which the average illuminances on other areas (immediate surrounding area and background area) were the same

as the one on the task area. In addition to those conditions, three non-uniform conditions were also prepared for comparison, whose target illuminances for task / immediate surrounding / background areas were 750 / 500 / 167 lx, 500 / 300 / 100 lx and 300 / 200 / 67 lx, respectively as shown in Figure 4. As a result of adjusting the dimming ratio of all the luminaries in the experimental room to make the actual illuminance values closely match with the target values above, we have got the measured illuminances as described in Table 1. The experiment was carried out during the night-time with blinds closed to eliminate the influence of the outside. Table 2 shows the pictures of the experimental space from the viewpoint of the subjects.

Figure 4 – Recommended illuminance values in the European Standard: EN 12464-1:2011

Table 1 – Experimental cases

	Case	Illuminance value [lx]		
		Task area	Immediate surrounding area	Background area
Uniform	700-1	750	680	660
	500-1	510	490	500
	300-1	330	300	290
Non-Uniform European Standard (EN-12464-1)	700-2	680	550	140
	500-2	490	340	100
	300-2	310	250	100

Table 2 – Pictures of the experimental space from the viewpoint of subjects

		Illuminance value of task area		
		700lx	500lx	300lx
Uniformity	Uniform
	Non-Uniform European Standard (EN-12464-1)

2.3 Subjects and evaluation methods

Twenty subjects, aged from 20 to 60, participated in the experiment. All subjects usually work in open offices of the same kind. Absolute levels of spatial brightness of the experimental space were evaluated by ME (Magnitude Estimation) method compared to the brightness level of the reference box, shown in Figure 5, which was a 1/8 scale model of a general small room and whose illuminance on the virtual desktop surface was set to be 300 lx. Subjects also answered the 7-point questions as follows: 1) visibility of figures and letters on a white paper and a display screen, 2) the appropriateness of brightness for working spaces, 3) the comfortableness of non-uniformity in the whole space, 4) the satisfaction levels with the lighting environment in the whole space for working spaces. The appropriateness of brightness is evaluated on the requirement levels of brightness for the working spaces. In the questionnaire, the area for evaluating the appropriateness of brightness: whole space/ceiling area/wall area/upper space not including the desktop area/desktop area, as shown in Figure 6, was clearly instructed to the subject to avoid unintended variations in evaluation.

Figure 5 – Reference box: external (left) and internal (right) appearances

Table 3 – Questionnaire

	Content	Evaluation methods and scales
1	Age/ date	
2	Absolute levels of spatial brightness	Subjects answered a positive number compared with the reference box whose brightness level was assumed to be 100.
3	Visibility of figures and letters on a white paper and a display screen	Very easy to see/Easy to see/Slightly easy to see/Neutral/Slightly difficult to see/Difficult to see/Very difficult to see
4	Appropriateness of brightness for working spaces on each area	Too bright/Bright/Slightly bright/Appropriate/Slightly dark/Dark/Too dark
5	Comfortableness of non-uniformity in the whole space	Neutral/Slightly uncomfortable/Uncomfortable/Very uncomfortable
6	Satisfaction levels with the lighting environment for working spaces	Very satisfied/Satisfied/Slightly satisfied/Neutral/Slightly dissatisfied/ Dissatisfied/Very dissatisfied

Figure 6 – Evaluation areas

3 Results

3.1 Absolute evaluation of brightness

Figure 7 shows the brightness evaluation by ME method. Evaluation area were clearly specified to the subject as the upper space which does not include displays and desktops. In the non-uniform case, the interquartile range of the evaluation narrowed compared with the uniform case. The non-uniform case at any illuminance value on task area has an evaluation value less than 100 despite the task area illuminance being equal or higher than the illuminance of reference space (equal to 300 lx). It is inferred that the low luminance of background area lowers the brightness in the whole space.

Figure 7 – Absolute evaluation of brightness levels by Magnitude Estimation method

3.2 Visibility for reading papers and display

In the evaluation results of the visibility for reading papers, when the illuminance level at task area was 300 lx, 35% of subjects in uniform case, and 70% of subjects in non-uniform case, felt dark (slightly dark/dark/too dark). This result shows that the illuminance level of 300 lx for task area is not enough for visibility for reading papers. In addition, when the illuminance at task area was 500 lx or more, visibility for reading papers was ensured even if the background illuminance was low. In the evaluation of visibility for reading display, there were more subjects who answered the side of visible than the evaluation for the papers. It is considered that the luminance of the display itself contributed to the visibility for reading display.

Figure 8 – Visibility for reading papers

Figure 9 – Visibility for reading display

3.3 Appropriateness of brightness

3.3.1 Appropriate brightness for desktop

More than half of the subjects evaluated that the brightness of the desktop surface is appropriate for the task area whose illuminance is 500 lx or more. On the other hand, in the task area whose illuminance is 300 lx, half of the subjects evaluated dark (slightly dark/dark/too dark) for the brightness. The brightness of the task area is insufficient at 300lx for desktops.

Figure 10 – Appropriate brightness for desktop

3.3.2 Appropriate brightness for walls

In the uniform case, more than half of the subjects evaluated the brightness on the walls as being appropriate at any illuminance levels in task areas. As the task area illuminance increased, the evaluation of brightness (slightly bright/bright/too bright) increased. On the other hand, in the non-uniform case, most of the subjects felt dark (slightly dark/dark/too dark). As the surrounding illumination darkened, the luminance of walls became lower, and the evaluation for appropriateness of brightness was lowered.

Figure 11 – Appropriate brightness for wall

3.3.3 Appropriate brightness for the whole space

In the uniform case, as the increase of task area illumination, the evaluation tended to be bright (slightly bright/bright/too bright). The proportion of brightness (slightly bright/bright/too bright) was 45% at the task area whose illuminance was 500 lx, and 75% at the illuminance 700 lx. The results show that the workers felt excessive brightness in a uniform lighting environment with high illuminance values. At 300 lx in task areas, the evaluation for the dark side (slightly dark/dark/too dark) was 35%, but the proportion of appropriateness of this case was the best among all the cases. If the illuminance of a uniform illumination would be set to 400 lx, it may become a well-balanced lighting environment that the proportion of bright and dark evaluation would be equivalent, and most occupants would evaluate brightness as being appropriate.

In the case of non-uniform, as the task area illuminance decreases, the evaluation for the whole space became darkened. When illuminance around a task area was 300 lx, 95% of subjects felt dark (slightly dark/dark/too dark), and the proportion of “slightly dark” and “dark” was 75% when the task area illuminance was 700lx. This means that the workers feel dark when the ambient illuminance is low, even if the task area illuminance value is high.

Figure 12 – Appropriateness of brightness for whole space

3.4 Comfortableness of non-uniformity in the whole space

The results in the uniform cases, it shows that the evaluation of "slightly uncomfortable" rating was 10% or less at task area illuminance of 500 lx or more, but it was 35% at the illuminance of 300 lx. Even if the illuminance setting is uniform, some occupants feel uncomfortable about non-uniformity when illuminance was around 300 lx. In the non-uniform case, over 60% of the subjects evaluated uncomfortable (slightly uncomfortable/Uncomfortable/Very uncomfortable) at all illuminance values in task areas. The subject felt uncomfortable about non-uniformity of brightness in the room if there is the difference between the illuminance of task areas and the illuminance of background areas according to the European standard.

Figure 13 – Comfortableness of non-uniformity in the whole space

3.5 Satisfaction of the whole space

Figure 14 shows the results of satisfaction of the whole space. In the uniform case, 25% or less subjects felt dissatisfied (Slightly dissatisfied/ Dissatisfied/Very dissatisfied) at all illuminance values of task areas. In the non-uniform case, as the task area illuminance decreased, the proportion of subjects who felt dissatisfied increased up to 95% at 300 lx.

In the lighting environment according to the European standard, it became clear that the satisfaction of the whole space was low even though the visibility and brightness around the task were satisfied as shown in 3.2 and 3.3.1.

Figure 14 – Satisfaction of whole space

4 Conclusion

The subjective evaluation of lighting environment was carried out in which horizontal illuminances were closely set to the recommended values of EN 12464-1:2011 at an open-office in Japan.

In the uniform illumination setting, most of the subjects highly evaluated the visibility for reading papers and displays when the illuminance level at task areas was 500 lx and 700 lx, while most of the subjects felt it was too bright for appropriateness for working space when the illuminance level at task areas was 700 lx.

In the non-uniform lighting environment of which illuminance of task areas and background areas largely differed according to the European standard, when the illuminance level at task areas between 300 lx and 700 lx, the results of the evaluations about the satisfaction and the appropriateness of brightness for the whole space were low, while the evaluations about visibility and the appropriateness of brightness around the desktop surface were high.

It was suggested that non-uniformity is one of the factors for lowering the evaluation of whole space, as over half of subjects answered that the non-uniformity was uncomfortable. In future research, it is necessary to analyse the impact of these factors as explanatory variable for the satisfaction.

In Japanese offices, it may be difficult to accept the illumination setting according to the European standard. The recommended illuminance ratio of background area to the immediate surrounding area is 1/3 in the European Standard, but it may be inferred that this ratio should be increased in Japanese offices.

Reference

EN-12464-1:2011 Light and lighting - Lighting of workplaces Part 1: Indoor work places