Paper

Preferred Illuminance Non-Uniformity of Interior Ambient Lighting

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ABSTRACT

In various interior spaces, specific trends are often discerned in combinations of the type of space and the method of lighting used. The type of space determines the type of lighting because of the relationship between characteristics of lighting methods and the ease of certain behaviors. This study examined the method of lighting preferred for interior behaviors. First, preferred lighting non-uniformity for behaviors was investigated using a questionnaire. Next, an experiment was carried out searching for the degree of lighting non-uniformity preferred for behaviors using a reduced scale model. The results of the questionnaire survey and the experiment were clearly similar, it was possible to quantitatively predict trends in the non-uniformity of interior lighting preferred for many other types of behavior not covered by this experiment.

KEYWORDS : non-uniform lighting, illuminance distribution, behavior, reduced scale model experiment, brightness

1. Introduction

While interior spaces can be illuminated in various ways, we can often discern specific trends in combinations of the type of space and the method of lighting used. For example, office rooms are usually equipped with general lighting that uniformly illuminates the whole rooms with high illuminance and equal intensity, rather than just illuminating individual desks. Places where people dine such as restaurants frequently offer a combination of brightness and darkness achieved by using pendant lights or spotlights. Thus, the type of space determines the type of lighting because of the relationship between characteristics of lighting methods and the ease of performing certain behaviors.

In reality, lighting design is influenced by a myriad of factors as the scale of the space, the interior decoration, the budget, and the preferences of the designer. The degree to which the usage of the space is reflected in the lighting method used is not altogether clear. The lighting design is a combination of many factors including the number of light sources, their size, the light distribution, the light position, and the color temperature of the lighting. To understand the relationship between the lighting method and the performance of certain behaviors, it is necessary to show lighting methods on some scale. This research investigates distributions of brightness and darkness (the non-uniformity of the lighting) to examine the relationship between interior lighting methods and behaviors.

2. Past Research

Existing behavior-based lighting standards include the recommended illuminance determined by JIS [1] and IES [2]

and other bodies associated with lighting. These standards provide, for each workspace, a degree of horizontal illuminance for a level plane used in visual tasks, and are based on the degree of visual difficulty for activities. Research on brightness in actual spaces was based on experiments into illuminance around desks, and illuminance on walls. Bean[3] and Slater[4,5] examined difficulties in seeing in visual environments, sought to limit unsatisfactory levels of lighting, and proposed lighting conditions that would not impede visual tasks.

As regards lighting uniformity, it had been traditionally recommended that the entire space of office room be evenly illuminated. If luminance within one's field of vision were not uniform, the eyes would tire (Rowlands[6]). Uniform lighting was preferable as every position in the room should obtain equal illuminance. However, uniform illuminance does not always result in the most preferred environment. Depending on the behavior and the conditions, some differences in the lighting distribution can improve the atmosphere.

In addition to research of brightness relating to the functionality of behaviors, researchers investigated the effects of levels of illuminance on behaviors. For example, to investigate the influence of lighting environment on interpersonal communication, Gifford[7] conducted experiments based on combinations of illuminance and interior decorations. These experiments found that high illuminance promoted business communication, while low illuminance encouraged intimate communication. Also, illuminance promoted business communication, while low illuminance encouraged intimate communication. Also, Veitch[8] measured conversational sound energy level

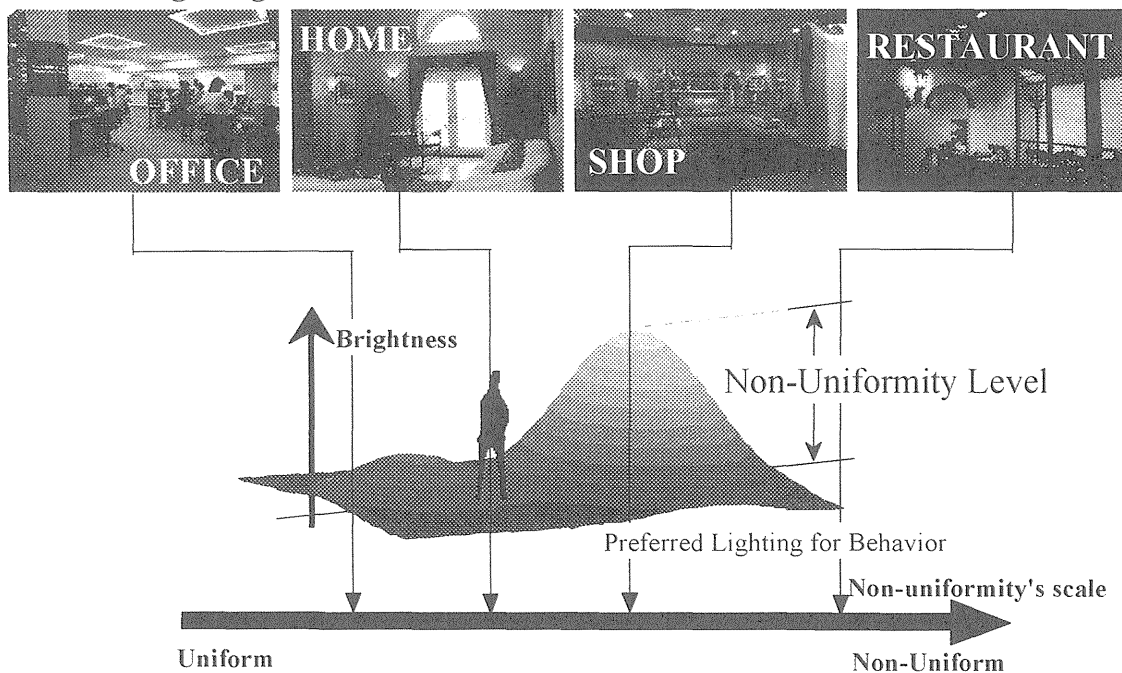**Various Lighting Methods in Various Situations**

Fig.1 Expressing various lighting methods on scale of lighting non-uniformity

among four students attending female colleges in a room with various illuminances, and found that high illuminance resulted in lower voices.

Flynn[9][10] investigated impressions about non-uniform lighting rooms. Semantic differential method was used to investigate subjective responses to the non-uniformity of lighting. He stated that uniform wall-lighting appeared to strengthen impressions of spaciousness, while non-uniform peripheral effected evaluative impressions. But these experiments targeted on only one place and did not investigate lighting non-uniformity as continuity, so the most suitable level of non-uniformity could not be expressed.

Past many researches sought levels of interior illuminance and uniformity of lighting targeted on limited places and behaviors. The differences between different types of interior spaces such as office rooms and homes were not examined. This research investigates, for the first time, using a questionnaire, broad trends in the levels of brightness or darkness desired for different types of behavior. We also attempted to express, by reduced scale model experiments, the quantitative distribution of levels of lighting and their relationship to behavior.

3. Optimal Levels of Non-uniform Lighting for Daily Behaviors

3.1 Purpose of Questionnaire Survey

This survey aimed to investigate the distribution of interior non-uniform lighting in relation to daily behaviors. The questionnaire survey was used to enable a large number of subjects to participate, and because we demanded them to comprehensively determine only the relationship of behavior and non-uniform lighting. Experiments can run into the danger of evaluations being influenced by the characteristics of the stimuli themselves, as the stimuli are explicit. To evaluate comprehensively the effect of lighting on behavior, this survey used a hypothetical approach that avoided the stimuli themselves by describing the behavior and lighting environment in words.

Biner[11][12] conducted a survey on behavior and brightness using a large number of subjects. Quite apart from functional aspects of behavior, the social variable ("Who are you with in this situation?") influenced the lighting level felt to be ideal. Keeping this result in mind, we decided to structurally investigate the relationship of behavior to preferred lighting non-uniformity.

3.2 Survey Outline

As Table 1 shows, the survey targets a total of 23 types of behavior in six types of place. These behaviors were selected from among daily places and behaviors, to achieve

Table 1 Targeted behaviors for the survey

Place	Behaviors
home in the livingroom	1 dining with your family 2 thinking 3 talking with your family 4 receiving guests 5 napping 6 reading a newspaper 7 having a party 8 listening to music 9 studying
home in your room	10 relaxing 11 studying 12 sleeping
home in the bathroom	13 taking a shower 14 looking in the mirror 15 washing
office	16 working 17 meeting with people 18 thinking 19 taking a break
school	20 studying 21 talking with friends
restaurant	22 dining with your partner 23 dining in a group

a balance among behaviors including high-level visual tasks, behaviors including cognitive tasks, interpersonal behaviors, and combinations of these. The questionnaire included items to evaluate four lighting environments in regard to behavior: bright environments, dark environments, uniform lighting environments, and non-uniform lighting environments.

The instructions to subjects were, for example: "When you are talking with your family in your living room, do you want the room to be very uniform illuminated, do you want the room to be uniform illuminated, do you want the room to be somewhat uniform illuminated, or don't have any particular feeling toward uniformity? Show a positive response to the first question by a double-rimmed circle, to the second by a circle, to the third with a triangle, and the fourth by entering nothing". The instructions did not specify uniformity in a particular part of the room. A total of 121

Japanese subjects took part in this survey. The composition of the subjects is shown in Table 2.

3.3 Survey Results and Investigations

The responses of the subjects were expected to vary depending on their daily environment and their interests. Therefore, the survey data were classified according to the attributes of the subjects and average scores were sought for each group. Average scores were little affected by age or sex.

Comparing subjects by occupation, those employed in the lighting field tended to strongly favor non-uniform lighting compared to other subjects, no doubt because of their higher awareness of lighting. However, no particular trends from other attributes were noted among the subjects in the survey. Therefore, our survey results are shown as average scores based on common trends exhibited by the subjects as a single group.

Figure 2 shows the desired levels of interior brightness and darkness, and their relationship to behaviors. Brightness was strongly desired for such behaviors as performing office work, studying at school or in one's living room, and looking in the bathroom mirror. These behaviors generally include high-order visual tasks, and from a functional viewpoint, require brightness. Almost no darkness is required.

Behaviors that demanded darkness more than brightness were sleeping in one's room, napping in the living room, listening to music in the living room, and dining at a restaurant with one's partner. These behaviors don't really involve visual tasks, so from a functional viewpoint, require little brightness. In behaviors that actively favor darkness, brightness is not only unnecessary but disliked no doubt because bright environments include elements unconductive to these behaviors.

Such behaviors as taking a break at the office, relaxing in one's room, or listening to music in the living room do not strongly favor both brightness and darkness. Not only the behaviors themselves, but also the places where they are performed can favor brightness or darkness. For example, dining favors brightness if the setting is with one's family in the living room, or darkness if the setting is with one's partner in a restaurant. The behavior is the same but the circumstances are different. Thus, the preference for brightness or darkness depends not just on the

Table 2　Composition of the subjects

	Men	Women	sum total		age	
employee in the lighting field	24	11	35		20~29	79
employee in the other fields	12	9	21		30~39	10
student	19	32	51		40~49	16
housewife	0	14	14		50~	16
sum total	55	66	121		sum total	121

All subjects are Japanese

somewhat   very

working at the office
studying in the living room
studying at school
looking in the bathroom mirror
studying in your room
reading a newspaper in the living room
meeting with people at the office
receiving guests in the living room
talking with your family in the living room
dining with your family in the living room
dining at a restaurant in a group
washing in the bathroom
having a party in the living room
talking with friends at the school
taking a shower in the bathroom
taking a break at the office
relaxing in your room
thinking at the office
thinking in the living room
dining at a restaurant with your partner
listening to music in the living room
napping in the living room
sleeping in your room

brightness
darkness

Fig.2 Desired levels of brightness and darkness for behaviors

somewhat   very

working at the office
studying at school
studying in the living room
studying in your room
looking in the bathroom mirror
reading a newspaper in the living room
meeting with people at the office
washing in the bathroom
taking a shower in the bathroom
talking with your family in the living room
talking with friends at the school
thinking in the living room
dining with your family in the living room
thinking at the office
receiving guests in the living room
dining at a restaurant in a group
napping in the living room
relaxing in your room
sleeping in your room
taking a break at the office
having a party in the living room
listening to music in the living room
dining at a restaurant with your partner

uniform lighting
non-uniform lighting

Fig.3 Desired levels of uniform lighting and non-uniform lighting for behavior

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behavior itself, but also on the circumstances in which that behavior takes place.

Figure 3 shows levels of uniform lighting and non-uniform lighting, and the relationship of the two to various behaviors. Uniform lighting was desirable for working at the office, or for studying at home or at school, etc. These types of behaviors were characterized by high-order visual tasks and orderly deskwork and did not particularly demand non-uniform lighting.

Behaviors favoring non-uniform lighting include dining at a restaurant with one's partner, having a party in the living room, or listening to music. These tend to be relaxed behaviors that do not really need lighting uniformity. Behaviors that simultaneously demand both brightness and darkness, such as taking a break at the office, relaxing in one's room, or listening to music in the living room, strongly demand non-uniform lighting rather than lighting uniformity. To achieve both darkness and lightness in the same interior space requires non-uniform, varied lighting.

3.4 Behavior Classification and the Relationship to the Lighting Environment

The preference for brightness and darkness is not only influenced by the behavior itself, but by the circumstances. Accordingly, to gain a structural understanding of the relationship between the behavior and the type of interior lighting environment, we decided to classify behaviors into different types.
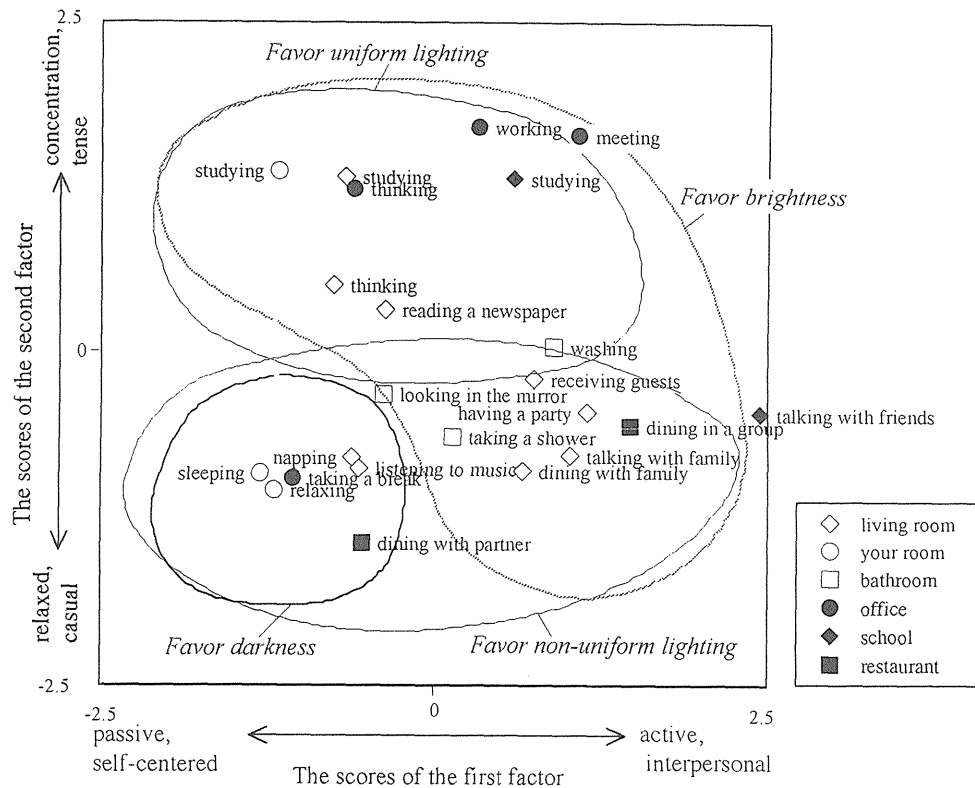
Table 3 Analysis of 14 adjectives classifying behaviors

	Factor I	Factor II	Factor III
active	0.938	0.026	-0.050
passive	-0.922	-0.071	0.125
self-centered	-0.807	-0.063	0.509
private	-0.763	-0.340	0.481
interpersonal	0.753	-0.082	-0.587
sociable	0.729	-0.131	-0.645
concentrate	-0.112	0.934	-0.141
cognitive	-0.165	0.909	-0.107
relaxed	-0.217	-0.898	-0.026
casual	-0.175	-0.859	0.405
tense	0.267	0.738	-0.579
extraordinary	0.219	0.124	-0.891
ordinary	-0.215	-0.405	0.843
respectful	0.380	0.419	-0.756
Percent Total Variance	32.1	30.7	27.7

Fig.4 Factor scores and results of the questionnaire survey

The 23 types of behavior covered in the survey questionnaire were divided into three responses for 14 items taken from Russel[13]. These responses were "I certainly think so", "I think so", and "I don't think so". The subjects were 20 architectural students.

Treating the classifications as quantitative amounts and seeking to educe an average score for all subjects, we carried out factor analysis of the 14 items. This resulted in the three factors shown in Table 3. The third factor, "ordinary-extraordinary", revealed no trends relevant

toward favoring a particular lighting environment. Therefore, we plotted the factor scores for the first (active, interpersonal vs. passive, self-centered) and the second factors (concentration, tense vs. relaxed, casual) in Figure 4 and compared the results to the questionnaire survey.

Behaviors favoring brightness fell in the first, second, and fourth quadrants, while behaviors favoring darkness fell in the third quadrant (passive, self-centered and relaxed, casual). Behaviors favoring uniform lighting mostly fell into the first and second quadrants, and can be described as "concentration, tense" behaviors. Behaviors favoring non-uniform lighting mostly fell into the third and fourth quadrants, and can be described as "relaxed, casual" behaviors. Thus, the lighting environment favored by a behavior relates to the circumstances in which the behavior takes place.

4. Degree of Lighting Non-Uniformity Favored by Behaviors

4.1 Purpose of the Experiment

The above questionnaire survey aimed to educe overall scores and does not show any data on spatial positions relating to lighting. The survey also did not show actual brightness and therefore cannot express brightness and non-uniformity as specific quantities. Therefore, to examine the distribution of the interior brightness and darkness favored by various behaviors, we conducted a reduced scale model experiment. Certainly, it is not justifiable to base general tendencies for relations between lighting non-uniformity and behaviors on the results of model studies alone, but these experiments will indicate non-uniformity to be tried in full scale studies.

We already knew that a certain level of illuminance was required for areas directly related to visual tasks. Also, visual tasks such as deskwork require uniformity of lighting. Therefore, the aspects of the experiment dealing with brightness and non-uniform lighting had no need to target deskwork, and so focused on other lighting environments.

4.2 Experiment Equipment

For the reduced scale model, a one-eighth scale was used, as shown in Figures 5. For spaces to target, we selected an office room and a home living room as they had different characteristics to the spaces covered in the questionnaire survey. For both of these spaces, the reduced scale model

represented a space 4.8m wide, 6.4m deep, and 2.5m high. In addition to various lighting fixtures, we used interior decorating materials, interior plants, and furniture to replicate the actual atmosphere of an office and living room. The contents of the room (computers, tableware, etc.) were changed depending on whether the room was set up as an office or as a living room, and care was taken that these furnishings would not greatly affect the distribution of the luminance or illuminance of the room.

The four types of lighting used in the room were general lighting, task lighting, spotlighting (local lighting to illuminate the center of the room), and wall lighting (to light the back walls). By use of a dimmer, we were able to freely turn on and adjust the general lighting that illuminated the model rooms uniformly and the spotlighting that lit local spots in the rooms (Figure 6). Or, we could turn on and adjust both the general lighting and wall lighting (Figure 7). This gave us the ability to create any distribution of brightness in the model room. The spotlighting and wall lighting were installed so they could not be on simultaneously.

4.3 Experiment Methodology

As Figure 5 shows, the subjects placed their heads in the model rooms and imagined they were seated at a desk inside the model. By controlling both the general lighting and the spotlighting (or wall lighting) for local areas, they were able to create the most suitable ambient lighting for a given behavior. Subject only imagined the given situation and did not behave actually.

A total of nine types of behavior were specified, including behaviors for the home and office. These nine behaviors were selected from among the 23 behaviors used in the questionnaire survey, and care was taken to include behaviors involving visual tasks and behaviors not involving visual tasks. The behaviors were also deliberately based on similar tasks in different environments (home and office), and care was taken to avoid bias in classifying the behaviors in Figure 4.

The subjects were 22 Japanese architectural students selected from among those who had participated in the questionnaire survey.

4.4 Experiment Results

4.4.1 Expressing Non-Uniformity in Interior Lighting

The index used to express uniformity of interior lighting is generally the uniformity ratio. That uniformity ratio is the ratio between the mean illuminance and minimum illuminance in the target plane, or the ratio between the maximum illuminance and minimum illuminance in the target plane. However, if the space includes areas with high or low local illuminance, the uniformity ratio is an expression of the intensity of light only in certain parts of the room and cannot be used as a scale adequately expressing the distribution of the room's illuminance.

Therefore, to express the non-uniformity of the interior illuminance, we measured the horizontal plane illuminance
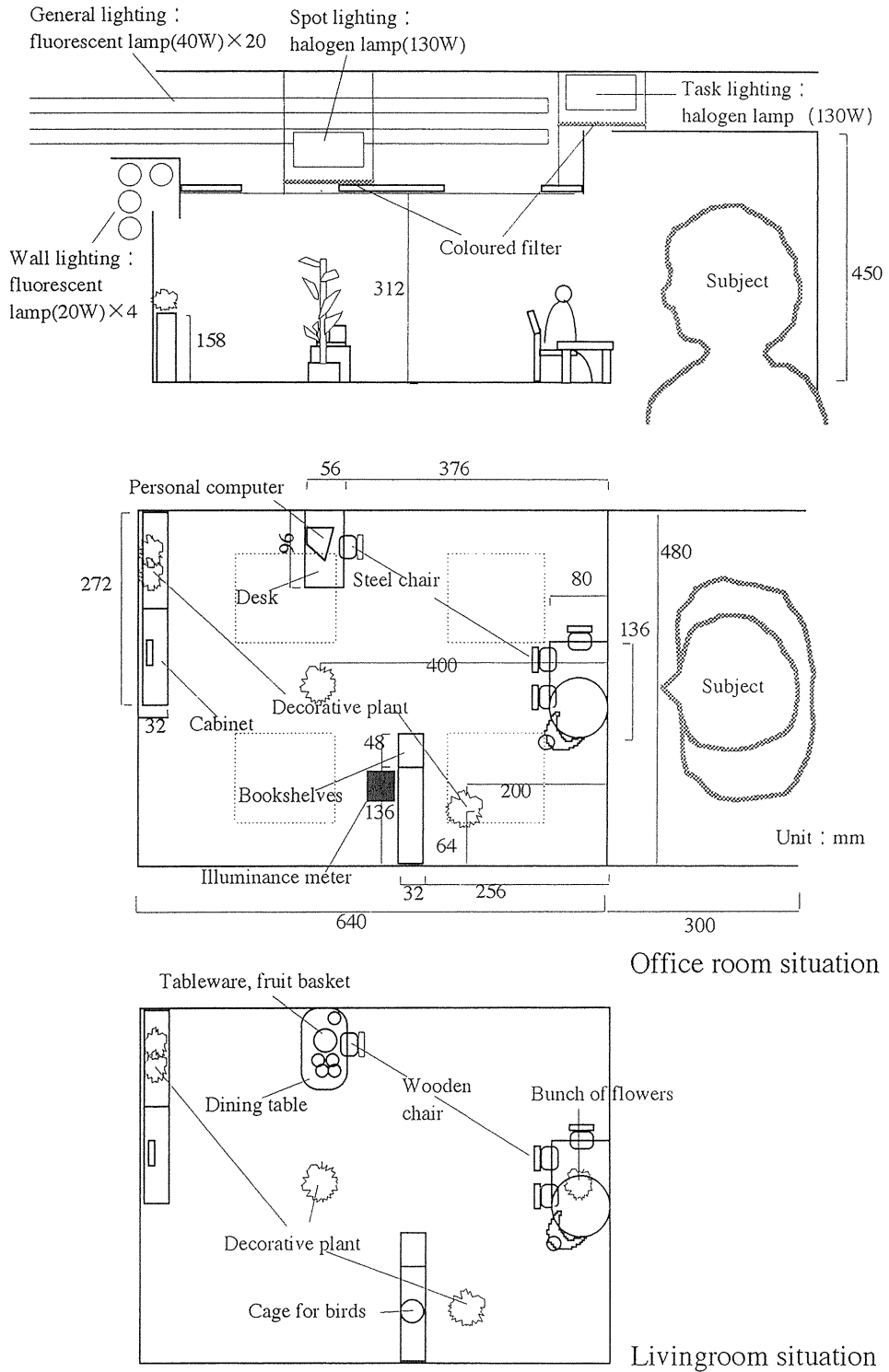
General lighting :
fluorescent lamp(40W)×20

Spot lighting :
halogen lamp(130W)

Task lighting :
halogen lamp (130W)

Wall lighting :
fluorescent
lamp(20W)×4

Coloured filter

Subject

450

312

158

Personal computer

56   376

480

272

Desk

Steel chair

80

136

400

32   Cabinet

Decorative plant

Subject

48

Bookshelves

200

136

640

300

300

32   256

64

Unit : mm

Illuminance meter

Office room situation

Tableware, fruit basket

Dining table

Wooden
chair

Bunch of flowers

Decorative plant

Cage for birds

Livingroom situation

Fig.5 The section and the plan of the experiment equipment

uniform lighting   ◀▌IIIIIIIIIIIIIIII▶   non-uniform lighting

Fig.6 Spotlighting and general lighting

uniform lighting   ◀▌IIIIIIIIIIIIIIII▶   non-uniform lighting
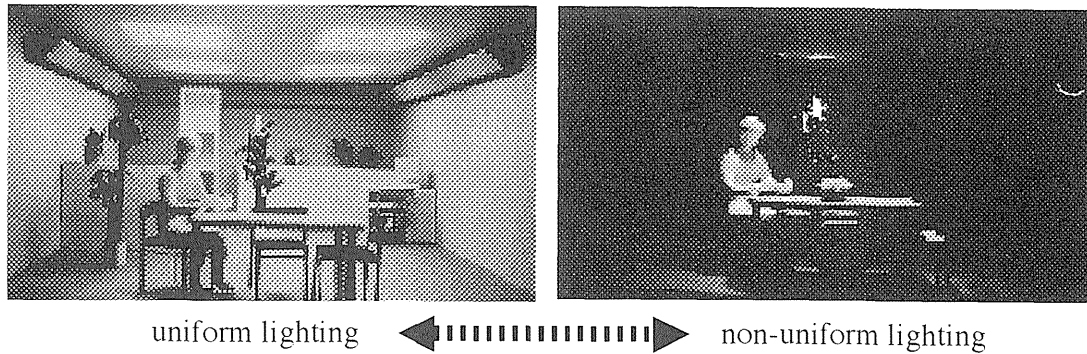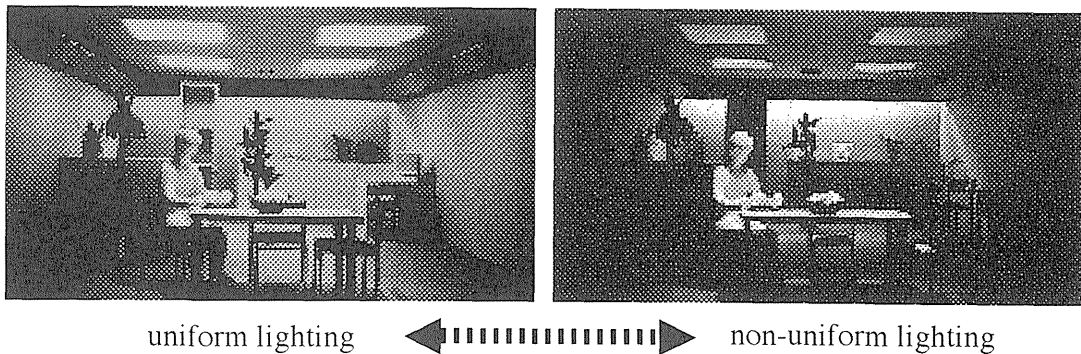
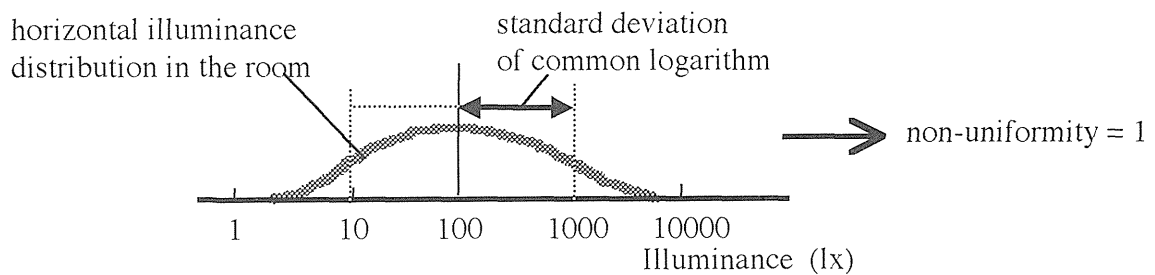Fig.7 Wall lighting and general lighting

Fig.8 Non-uniformity in interior lighting

in several parts of the room and used the standard deviation of the common logarithms of that illuminance distribution. For example, with the interior illuminance distributed as in the Fig.8 histogram, when the mean illuminance (geometrical mean) was "100 lx" and the standard deviation of the common logarithms of the illuminance was "1", the non-uniformity of the illuminance was "1". To calculate the non-uniformity of the lighting, thisexperiment measured the horizontal plane illuminance at desktop height at 26 equally distributed points throughout the model room.

4.4.2 Preferred Lighting Non-Uniformity and Personal Differences

In comparison to findings in past researches and daily lighting environments, the illumination values obtained by this experiment were very high. Using a scale model seemed to cause differences in amounts of illuminance
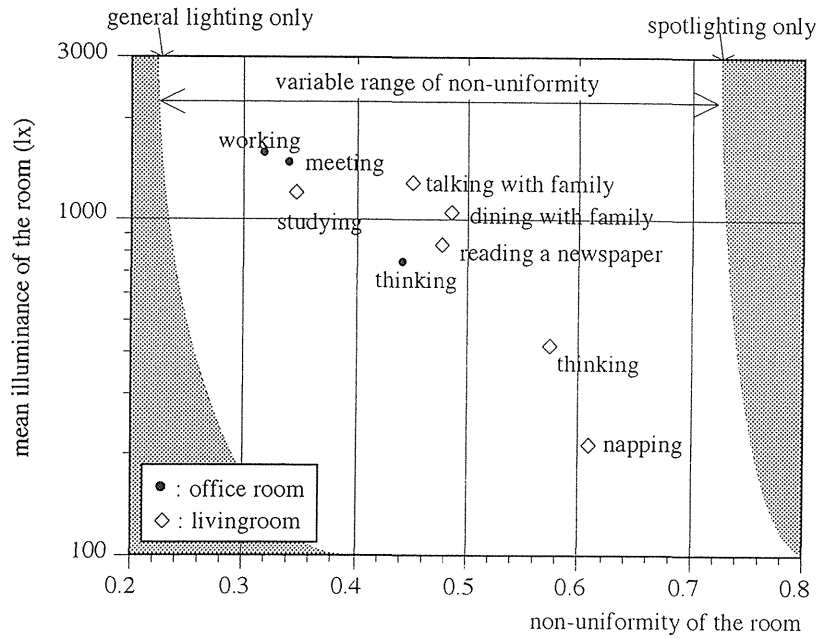
general lighting only

spotlighting only

variable range of non-uniformity

working
● meeting
◇
studying
◇ talking with family
◇ dining with family
◇ reading a newspaper
● thinking

◇ thinking

◇ napping

● : office room
◇ : livingroom

mean illuminance of the room (lx)

3000

1000

100

0.2   0.3   0.4   0.5   0.6   0.7   0.8

non-uniformity of the room

Fig.9 Preferred non-uniform lighting (spotlighting and general lighting)

general lighting only

wall lighting only

variable range of non-uniformity

● working
● meeting
studying
◇ talking with family
dining with family
◇ reading a newspaper
thinking

◇ thinking

◇ napping

● : office room
◇ : livingroom

mean illuminance of the room (lx)

3000

1000

100

0.2   0.3   0.4   0.5   0.6   0.7   0.8

non-uniformity of the room

Fig 10 Preferred non-uniform lighting (wall lighting and general lighting)

Spotlighting and general lighting
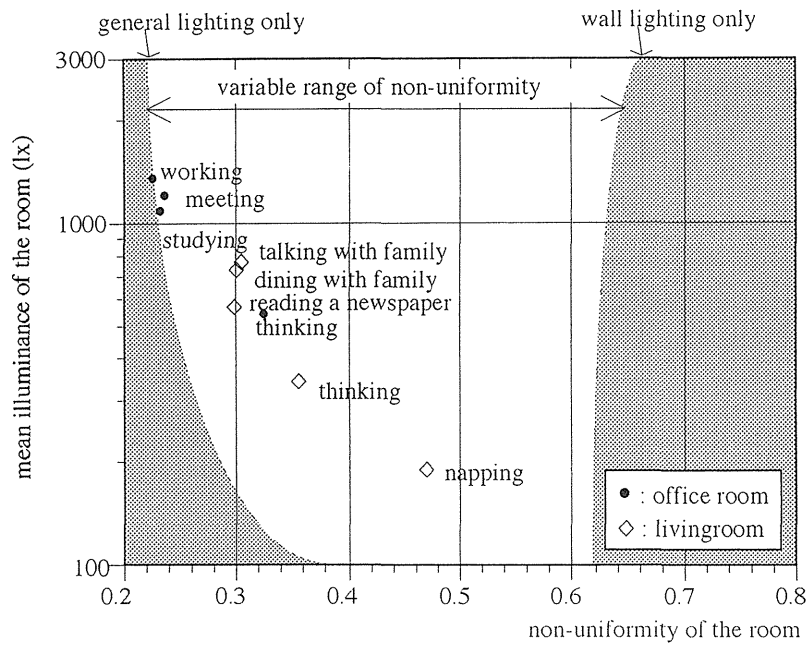

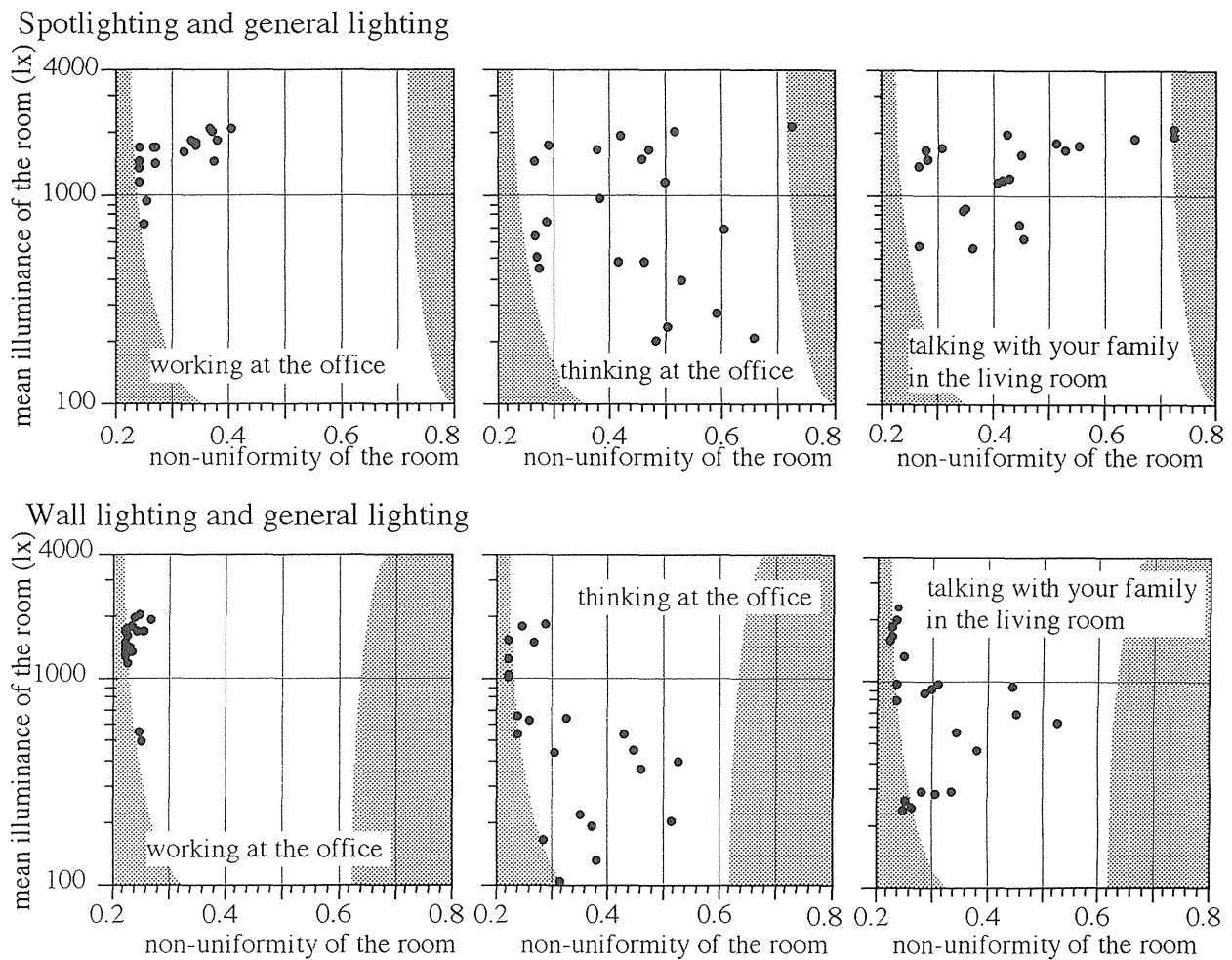Wall lighting and general lighting

Fig.11 Light control values for subjects

perceived in comparison to the full-scale model. The further work required on the flux distribution of lighting fittings to produce desirable lighting non-uniformity for behaviors. However, in a scale model experiment, we considered it was possible to interpret the relative results between the behaviors.

For spotlighting and general lighting, Figure 9 shows the mean illuminance and non-uniformity of interior lighting for various behaviors. Figure 10 shows this for wall lighting and general lighting. The values in both figures are averages for all the subjects. A comparison between Figure 9 and Figure 10 reveals that spotlighting results in higher overall non-uniformity than wall lighting. This appears to be a result of subjects' different tastes for the two lighting methods. However, the relationship of the behaviors to levels of non-uniformity and levels of mean illuminance is generally same for the two lighting methods.

Behaviors such as working at the office or meeting with people at the office favor an environment with high mean illuminance and uniform lighting. Behaviors such as thinking or napping in the living room favor ambient lighting with low mean illuminance and non-uniform

lighting.

Figure 11 shows the light control values for each behavior for the 22 subjects. Some behaviors resulted in large variations among individuals, while other behaviors resulted in little variation in the light control values selected. Behaviors like working at the office, which favor high illuminance and uniform ambient lighting, produced little variation among individuals. However, behaviors such as "thinking in one's living room", which require little illuminance and favor non-uniform ambient lighting, produced large differences among individuals in the light control values selected. The fact that few differences were recorded for the former types of behavior suggests that the atmospheres of environments be relatively fixed. The atmosphere of environments in which the latter types of behavior take place appears not fixed.

5. Relationship between Behavior Classification and Non-Uniformity Preferences

Based on behavior classifications, we investigated experimental results where non-uniform lighting was preferred. Figure 12 (upper diagram) plots the nine types

concentration, tense

working at the office

studying in the living room

meeting with people at the office

thinking at the office

thinking in the living room

reading a newspaper in the living room

passive, self-centered ← → active, interpersonal

napping in the living room

talking with your family in the living room

dining with your family in the living room

relaxed, casual

Begaviors classified
(from Figure.4)

mean illuminance of the room (lx)

non-uniformity of the room

0.3

studying in the living room

working at the office

meeting with people at the office

0.4

thinking at the office

talking with your family in the living room

reading a newspaper in the living room

0.5

dining with your family in the living room

thinking in the living room

0.6

napping in the living room

1000

200

500

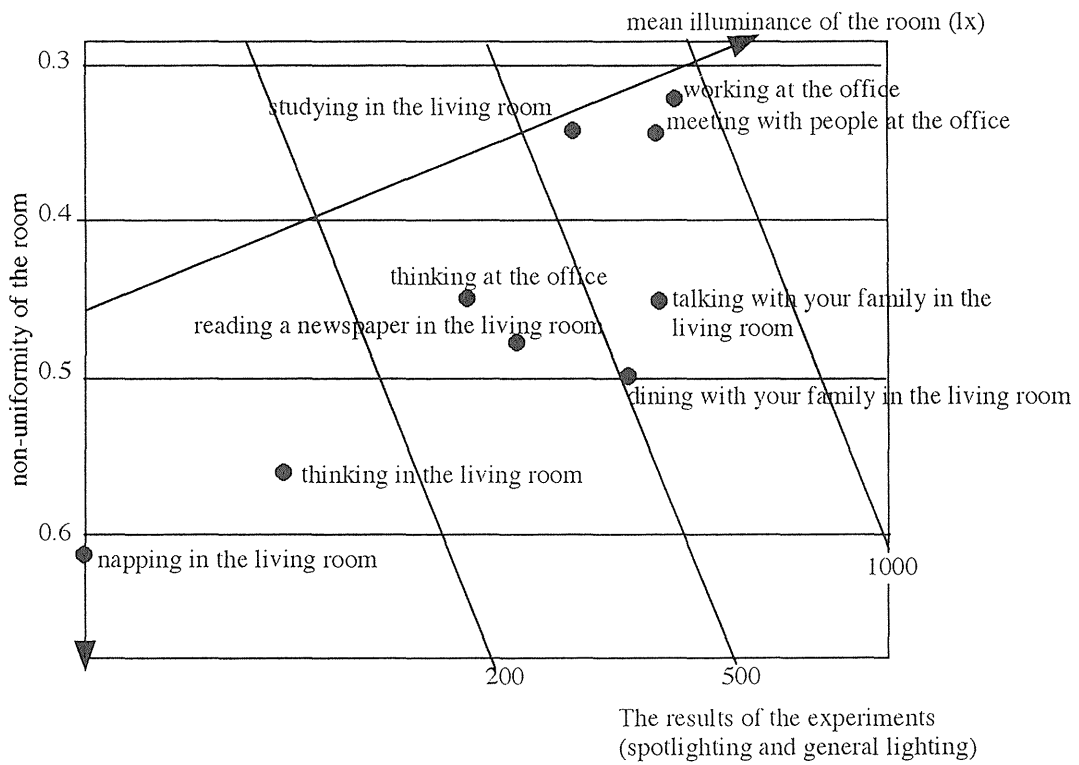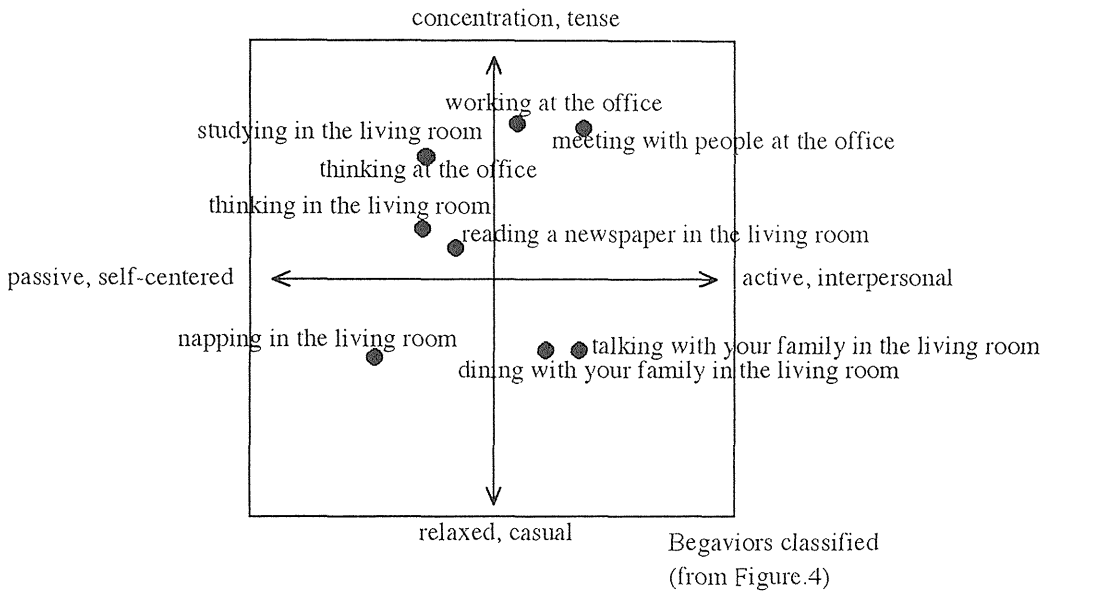The results of the experiments
(spotlighting and general lighting)

Fig.12 Relationship between behaviors classification and non-uniformity preference

of daily behaviors used in the reduced scale model experiments on two factor axes of "active, interpersonal vs. passive, self-centered" and "concentration, tense vs. relaxed, casual" values. Figure 12 (lower diagram) distributes the behaviors on an oblique axis of mean interior illuminance and non-uniformity. The relative positions of the behaviors are similar on both diagrams. In other words, the higher the preferred mean interior illuminance, the greater the number of behaviors classified as "active, interpersonal" and "concentration, tense". The higher the non-uniformity of the lighting, the greater the number of behaviors classified as "relaxed, casual". The relationship between illuminance level and illuminance non-uniformity in Figure 12(lower diagram) reflects the same trends as the relationship between the 23 types of behavior and the preferred brightness, darkness, uniform lighting, and non-uniform lighting as shown in Figure 4. While the questionnaire survey was not based on an actual lighting environment, it showed the relationship of all preferred interior illuminance distribution, not only functional illuminance required for visual tasks.

The scale model experiment used in this research investigated only a small number of behaviors (nine). However, as the classifications of these behaviors were confirmed in the results of the experiments, it should be possible to predict trends in the non-uniformity of interior lighting preferred for many other types of behavior not covered by the experiment.

6. Conclusion

This research investigates, for the first time, using a questionnaire, broad trends in the levels of brightness or lighting non-uniformity desired for different types of behavior. In questionnaire, the following three trends were revealed :
(1) "Concentration, tense" behaviors favor bright, uniform lighting.
(2) "Active, interpersonal" and "relaxed, casual" behaviors favor bright, non-uniform lighting.
(3) "Passive, self-centered" and "relaxed, casual" behaviors favor dark, non-uniform lighting.

Next, we attempted to express the quantitative distribution of levels of lighting and their relationship to behavior, by reduced scale model experiments. The experiment results and the questionnaire survey results were similar; clearly, we can classify behaviors and make quantitative inferences about the illuminance non-uniformity preferred for various behaviors.

However, no specific conclusions could be drawn regarding preferred luminance levels and lighting non-uniformity for behaviors in this paper. It is recommended that the relationships of illuminance and lighting non-uniformity given in Figure 9 and 10 should be investigated in some full-scale installations. Preferably, experiment should be conducted in office and living room where occupants response actually to the subject's behavior.

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