Preferred Illuminance and Color Temperature in Creative Works

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***Abstract*—The improvement of the lighting environment in offices leads to the improvement of intellectual productivity. We constructed a system that provides individual illuminance and color temprature preferred by workers, and we carried an experiment to clarify the favorite illuminance and color temperature in the office. From this experiment, it is found that each person's favorite lighting environment was different each other and it changed by health condition and time in a day. We consider that creative works are improved when workers are provided the their preferred lighting environment.**

***Index Terms*—Intelligent lighting system，preferred illuminance，preferred color temprature**

I. Introduction

In recent years there has been increasing interest in office environments, and it has been reported that improvement of the lighting environment in offices improves intellectual productivity[1],[2]. Some of these reports have indicated that work efficiency is improved by changing the lighting environment in accordance with human biorhythms[3],[4]. There are two indicators of the lighting environment: illuminance and color temperature. Illuminance is the brightness of a desired location illuminated by light, and is given in lx (lux) units. Color temperature is a scale which expresses the color of light in quantitative numerical units, and its units are degrees K (Kelvin). It has been reported that reducing color temperature of lighting creates a feeling of relaxation, while increasing it creates a feeling of refreshment[5]. At present in Japan, the illuminance standard for the top surface of desks in ordinary offices is set to 750 lx or more. A uniform brightness is provided for the room overall, and worker preferences and work content are not taken into account. It is known that there are differences in individual preferences for illuminance, and that there are subjects who prefer only high illuminance or low illuminance, as well as subjects who prefer a variety of illuminance levels[4]. Thus there are likely to be differences in individual preferences not only for illuminance, but also for color temperature. Furthermore, it may be possible to improve intellectual productivity and work efficiency by varying color temperature.

In this research, we clarify the illuminance and color temperature which each individual feels is optimal for creative work. Here, the term ”creative work” refers not to plain work, but to planning, design, program development and other tasks involved in conducting research. These types of work are mainly carried out using computers. We clarify the illuminance and color temperature which each individual feels is optimal for carrying out work, as well as whether there are changes in the individual's preferred illuminance and preferred color temperature depending on their health condition and the time of day. First, we build a system to realize the illuminance and color temperature requested by the user. Then using the constructed system, we conduct experiments on the illuminance and color temperature preferred by each individual. Based on these results, we determine how the illuminance and color temperature preferred by the individual change due to the individual's health condition and the time of day.

II. The effects of illuminance and color temperature on people

Illuminance is the brightness of a desired location illuminated by light, and is given in lx (lux) units. Luminous intensity is the intensity of light in a certain direction, and is given in cd (candela) units.

Color temperature is a scale which expresses the color of light in quantitative numerical units, and its units are degrees K (Kelvin). This measure indicates the color of light using the temperature in degrees K (Kelvin) of a perfectly black body when it radiates light with spectra the same as the color of light due to lighting. Lower color temperatures have a reddish color, while higher color temperatures have a bluish-white color. It has been reported that reducing the color temperature creates a feeling of relaxation, while increasing it creates a feeling of refreshment[6]. Low color-temperature lights can be used to create a warm, calm atmosphere, while high color-temperature lights can be used to create a cool, refreshing atmosphere. However, in Japanese offices, it is typical for lighting to have a high color temperature of 4500-5000 K. It has been reported that, if the illuminance of lighting is increased, then the arousal level of workers s kept high, and work efficiency improves[3],[4]. For this reason, research is being conducted on lighting control methods, such as setting to a lower illuminance only during office break times. It is thought that work efficiency can be expected to improve as a result. In addition, it has been reported that work efficiency is improved by varying the light environment in accordance with human biorhythms[3],[4]. Previous research has reported that the preferred illuminance varies depending not only on biorhythms but also on the worker, and that the proper lighting environment varies depending not only on biorhythms but also on the work content.

Thus, in this research, we determine the illuminance and color temperature which each individual feels is optimal for doing creative work. To achieve that, a system with variable illuminance and color temperature is built to automatically provide the illuminance and color temperature requested by each individual. Using the constructed system, it is possible for each individual to freely select the illuminance and color temperature felt to be ideal for work, and each individual's preferred illuminance and preferred color temperature are identified by providing that environment. We also examine what sort of distinguishing characteristics can be found in the light environment preferred by each individual depending on the time of day, the individual's health condition or other circumstances. ”Creative work” refers not to plain work, but to planning, design, program development and other tasks involved in conducting research. These types of work are mainly carried out using computers.

III. Building a system with variable illuminance and color temperature

A. System overview

A lighting system is built to realize the illuminance and color temperature requested by the user.

This system uses fluorescent lamps. Because the fluorescent lamps are used for lighting in general Japanese office. This system realizes the illuminance and color temperature requested by the user by adjusting the luminous intensities of a cool white fluorescent lamp with color temperature of 4600 K and a warm white fluorescent lamp with color temperature of 3000 K. Illuminance is controlled by increasing/decreasing the total luminous intensity of the cool white fluorescent lamp and warm white fluorescent lamp based on illuminance sensor data. Intermediate color temperatures are realized by varying the lighting ratio of the high and low color temperature light sources. These lighting ratios are found from preparatory experiments using a color meter.

B. System construction

The system uses 1 dimmable Panasonic cool white fluorescent lamp (FHF32EX-N-H), 1 dimmable Toshiba warm white fluorescent lamp (FHF32EX-L-H), 1 control PC, 1 dimmer, 1 A/D converter, and 1 illuminance sensor. Fig.1 shows the system construction diagram. The dimming range of these fluorescent lamps is 20-100 %.

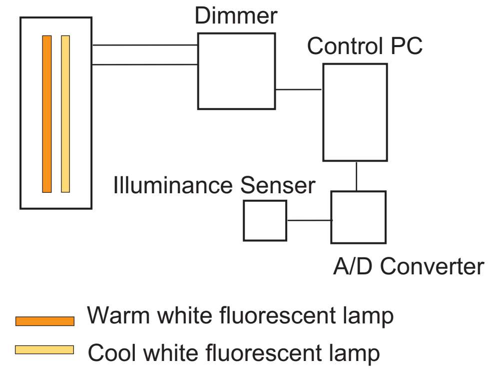


Fig. 1. Construction of the system

The control PC dims these two fluorescent lamps by sending instructions to the dimmer. The illuminance sensor connects to the control PC via an A/D converter. The control PC acquires the digitized illuminance data.

C. Method of color temperature control

The color temperature requested by the user is realized by varying the ratio of luminous intensities of the two different light sources. Thus the following experiment was conducted to investigate the relationship between this ratio and color temperature. The experimental environment was assumed to be a space with dimensions 3.5 (width) x 5.9 (length) x 2.5 (height) m, as shown in Fig.2 and Fig.3 Within this space, 10 cubicles were set up, with each cubicle having one set of light sources comprised of 1 cool white fluorescent lamp with a color temperature of 3000 K, and 1 warm white fluorescent lamp with a color temperature of 4600 K. One set of lighting fixtures forms the lighting environment for a single user. Illuminance can be selected in 50 lx increments over the range 250-850 lx, and color temperature can be selected in 200 K increments over the range 3000-4600 K. Color temperature was measured by providing a color meter (made by Konica Minolta) 1.7 m below the center of each light. Rollscreens were provided on the front and both sides of the desk because the color temperature value can be easily affected by nearby lighting.

In this experimental environment, color temperature was measured by lighting up the cool white fluorescent lamp and warm white fluorescent lamp at various ratios. Table.I shows the lighting ratio.

Color temperatures are realized by varying the lighting ratio of the cool white fluorescent lamp and warm white fluorescent lamp based on the measurement results in Table.I.

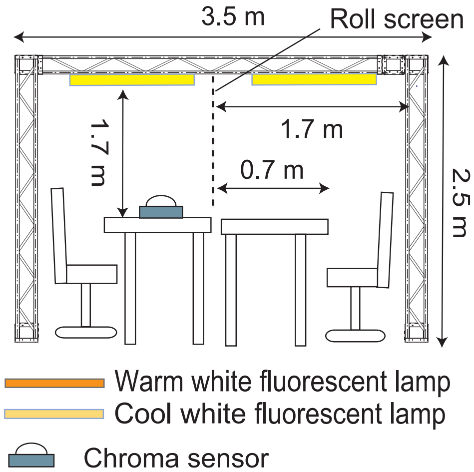


Fig. 2. Experimental environment

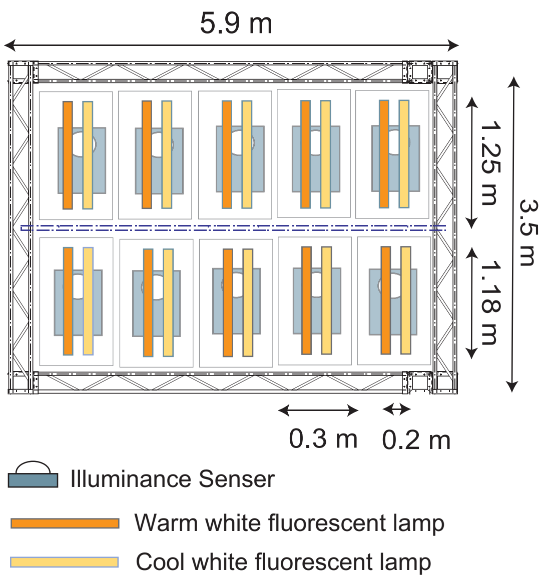


Fig. 3. Experimental environment

D. System algorithm

This system achieves the illuminance and color temperature requested by the user by varying the lighting ratio of the two fluorescent lamps based on Table.I.

The following explains the specific steps of processing.

(1) The lighting is lit up at the lighting ratio corresponding to the target color temperature.

(2) The target illuminance and target color temperature selected by the user are acquired.

(3) The current illuminance is acquired from the illuminance sensor.

(4) If the current illuminance is 50 lx or more less than the target illuminance, the luminous intensity is raised by 3 % of the maximum lighting luminous intensity, and, conversely, if the current illuminance is 50 lx or more greater than the target illuminance, the luminous intensity is lowered by 3 % of the maximum lighting luminous intensity.

(5) If the current illuminance is in the range of $\pm$ 50 lx of the target illuminance, then the target value is approached by raising or lowering the luminous intensity by 1 % of the maximum lighting luminous intensity, and then control returns to step (2).

(6) Otherwise, control returns to step (4), without changing the luminous intensity.

TABLE I
LIGNTING RATIO OF WARM WHITE FLUORESCENT LAMP AND COOL WHITE FLUORESCENT LAMP

Color temperature[K]	Neutral white fluorescent lamp[%]	Incandescent fluorescent lamp[%]
3000	0	100
3400	33	67
3600	47	53
3800	57	43
4000	69	31
4200	80	20
4600	100	0

In (4) and (5), the requested illuminance is achieved by increasing or decreasing luminous intensity of the cool white fluorescent lamp and warm white fluorescent lamp, while maintaining the lighting ratio corresponding to the target color temperature. Changes in color temperature are achieved by varying only the lighting ratio, without changing the total luminous intensity of the two fluorescent lamps. The color temperature and illuminance requested by the user are achieved through the above operation.

From the operion experiment with the cousutructed system, the target illuminance and color temperature were acheived in about 60 seconds. Therefore in the actual experiment with subjects, illuminance control is performed using only the illuminance sensor, with no color meter.

IV. EXPERIMENTS WITH UNIFORM ILLUMINANCE AND UNIFORM COLOR TEMPERATURE

A. Overview of experiments

Experiments with uniform illuminance and uniform color temperature were performed on 10 subjects (ages 21-24) using the experimental space shown in Fig.2 and Fig.3. Fig.4 shows the experimental situation. They did creative work for the experment period.

In the experiment with uniform illuminance, the illuminance was set to 400, 600 and 800 lx, and the color temperature was set to be selectable in 200 K increments over the range 3000-4600 K. In the experiment with uniform color temperature, the color temperature was set to 3000, 3800, 4000 and 4600 K, and the illuminance was set to be selectable in 50 lx increments over the 250-850 lx range.

Fig.5 shows the results of the experiment with uniform luminance. The graph plots the mode values, i.e., the values selected the longest by the subjects throughout the day. The

Fig. 4. Experimental situation

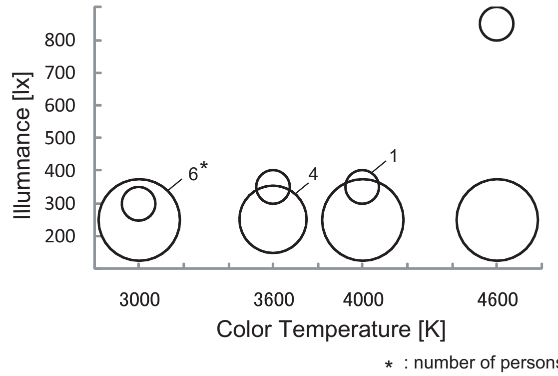


Fig. 6. Experimental result of uniform of color temperature (The area of the circle represents the number of persons who selected the values)

area of each circle indicates the frequency with which that value was selected.

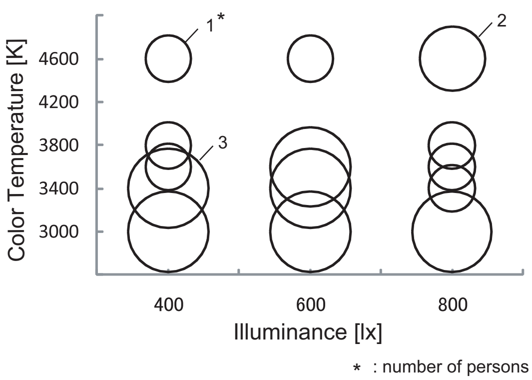


Fig. 5. Experimental result of uniform illuminance (The area of the circle represents the number of persons who selected the values)

It was found from Fig.5 that many people prefer comparatively low illuminance, but there were also some subjects who preferred high color temperature. The experiment with uniform color temperature was conducted with color temperature set to 2800, 3800, 4000 and 4600, and Fig.6 shows the results plotting the values most frequently selected by the subjects.

Fig.6 shows that a large number of subjects prefer low illuminance, regardless of whether color temperature is low or high.

V. Preferred illuminance and preferred color temperature

A. Overview of experiments

Using a system constructed in the actual work space, an experiment was conducted where 10 subjects were allowed to freely select illuminance and color temperature for a period of about 2 months. Fig.4 showed the experimental experimental landscape. They do creative work for the experment period. The illuminance preferred by a subject is called preferred illuminance, and the color temperature preferred by a subject is called preferred color temperature. The subjects can select the target illuminance in 50 lx increments over the range 250 850 lx, and can select the target color temperature in 200 K increments over the range 3000 4600 K. When the target value is changed, the subjects note the reason for the change, and when they go home, they provide their impressions and comments on the day in a questionnaire. The experimental environment was as shown in Fig.2.

B. Experimental results

Fig.7 shows the results on target illuminance and target color temperature for all subjects over the 14 days where both illuminance and color temperature were selectable.

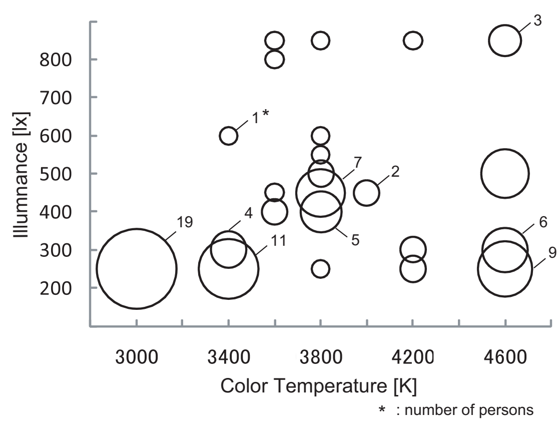


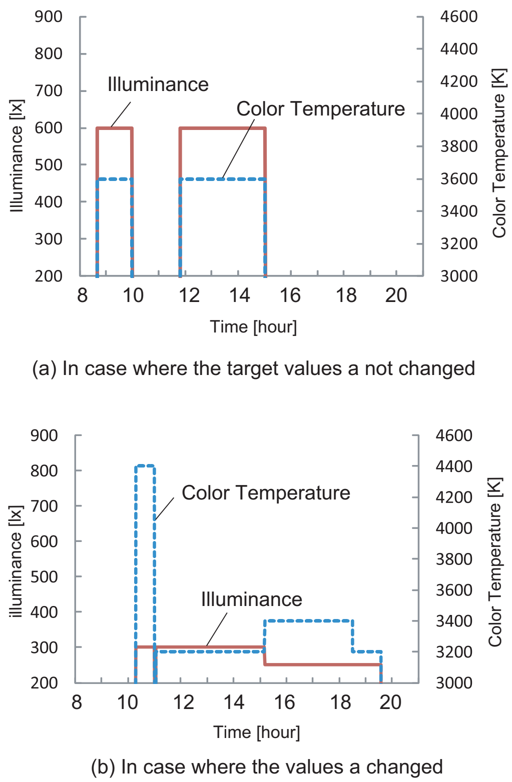
Fig. 7. Distribution of the preferred illuminance and color temperature (The area of the circle represents the number of persons who selected the values)

From Fig.7 it is evident that there is a tendency for subjects to prefer lower illuminance, regardless of their color temperature preferences. It was also found that there were no subjects who preferred low color temperature with high illuminance. Subjects made the following sorts of comments on the questionnaire.

1) They changed the target illuminance and target color temperature for a change of mood.

2) When the subjects did not feel well, the preferred a low color temperature, but when they felt good, they felt they could concentrate better with a higher color temperature.
3) They felt that lighting from the cool white fluorescent lamp alone made them feel poorly.

For the questionnaire result (1), Fig.8 shows the illuminance and color temperature record for a certain subject over two days.



(a) In case where the target values a not changed

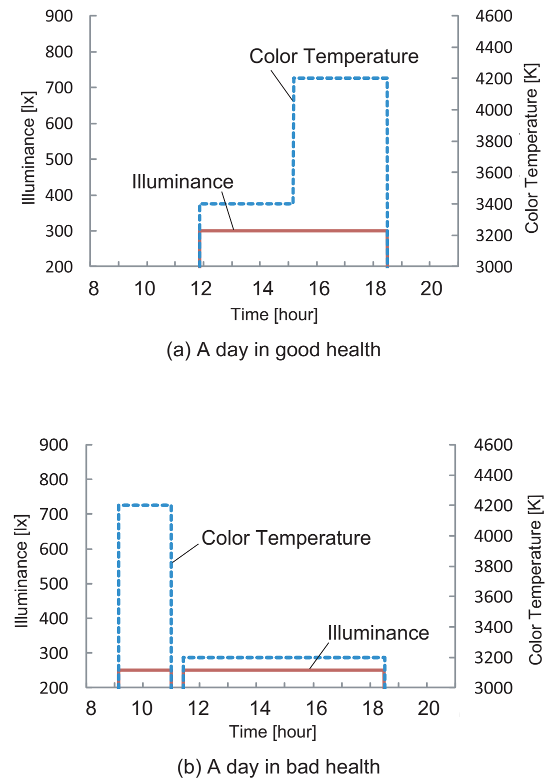
(b) In case where the values a changed

Fig. 8. The change of the target values in a day

Fig.8(a) shows a case where there are no changes in preferences for illuminance and color temperature throughout the day for the subject. On the other hand, Fig.8(b) shows a case where there are changes in preferences for illuminance and color temperature throughout the day for the subject. From these results, it is evident that there are people whose preferences for illuminance and color temperature change depending on the time, and those whose preferences do not change depending on the time.

For the questionnaire result (2), Fig.9 shows the illuminance and color record for a certain subject on a day where the subject responded that his health was good, and on a day where he responded that his health was bad.

Fig.9(a) shows that the subject selected a high color temperature of 4200 K when his health was good. On the other hand, Fig.9(b) shows that the subject selected a low color temperature of 3200 K when his health was bad. Fig. 8 also shows that the subject's preference for color temperature changed during the day both when his health was good and when his health was bad.



(a) A day in good health

(b) A day in bad health

Fig. 9. The change of the target values due to the health comdition

Due to the above results, it was observed that preferred illuminance and color temperature vary depending on time and health condition.

VI. Conclusion

In this research, we built a system where the illuminance and color temperature of lighting can be set in accordance with the requests of individuals, and we investigated the illuminance and color temperature which individuals feel is ideal for work. We also examined what kind of effects the time of day and the person's health condition have on preferences for illuminance and color temperature. As a result, it was found that the illuminance which subjects feel is optimal for creative work is a comparatively low illuminance (250 500 lx). It was also found that there were no subjects who preferred low color temperature with high illuminance. Many subjects preferred a low color temperature, but the preferred color temperature varied depending on the individual. It was also found that preferences vary depending on the subject's health condition, the time of day, and the work content. The above results suggest that, when doing creative work, it is thought that a comparatively low illuminance and low color temperature are suitable. When doing creative work, work efficiency and comfort can be improved by realizing a light environment which suits individual preferences.

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