Subjective experiments on the suitable illuminance in a living room daylit by Mirror Duct System

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ABSTRACT
The objective of this study is to identify the effects of mirror duct system on energy savings for luminaries. The results of the experiments showed that more than half of the subjects judged the room was bright when the illuminance on the desk from mirror duct system was higher than 100 lx. Half of the subjects judged ceiling luminaire could be turned off when the illuminance on the desk was higher than 100 lx in the case of relaxing. On the other hand, about 80% of the subjects always switched on the luminaire regardless of the illuminance on the desk in the case of reading.

1. Introduction

Energy consumption for interior lighting, which accounts for about 10% of all energy use in a house, cannot be neglected to cut down CO_2 discharge. Some window systems which relieve excessive heat gain or discomfort glare from direct sunlight are necessary for practical use of solar energy as interior lighting.

Recently, several tubular type daylight guidance systems have been developed (Marwaee, 2006). Also in Japan, mirror duct system has been introduced into some buildings or houses for energy conservation or the occupants' visual comfort (Kaihou, 2002). However, energy efficiency of the system being compatible with the occupants' visual comfort has not been confirmed concretely.

The objective of this study is to identify the effects of mirror duct system on energy conservation for ceiling luminaries in a house based on human sensation.

2. Method

Subjective experiments were conducted in an experimental house in Koshigaya, Saitama to identify the suitable brightness as a living room using mirror duct system.

2.1 Experimental room

Figure 1 shows the experimental rooms whose sizes were the same (2.4 m in wide, 3.6 m in depth and 2.5 m in height). Also, the outline of the mirror duct system is shown in the right part of Figure 1. Daylight reflected on the reflecting mirror whose slope is adjustable according to the solar position can be carried into the deeper part of the room by interreflection within the mirror duct system and it comes out into the room through the translucent panel fitted into the openings of the duct.

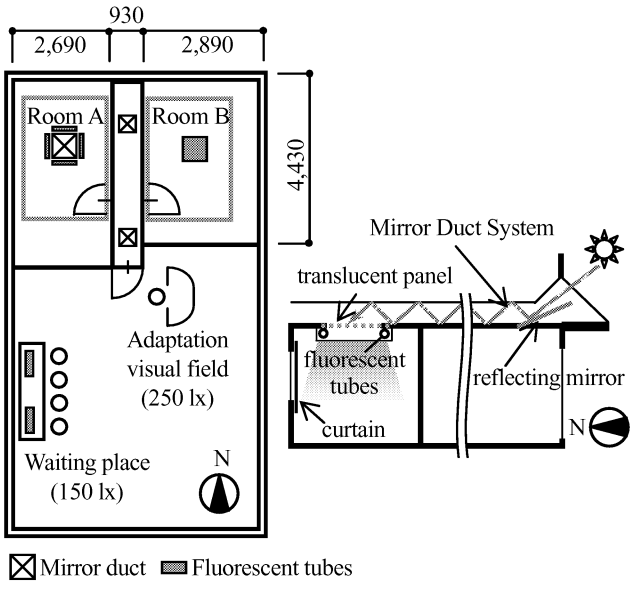

Figure 1. Plan & section of the experimental room

The interior surfaces of the two experimental rooms were finished with gray wall papers. One was daylit by mirror duct system (Room A) and the other was lit by fluorescent tubes (Room B). Four fluorescent tubes (two were neutral white color and the other two were warm white color) were also equipped around the part on the ceiling which emitted light from the mirror duct system in Room A (after this, we call the part of emitting light from the mirror duct system surrounded with fluorescent tubes as 'luminaire system'). Also in Room B, two neutral white color fluorescent tubes and two warm white color fluorescent tubes were equipped on the ceiling to be the same size as the luminaire system in Room A. Illuminance on the desk of each room was dimmable by the subjects.

2.2 Experimental procedure

The experiments were conducted for 4 days each in two seasons (autumn: 2007/9/21-10/6, winter: 2007/12/17-21). The experiments were conducted 4 times a day (9:00, 12:00, 14:00, 16:00). Each 20 subjects (autumn: 17 male, 3 female, winter: 14 male, 6 female, both 22 years old on average) participated in the experiment. The weather during the experimental term in each season was sunny or slightly cloudy.

First, the subjects were asked to wait watching at the desktop with 150 lx of the horizontal illuminance in the waiting place. Then he/she was asked to adapt his/her eyes to the visual field with 250 lx of the vertical illuminance set aside the corridor which led to the experimental rooms for two minutes. After the adaptation, he/she entered into Room A/B to evaluate the light environment in each room. The subjects evaluated the brightness in Room A as it was and that in Room B set at two different levels, 150 lx and 300 lx. After the evaluation, he/she was asked to adjust the illuminance on the desk to be suitable each for reading and relaxing. After the adaptation he/she judged the brightness sensation and acceptability against the luminous environment in each room. In autumn, subjects experienced the ceiling luminaire only with neutral white color. In winter, subjects experienced the ceiling luminare both with neutral white color and warm white color individually. Table 1 shows the questionnaire used in the experiments. Illuminance and correlative color temperature on the desk in each room were measured every one second continuously at the center of the room (0.7 m from the floor, by chroma meter (KONICA-MINOLTA CL-200)).

3. Results

3.1 Illuminance from the mirror duct system

Figure 2 shows the illuminance on the desk measured in Room A during the experiments on 28th September and on 21st December as examples. Four projecting values in autumn and eight projecting values in winter could be seen in each experimental period. They meant the illuminances on the desk which were set by the subjects to be suitable for reading or relaxing. It can be seen that the lower the illuminance on the desk from the mirror duct system, the lower the illuminance on the desk the subjects adjusted.

Table 1. Questionnaire

Item	Category	Timing
Glare from the system	Very glaring/ Glaring/ Slightly glaring/ Neutral/ Not glaring	Just after the entrance
Variation of brightness	Acceptable / Not acceptable	
Brightness of the room	Very bright/ Bright/ Slightly bright/ Neutral/ Slightly dark / Dark/ Very dark	After the adjustment
Comprehensive evaluation	Comfortable / Uncomfortable	

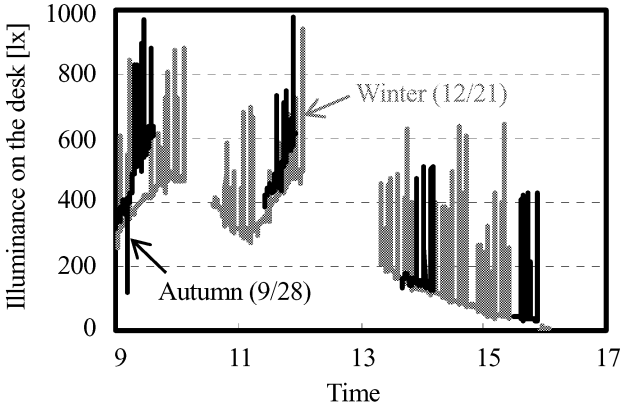

Figure 2. Illuminance on the desk

3.2 Brightness sensation of the room

Figure 3 shows the brightness sensation in Room A (daylit by the mirror duct system) judged by the subjects just after they entered the room. The upper figure shows the results of the experiments in autumn and the lower figure shows the results of the experiments in winter. The numbers of the subjects who experienced each classification of the illuminance on the desk were almost the same (the number of the subjects in each classification ranged from 15 to 22).

Both in autumn and in winter, more than half of the subjects judged the room was rather bright in the case when the illuminance on the desk was higher than 100 lx.

3.3 Glare from the mirror duct system

Figure 4 shows glare sensation, evaluated by the subjects just after they entered the experimental room Room A, from the mirror duct system. The upper figure shows the results in autumn and the lower figure shows those in winter. The classification of the illuminance on the desk was just the same as that indicated in 3.2.

In autumn, about 70% of the subjects did not sense glare from the mirror duct system in the case when the illuminance on the desk was lower than 250 lx. However in winter, the subjects sensed glare from the mirror duct system in the case when the illuminance on the desk was higher than 100lx. The difference between the results in autumn and those in winter may be caused by the directional direct sunlight reflected on the surface of the aluminum mirror which was introduced into the system by the sun with different solar altitude.

3.4 Probability of turning off the ceiling luminaire

Figure 5 shows the probability of turning off the ceiling luminaire with different lamp colors by the subjects in each season for each behavior (reading or relaxing). The upper figure shows the results in the case of neutral white color and the lower one shows the results in the case of warm white color.

In the case of neutral white color, it was found that the higher the illuminance on the desk, the lower the percentage of the subjects who turned on the ceiling luminaire on occasion of relaxing (□, ○). On the other

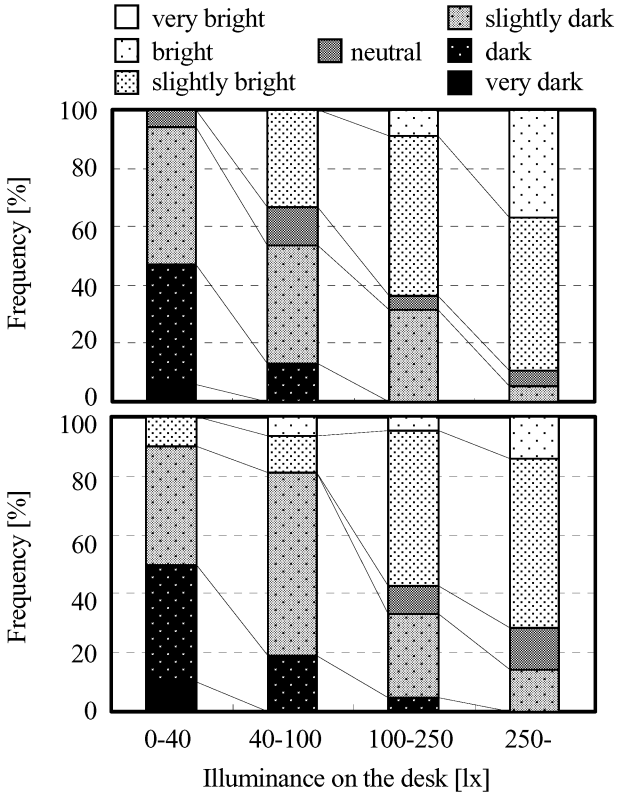

Figure 3. Brightness sensation in Room A (upper: autumn, lower: winter)

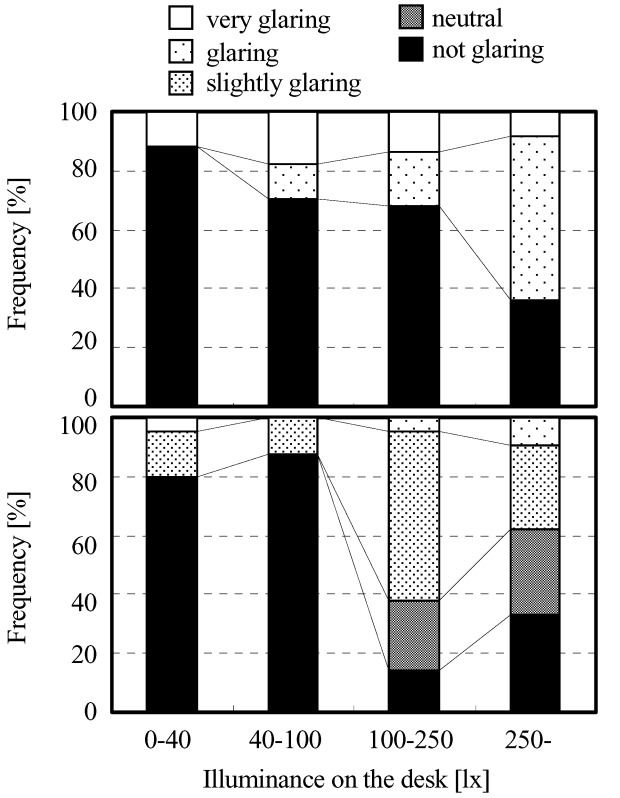

Figure 4. Glare from mirror duct system (upper: autumn, lower: winter)

hand, on occasion of reading, over 80% of the subjects always turned on the ceiling luminaire regardless of the illuminance on the desk in both seasons (■, ●).

3.5 Suitable illuminance on the desk

Figure 6 shows the illuminance on the desk whose brightness adjusted by the subjects to be suitable for reading and relaxing in each room. The bars in gray show the illuminance on the desk from the mirror duct system on average and the bars in other colors show the illuminance on the desk the subjects supplemented with fluorescent tubes on average.

It can be seen that the higher the illuminance on the desk from the mirror duct system, the higher the illuminance on the desk the subjects adjusted for each behavior in both seasons and with both lamp colors. The suitable illuminance on the desk on occasion of reading was higher about 65 lx on average than that on occasion of relaxing. The results in winter showed that the suitable illuminance on the desk with warm white color (⬚, ▩) was higher than that with neutral white color (□, ■) for both behaviors. Comparing the results in autumn and those in winter with neutral white color showed that suitable illuminance in winter was lower than that in autumn.

The results of analysis on the variance showed that the difference of illuminance between different lamp colors, that between different seasons and that between different behaviors were all significant ($P<0.01$).

On the other hand, the suitable illuminance on the desk in Room B (lit only by fluorescent tubes) showed no significant difference between different seasons nor different lamp colors. The suitable illuminance on the desk on occasion of reading was 374 lx and that on occasion of relaxing was 262 lx on average.

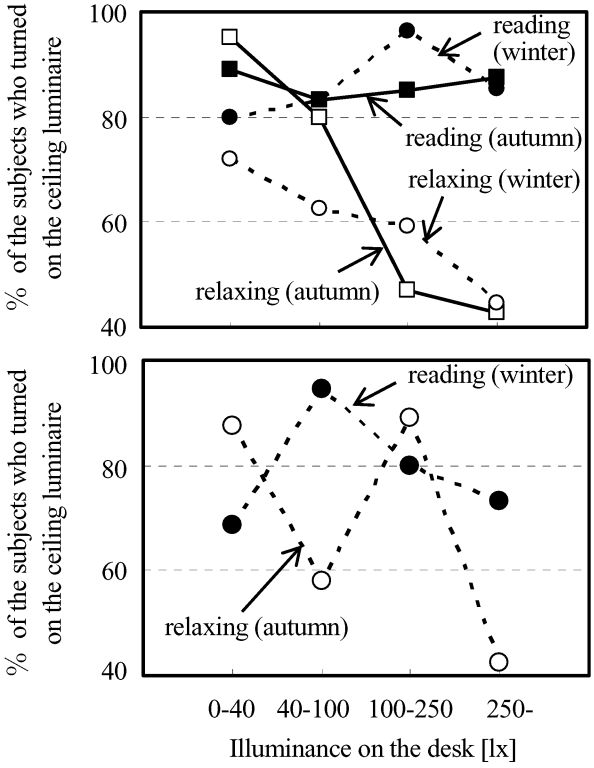

Figure 5. Probability of turning off the luminaire (upper: neutral white, lower: warm white)

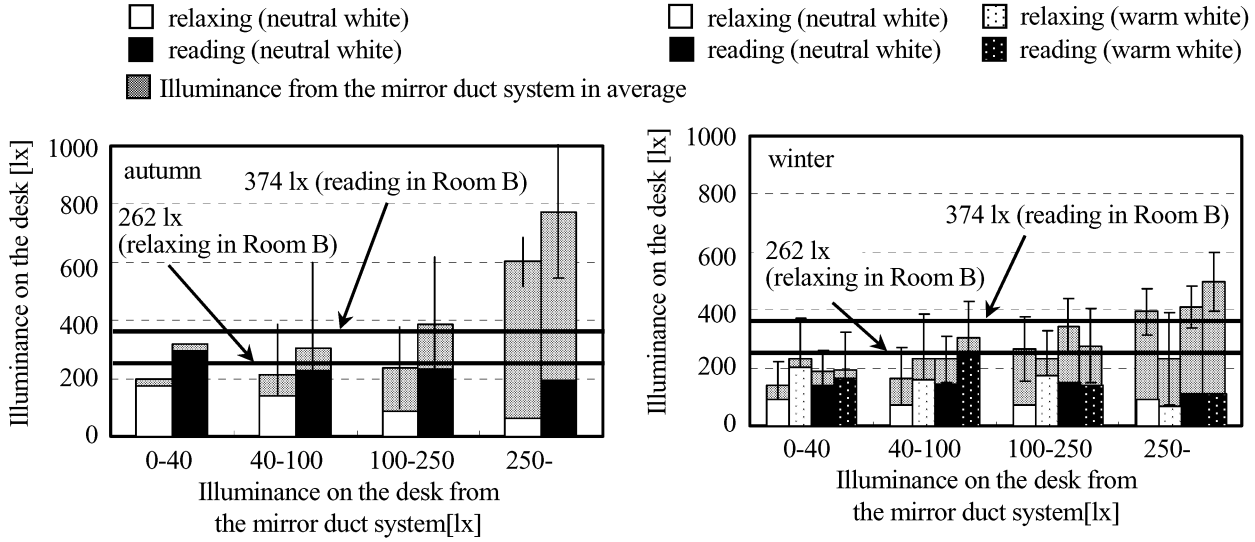

Figure 6. Suitable illuminance on the desk the subjects adjusted (left: autumn, right: winter)

4. Discussion

As mentioned in 3.4, more than 80% of the subjects turned on the ceiling luminaire regardless of the illuminance on the desk from the mirror duct system on occasion of reading. However it was found that the output of the ceiling luminaire in the room lit by mirror duct system became much lower than that lit only by fluorescent tubes as shown in Figure 6. Moreover on occasion of relaxing, the output of the ceiling luminare in the room lit by the mirror duct system became below the half of that only lit by fluorescent tubes.

Simulation study should be conducted to estimate the annual effects of the system to reduce electrical energy for ceiling luminaire based on the results of this study.

5. Conclusion

Subjective experiments were conducted to identify the suitable brightness in a living room daylit by mirror duct system. The results showed that the output of the ceiling luminaires in a living room daylit by mirror duct system could be set significantly lower than that in a living room lit only by fluorescent tubes. Simulation study on the annual energy conservation by mirror duct system should be conducted in the near future.

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References

M, Al, Marwaee. (2006). A field study of tubular daylight guidance installations, Lighting Research & Technology, 38, 3, pp. 241-258

Kaihou, K. (2002). A Mirror Duct System Technique for Receiving Natural Light, Journal of the Illuminating Engineering Institute of Japan, Vol.86, No.6, pp. 358-361 (in Japanese)