LIGHT ENVIRONMENT IN JAPANESE OFFICE BUILDINGS AFTER THE 3.11 EARTHQUAKE -FIELD MEASUREMENTS ON ILLUMINANCE LEVELS AND OCCUPANTS' SATISFACTION -

Nozomu Yoshizawa[1], Etsuko Mochizuki[2] and Toshie Iwata[3]

[1] Nozomu Yoshizawa, Tokyo University of Science
yosizawa@rs.noda.tus.ac.jp

[2] Etsuko Mochizuki, Chiba Institute of Technology
etsuko.mochizuki@it-chiba.ac.jp

[3] Toshie Iwata, Tokai University
iwata@keyaki.cc.u-tokai.ac.jp

Abstract: After the accident of the Fukushima nuclear power plant caused by the 2011 off the Pacific coast of Tohoku Earthquake, the supply of electricity in Japan continues to be tight. In the summer 2011, the Japanese government asked residents and businesses to reduce electricity consumption by 15 percent or more in the eastern half of the Japanese mainland including Tokyo metropolitan area. Several energy saving measures, such as setting the air conditioning temperature higher, replacing less efficient lamps and removing some lamps, have been taken in many office buildings.
The purpose of this study is to collect and analyse basic data on light environments in Japanese office buildings after the 3.11 earthquake, and reconsider the office lighting standard. Nationwide questionnaire surveys on energy saving measures in office buildings have been conducted since 2011 summer, and field measurements of the actual lighting environment and occupants' evaluation surveys were done at 14 buildings in 2011. Results indicate that the rate of workplace dissatisfaction decreases until an desktop illuminance of approximately 400 lux is reached: above this illuminance the dissatisfaction rate remains almost constant. These results will contribute to discussions on the adequacy of the recommended illuminance level for the workspace in Japan.

Keywords: Illuminance, Electricity-saving, Offices, Occupants' satisfaction, Field measurement

1. Introduction

After the accident of the Fukushima nuclear power plant caused by the 2011 off the Pacific coast of Tohoku Earthquake, the supply of electricity in Japan continues to be tight. In the summer 2011, Japanese government asked residents and businesses to reduce electricity consumption by 15 percent or more in eastern half of Japanese mainland including Tokyo metropolitan area. In the summer 2012, Electric Power Companies in several other areas also asked their users to voluntarily cut power consumption during peak hours to avoid supply shortages as the reactors currently under regular inspections are unlikely to resume operations soon.
Lighting accounts for about 20% of total primary energy use in the Japanese office buildings (Japan Luminaires Association. 2009) [1]. Energy-efficient lighting reduces electricity consumption not only for lighting but also for building cooling systems, because lighting systems produce heat as well as light. The reduction of lighting energy use, therefore, is quite effective for lowering total energy use in buildings.
One of the simplest measures to reduce lighting energy is to lower ambient light levels. In JIS Z 9110: 2010 General rules of recommended lighting levels (JIS: Japanese Industrial Standards), the recommended maintained illuminance on work planes in offices is 750 lux (in the range 500 to 1000 lux), which is higher than the ISO standard ISO 8995-1:2002 (CIE 2001/ISO 2002). Since the 3.11 earthquake, there have been controversies concerning the interpretation of this standard and its recommended illuminance level in Japan.
In Architectural Institute of Japan(AIJ), Working Group on Investigation into Luminous Environment with Urgent Electricity Saving Caused by 2011 Earthquake(Chairperson: N.Yoshizawa, Secretary:

E.Mochizuki) was organized on March 2011, and started the investigation through the cooperation of Tokyo Branch Working Group of Lighting Environment and Saving-Electricity and Division of Environment and Energy in the Illuminating Engineering Institute of Japan(IEIJ). The purpose of this Working Group is to collect and analyse basic data on light environments in Japanese office buildings after the 3.11 earthquake, and contribute to an adequate energy-saving lighting in the future. Nationwide questionnaire surveys on energy saving measures in office buildings have been conducted since 2011 summer, and field measurements of the actual lighting environment and occupants' evaluation surveys were done at several buildings in the summer and winter of 2011 in Kanto area and in the summer of 2012 in Kansai area and Tokyo.

The nationwide questionnaire survey has been conducted on the facility managers of the office buildings about the measures for electricity-saving. The survey's respondents were employees in 58 office buildings, including 39 from the Tokyo metropolitan area (as of the end of 2011). In the questionnaire, the following items were asked of facility managers of each building.
- What kind of measures for electricity-saving were taken in your office space just after the earthquake and in summer 2011?
- How high was the desktop illuminance set in your office space before and after the earthquake?
- By how much was the amount of electricity use reduced in summer 2011 compared with the previous year?
The results of the nationwide questionnaire surveys show that for about half or more buildings saving measures for lighting and for air-conditioning in summer season were taken. Especially for lighting, about half of the ceiling luminaires were turned off and the desktop illuminance was reduced by half compared with that before the earthquake[2].

This paper focuses on the results of field measurements on illuminance levels and occupants' satisfaction surveys in 2011 summer.

2. Methods

2.1 Measured buildings

The field measurements were conducted in 16 office spaces of 14 different office buildings located in the Tokyo metropolitan area during July and November 2011. For buildings A and C, two different areas were measured in each building. Table 1 shows the few characteristics of the measured buildings. In this paper buildings E and H are extracted from the analysis because essential data are lacking.

Table 1: Characteristics of the measured office buildings

	Measurement date	Total floor area [m^2]	Numbers of floors above/below the ground	Numbers of occupants who answered the questionnaire		
				During daytime		At night
				on a sunny day	on a cloudy day	
A1 A2	July.-Aug.	6,410	4/1	18 19	20 16	7 13
B	Aug.	-	10/1	32	32	32
C1 C2	Aug.-Sept.	11,200	10/1	42	32	22
D	Sept.	2,802	10/1	43	41	25
E	Sept.	216,718	44/4	38	38	38
F	Sept.	4,338	8/2	30	30	30
G	Sept.	-	9/2	8	8	-
H	Sept.	337,000	31/3	27	27	27
I	Sept.	1,498	14/1	115	58	75
J	Sept.-Oct.	9,064	10/1	57	10	25
K	Oct.	1,300	4/1	13	13	9
L	Sept.-Oct.	-	5/0	18	11	13
M	Oct.	-	5/0	25	25	24
N	Nov.	7,949	6/1	28	25	20

2.2 Measurements

Horizontal illuminance, vertical illuminance, luminance distribution in the occupants' visual field and electric power consumption were measured. The measurements were conducted for a week or two in each building to identify the effects of outside conditions on the interior lighting environment.

2.2.1 Horizontal and Vertical illuminance

Horizontal illuminances were measured at intervals of 1 minute by illuminance meters with data loggers (HIOKI 3640). In order to avoid disturbing occupants' daily works, illuminance meters were installed on desk partitions, the height of which was about 120cm (See Fig.1). When there were no partitions between desks, illuminance meters were set up on the poles of 40cm height, fixed on the desks.

Fig.1 Illuminance meters for Horizontal illuminance(Left) and Vertical illuminance(Right)

Basically the illuminance meters were installed at regular intervals on the line normal to windows. Fig.2 gives a basic illustration of the measurement points. The meters for vertical illuminance were oriented to face the direction that each occupant was seeing when he/she was sitting at the desk.

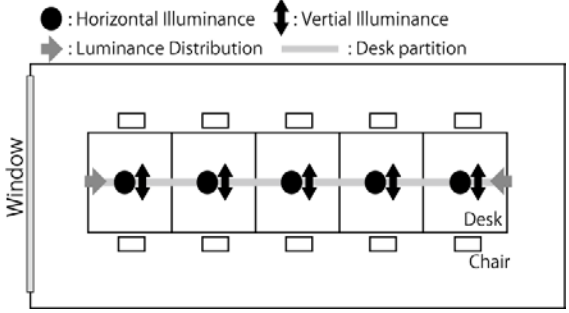

Fig.2 Basic diagram of measurement points (Floor plan)

2.2.2 Luminance distribution

Luminance distribution in the occupants' visual field was measured at intervals of 1 hour, using "Luminocam" made by Kozo Keikaku Engineering Inc. or a digital camera with a fisheye lens. Those measuring instruments were installed at a height of approximately 120cm above the floor level, and one of them measured the luminance distribution of the entire room from the opposite side of the windows.

2.2.3 Electric power consumption

Electric power consumption for ambient lighting was measured at intervals of 1 minute by a clamp meter (HIOKI CLAMP ON POWER HiTESTER 3169). In some buildings, electricity consumption by task lighting was also measured using watt meters.

2.3 Occupants' evaluation surveys

Occupants evaluated the visual comfort in office space, such as brightness (desktop and whole office space), visibility (task area and VDT monitor), task performance and visual fatigue. The occupants answered the questionnaire at 3 different times, during daytime on a sunny day, during daytime on a cloudy day and at night. The total number of respondents, excluding buildings E and H, was 1064 (448 during daytime on a sunny day, 321 during daytime on a cloudy day, 295 at night).

3. Analysis method : illuminance

3.1 Determination of the weather type

In order to correspond to occupants' evaluation as to the visual comfort in offices on a sunny and cloudy day respectively, the weather type of each measurement day has been determined through the regional weather information which Automated Meteorological Data Acquisition System(AMeDAS) provides in Japan, and the sunniest day and cloudiest day have been selected.

3.2 Estimation of desktop illuminances

Desktop illuminances are estimated from the horizontal illuminance data measured on the desk partitions in the following way: 1) Measuring the desktop illuminance on every desk manually at 3 different times, during daytime on a sunny day, during daytime on a cloudy day and at night. 2)

Correction coefficient is calculated for every desktop individually by dividing this desktop illuminance by the horizontal illuimance on the nearest point to that desk measured on the desk partition using the illuminance meter with a data logger. 3) Estimating the desktop illuminance on each desk during daytime on a sunny day, cloudy day and at night, respectively, by multiplying correction coefficient and horizontal illuminance on the desk partition measured on the sunniest day and cloudiest day. In this study it is reasonable to assume that those estimated desktop illuminances represent the ambient light levels, because the influence of task lighting is left out of consideration throughout the measurements and their analyses.

3.3 Typical value: desktop illuminances

3.3.1 Median of illuminances in each office space

In order to understand the light environment of each office space roughly, the median of desktop illuminances is calculated for a sunny day, cloudy day and night individually. Because the illuminance is not stable during the daytime, the medians of the desktop illuminances in the whole room at the same time are first calculated during the daytime, then the middle value of which is computed. The term 'typical value of desktop illuminances in each office' will be used to refer to this middle value in this paper.

3.3.2 Median of illuminances on each desk

In order to grasp each occupant's environment, the medians of the desktop illuminances on each desk during daytime on a sunny day, during daytime a cloudy day and at night, respectively, are calculated. The term 'typical value of desktop illuminances on each desk' will be used to refer to these medians in this paper.

4. Results

4.1 Typical value of desktop illuminances in each office

Fig.3 shows the typical value of the desktop illuminance in each office during the daytime. In most offices the value remains in the range of 300 to 750 lux, whereas the value is below 300 lux in some buildings.

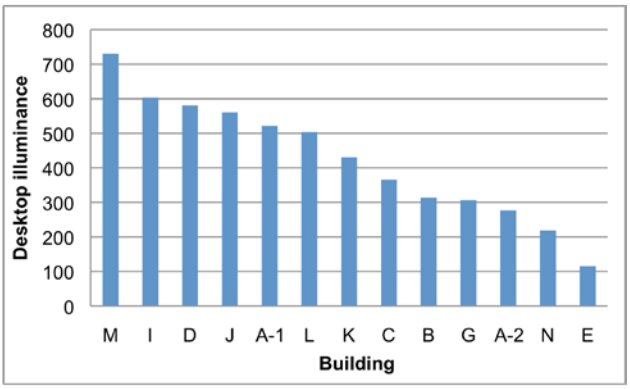

Fig.3 Typical value of the desktop illuminance in each office

4.2 Typical value of desktop illuminances on each desk

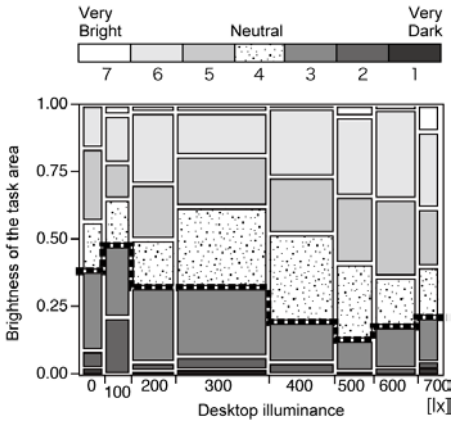

Fig.4 Brightness of the task area and illuminance

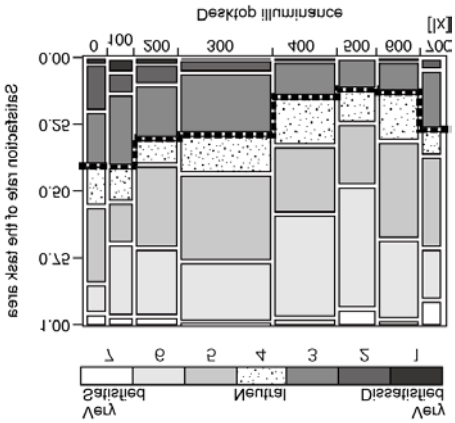

Fig.5 Satisfaction rate of the task area and illuminance

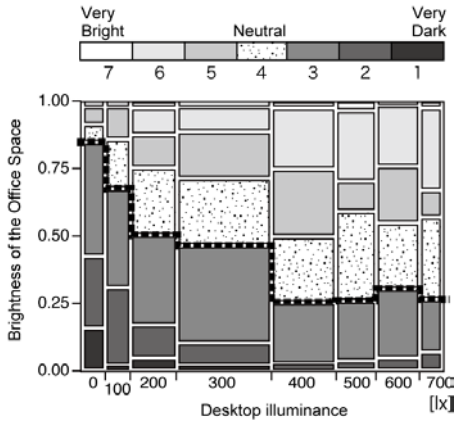

Fig.6 Brightness of the office space and illuminance

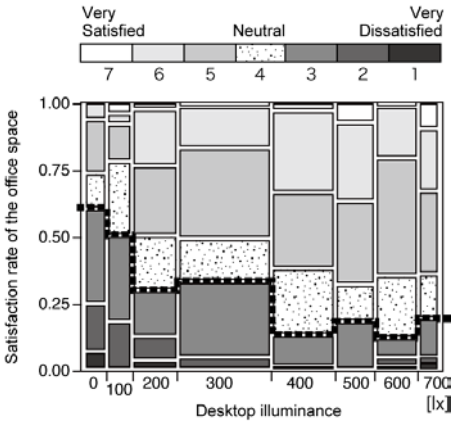

Fig.7 Satisfaction rate of the office space and illuminance

Fig.4 - Fig.7 are variable width column charts which show the relationship between 'typical value of the desktop illuminance on each desk' and occupants' evaluation. Desktop illuminances are rounded off to the nearest hundred, and the width of each column indicates the sample size. As shown in these figures, the rate of dissatisfaction or brightness evaluation decreases until an desktop illuminance of approximately 400 lux is reached: above this illuminance the dissatisfaction rate remains almost constant.

As to the satisfaction around the task area, a percentage of dissatisfied workers increases when the ambient illuminance exceeds 700 lux. The more detailed analysis shows that almost all the occupants who assessed their task environment as dissatisfied, although the the desktop illuminance was high, sat at the desk near windows. According to their free answers, there are several reasons for feeling dissatisfied. One is glare caused by direct sunlight, and another is that there is a too much contrast on the desk.

5. Conclusion and Future works

Field measurements of the light environments in 14 different office buildings, as well as the occupants' evaluation of the visual environments were conducted to identify the effects of the limitation of electricity use due to the "Great East Japan Earthquake".

Results are as follows:

1. In most offices the value remains in the range of 300 to 750 lux, whereas the value is below 300 lux in some buildings. 300 lux is below the recommended level in Japanese lighting standards (JIS Z 9110: 2010).
2. the rate of dissatisfaction or brightness evaluation decreases until an desktop illuminance of approximately 400 lux is reached: above this illuminance the dissatisfaction rate remains almost constant.

The desktop illuminances estimated in this paper represent the ambient light levels, and some buildings introduced task lighting. Detailed analyses on the effect of the task lighting and relationship between brightness and vertical illuminance / luminance distribution are currently under way.

Until the 3.11 earthquake it has been said that brighter work spaces earn favourable evaluation in Japan than western countries, and ambient and task lighting has not been widely accepted. There is no doubt that continuous surveys are necessary to make sure that the current trend will continue or not.

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REFERENCES

[1] Japan Luminaires Association. 2009. Recommendation for renewal of luminaires, p. 3 (in Japanese)
[2] Mochizuki, E., Yoshizawa, N., Munakata, J., Iwata, T. „*Lighting environments in Japanese office buildings after the March 2011 earthquake*". Brisbane, Health Buildings 2012.