Paper**Evaluation of Lighting Environment Using Conjoint Analysis (Part 1)
— for the Case of Office —****Rikuo MURAMATSU**

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ABSTRACT

In this study, evaluation of the lighting environment in offices, which consists of various attributes that are trade-offs, is conducted using the Conjoint Analysis, common in the field of marketing research. The attributes are illuminance, lighting distribution, glare, design, cost, usage of daylight, and recycling (229 subjects participated.) As a result, preferences of office lighting were quantitatively externalized. In other words, part-worth utilities and importance levels of attributes for office lighting displayed general characteristics of all subjects. Moreover, a method of research by grouping the subjects according to the importance levels of attributes or according to their characteristics is proved to be valuable for better understanding the preferences of office lighting.

KEYWORDS: conjoint analysis, evaluation of lighting environment, quality of lighting environment**1. Introduction**

When asked, "What is a high quality lighting environment?" Some people may respond, "Brighter the better," while others may say, "No, a gorgeous lighting environment with shades is preferable." In other words, factors, which determine the quality of lighting environment, vary depending on the evaluator's perspective, namely, activities to be conducted under the targeted lighting environment¹⁾, the evaluator's sense of values²⁾, and social values, such as impact on global environment³⁾.

Previous studies on lighting environment evaluation^{4) 5)} were made only within the scope of each individual evaluation perspective. As a result, each of the individual evaluation perspectives yielded greater precision and understanding. However, these studies alone do not enable the reviewing of mutual relationships among different evaluation perspectives⁶⁾. In other words, it is not possible to judge the quality of a lighting environment when one evaluation perspective is a trade-offs of another in actual lighting design. For example, it is extremely difficult to judge the quality of a lighting environment aimed at achieving both "bright as possible" and "environmentally conscious". Studies on lighting environment evaluation in the past have not sufficiently taken into account the mutual relationships among various evaluation perspectives. In order to develop evaluation of lighting environments, it is necessary to conduct studies that take this issue into account.

This study adopts the conjoint analysis (to be explained in detail in the next chapter), a highly reputable method to analyze the mutual relationships among different attributes often used in the field of marketing research, so that both the different evaluation perspectives and their trade-offs relationships are taken into account. Furthermore, based on the above analysis, this study aims at resolving the problems in lighting environment evaluation and seeking an evaluation method for the next generation.

2. Conjoint Analysis

In the field of marketing research studies, Compositional Approach and Decompositional Approach have been mainly used as methods to predict consumer preference behavior.

The former method, Multi-attribute Attitude Approach, is to evaluate the satisfaction level of consumers to a particular product, by measuring part-worth utilities^{1*)} of each attribute based on the subject's direct evaluation of a particular attribute in terms of importance level and by calculating the weighted sum of part-worth utilities of each attribute. The latter method is to seek the importance level of each attribute of the product by analyzing the total evaluation of the product as a whole and Conjoint Analysis is its representative. Conjoint analysis is a method to estimate the importance level of each attribute based on the subject's total evaluation of the object, which is assumed to be a combination of various attributes (variables).

^{1*)} Part-worth utilities are subjective measurements representing the level of influence that each attribute of the product gives to the level of satisfaction gained from purchasing behavior.

Table 1 Attributes and levels.

1. Illuminance	(1) Newspaper prints are highly readable and it feels extremely bright (1500 lx) (2) Newspaper prints are generally readable and it feels rather bright (750 lx) (3) Newspaper prints are generally readable (400 lx) (4) Newspaper prints are generally readable but it feels rather dark (200 lx)
2. Lighting distribution	(1) The space is uniformly illuminated (minimum illuminance/average illuminance=0.8) (2) The space has slightly dark areas (minimum illuminance/average illuminance=0.5) (3) The space has significantly dark areas (minimum illuminance/average illuminance=0.2)
3. Glare from lighting equipment and window	(1) Glare is significantly noticeable (Glare caused by a ceiling mounted luminaire with naked fluorescent lamps) (2) Glare is somewhat noticeable (Glare caused by a recessed luminaire using fluorescent lamps with no louvers) (3) Glare is barely noticeable (Glare caused by a recessed luminaire using fluorescent lamps with white louvers) (4) Glare is not noticeable at all (Glare caused by a recessed luminaire using fluorescent lamps with mirror finished louvers)
4. Design	(1) A lighting environment that is well designed (2) A lighting environment without particular design features
5. Cost	(1) Total cost is low compared to average offices (0.8 times the average cost) (2) Total cost is the same as average offices (3) Total cost is high compared to average offices (2 times the average cost)
6. Usage of daylight	(1) Aggressive use of daylight is considered as a distinctive feature (2) Usage of daylight is not particularly considered
7. Recycling	(1) High concern for recycling effects (2) No particular concern for recycling effects

With regards to Compositional Approach (Multi-attribute Attitude Approach), it is said that, the appropriateness of measurements are problematic⁷⁾ and subject's responses can easily become biased⁸⁾, as subjects are requested to evaluate the importance level of individual attributes. In fact, in actual purchasing behavior, products are evaluated only by specific attributes or preferences that are not always determined by clear reasons^{7) 9)}.

On the other hand, through Decompositional Approach, represented by conjoint analysis, more reliable effectiveness values can be obtained, because subjects are requested to evaluate the product in a situation similar to actual purchasing behavior⁹⁾. In this regard, conjoint analysis is being widely used to analyze consumer preference behavior in the field of marketing^{10) 11)}. (Refer to basic publications^{12) 13)} for outline of conjoint analysis)

Examples of conjoint analysis being used in environment-related evaluations are preliminary evaluation of a ski resort facility plan by Ujigawa⁸⁾, survey on preference behavior in commercial sports facilities by Ninomiya¹⁴⁾, and assessment of the recycling value of various products by Kuriyama¹⁵⁾. These previous studies prove that conjoint analysis is an effective method, not only in the field of marketing, but also in environment-related evaluations, as conjoint analysis provides useful information.

Neither Compositional Approach nor Decompositional Approach has yet been applied to lighting environment evaluation. Since Decompositional Approach has been proven to be superior to Compositional Approach in other fields of evaluation, it can be said that applying Decompositional Approach, particularly conjoint analysis which has a good track record, to lighting environment evaluation would serve as an effective gauge.

Fig. 1 Procedures of conjoint analysis.

conducted (without using conjoint analysis). An outline of the procedure is described in Fig. 1.

First, attributes, or the elements constituting the office lighting environment and their levels were determined. With reference to previous studies^{4) 5)}, seven attributes and a total of 20 levels were established (Table 1). The attributes relating to lighting plan are, illuminance, lighting distribution, the glare from lighting equipment or window, and design. The attribute relating to the economic element is solely cost and those relating to impact on global environment are usage of daylight and recycling. In order to review the appropriateness of the attributes and the levels selected for this study, several preliminary surveys were conducted with experts in the field of lighting who participate in Illuminating Engineering Society of Japan's "Research & Investigation Committee on Qualitative Evaluation of Office Lighting (CQEO)" and with non-experts.

Next, profiles that are the combinations of these attributes were prepared. Theoretically, $4 \times 3 \times 4 \times 2 \times 3 \times 2 \times 2 = 1152$ different combinations exist out of the seven attributes and 20 levels selected for this study. However, based on the theory of orthogonal table and thus by letting all attributes and all levels be included in the same probability, 60 profiles were randomly extracted and shown to the subjects. Interactive computer interview^{2*)} was adopted as the research method. Data on preference order from each subject

3. Procedure

In this study, conjoint analysis is applied to lighting environment for offices, as there are a number of evaluations

^{2*)} Interview Land ver 1.0 of Kozo Keikaku Engineering Inc. was used.

Which of the two offices would you choose for your new office?

<p>Newspaper prints are highly readable and it feels extremely bright (1500 lx)</p> <p>The space is uniformly illuminated (minimum illuminance / average illuminance=0.8)</p> <p>Glare is significantly noticeable (Glare caused by a ceiling mounted luminaire with naked fluorescent lamps)</p> <p>A lighting environment that is well designed</p> <p>Total cost is low compared to average offices (0.8 times the average cost)</p> <p>Aggressive use of daylight is considered as a distinctive feature</p> <p>High concern for recycling effects</p>	<p>Newspaper prints are generally readable and it feels rather bright (750 lx)</p> <p>The space has slightly dark areas (minimum illuminance / average illuminance=0.5)</p> <p>Glare is somewhat noticeable (Glare caused by a recessed luminaire using fluorescent lamps with no louvers)</p> <p>A lighting environment without particular design features</p> <p>Total cost is the same as average offices</p> <p>Usage of daylight is not particularly considered</p> <p>No particular concern for recycling effects</p>
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definitely choose
the left
would rather
choose the left
would rather
choose the right
definitely choose
the right

1	2	3	4
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proceed to the next step

Fig. 2 A computer display example of questionnaire.

were collected. Floppy disks installed with the necessary program to conduct this interview were widely distributed to lighting manufacturers, general construction companies and architectural offices via members who participate in CQEO. Later, the floppy disks with responses of the subjects were returned and responses of 229 subjects were found to be effective. Fig.2 shows an example of the computer displays that were presented to the subjects. Subjects were requested to compare two profiles and indicate their preference order on a scale of 1 to 4 (1= definitely choose the left, 2=would rather choose the left, 3=would rather choose the right, and 4=definitely choose the right). Data of preference orders were thus gathered.

Finally, part-worth utilities, which indicate the subjects' importance level of each attribute and preference level of each level for all attributes, are calculated through data that were obtained above. Specifically, part-worth utilities are calculated based on simple regression pair comparison

method^{3*}. Importance level of each attribute is calculated by dividing variance of part-worth utilities of each level of attribute by whole variance. Furthermore, in addition to items relating to conjoint analysis, the subjects' demographic information (age, gender, occupation, specialization, etc.) are evaluated and cross analyses are conducted between these results and those of conjoint analysis in order to grasp more precisely the structure of preference behavior.

4. Result

4.1 Characteristics of the Subjects

The subjects for this study are 161 males and 68 females between the ages of 21 and 63, for a total of 229 (average age is 32.5). Tables 2 to 6 describe their occupation, job description, specialization, qualifications and educational background. Therefore, it can be said that the subjects sampled for this study were broad and unbiased.

^{3*} Japanese version of CVA system of Kozo Keikaku Engineering Inc. was used. In some past studies, part-worth utilities are standardized so that the sum of part-worth utilities for all attributes for each subject becomes zero, and the sum of the 2nd power of these values becomes one. In this study, in addition to the above method, the differences between each of the above values and the minimum of the values for the respective attributes are calculated, and another standardization is executed so that the sum of part-worth utilities for all attributes becomes 700.

Table 2 Occupations (Multiple answers allowed).

Occupations	Number of the subjects
electric business	4
electric construction	4
lamp/lighting equipment related manufacturing	59
other manufacturing businesses	1
research business	21
facility maintenance business	0
construction business	77
real estate business	0
distribution/transportation business	0
printing/publishing business	1
school/education related	10
hospital/medical related	0
lamp/lighting equipment related sales	10
design/decoration related	21
lighting equipment design business	31
architectural design business	13
others	22
no occupation	5

Table 3 Types of occupation (Multiple answers allowed).

Types of occupation	Number of the subjects
corporate executive	3
research/development	56
maintenance/design/planning	67
manufacturing	1
SE/marketing/sales	21
editing	2
general administration	21
quality assurance/control	1
coordinator	4
consultant	16
designer	29
education	3
student	27
others	14

Table 4 Specialty (Multiple answers allowed).

Specialty	Number of the subjects
light source/circuit	5
light related material/device	2
other light related fields	3
light/radiation application	4
visual psychology/visual physiology	22
lighting theory	13
actual lighting	36
lighting environment design/evaluation	69
photometry/colorimetry/radiometry	3
lighting related laws and regulations/design	14
art/design	32
education/lighting promotion	4
others	99

Table 5 Qualifications (Multiple answers allowed).

Qualifications	Number of the subjects
certified architect (1st degree)	39
certified architect (2nd degree)	10
certified architect for wooden houses	0
interior planner	2
interior coordinator	11
color coordinator (1st degree)	1
color coordinator (2nd degree)	6
color coordinator (3rd degree)	3
kitchen specialist	0
certified realtor	7
certified lighting specialist	44
lighting consultant	51
civil engineering and supervisor (1st degree)	1
civil engineering and supervisor (2nd degree)	0
building construction contractor and supervisor (1st degree)	6
building construction contractor and supervisor (2nd degree)	0
certified plumbing contractor and supervisor (1st degree)	5
certified plumbing contractor and supervisor (2nd degree)	0
certified electrical engineer (1st degree)	14
certified electrical engineer (2nd degree)	7
certified landscaper (1st degree)	0
certified landscaper (2nd degree)	0
construction machinery contractor and supervisor (1st degree)	0
construction machinery contractor and supervisor (2nd degree)	0
certified accountant for construction business	1
electrical engineering chief (2nd degree)	0
electrical engineering chief (3rd degree)	3
building facility manager	5
water systems engineering contractor	0
electrical inspector (1st degree)	0
electrical inspector (2nd degree)	0
electrical inspector (3rd degree)	4
technician	6
no qualifications	91

4.2 Verification of Appropriateness of Estimated Effectiveness Value

In order to review the appropriateness of estimated effectiveness values, the subjects' preference orders of the profiles and the quality of all estimated effectiveness values

are verified by using Kendol's rank correlation coefficient τ_a . As a result, τ_a is 0.92, which is extremely high, and thus part-worth utilities obtained in this study can be said to possess high appropriateness.

⁴ Kendol's rank correlation coefficient τ_a is calculated in the following procedure.

1. Align the ranking value X_i in the order of small to large ($i=1,2,\dots,n$)
2. Count the number of Y_j ($j < i$) that is larger than X_i .
- 3.

$$\tau_a = \frac{4}{n(n-1)} \times m-1$$

Table 6 Educational background (Multiple answers allowed).

Educational background	Number of the subjects
architecture	93
civil engineering	2
environmental engineering	21
person-environment	24
system engineering	5
electrical engineering/electronics	52
communication engineering	3
control engineering	5
mechanical engineering	10
agriculture	1
science	6
home economics	5
residence	15
interior	18
law	5
economy	7
literature	6
sociology	5
cultural anthropology	3
psychology	9
others	38

4.3 Evaluation Structure of Office Lighting Environment
Results of part-worth utilities and the importance level of attributes for all subjects will be closely examined (Fig. 3 and 4). As shown in Fig.4, the importance level of attributes vary in the order of illuminance (25.3%), glare (23.3%), cost and lighting distribution (12.1%), usage of daylight (11.2%), recycling (8.6%) and design (7.5%). This shows that attributes of lighting performance, such as illuminance and glare, are generally considered more important than other attributes when evaluating lighting environment of offices.

With regards to illuminance, which is the attribute evaluated as most important, part-worth utility of that at 200 lx is the smallest and part-worth utilities increase as illuminance increases until it peaks out at 750 lx. However, part-worth utility of illuminance at 1500 lx is reduced to almost the same level as that of illuminance at 400 lx. Moreover, because part-worth utility at 200 lx is not 0 (but 8.7%), it can be said that there are some subjects who did not evaluate 200 lx as being most unfavorable.

With regards to glare, in the condition "glare is significantly noticeable," part-worth utility is extremely small, and it can be seen that as glare becomes less noticeable, part-worth utilities tend to increase. However, part-worth utilities do not increase drastically when changing the condition from "glare is barely noticeable" to "glare is not noticeable at all." Moreover, because part-worth utility at "glare is significantly noticeable" is not 0 (but 6.2%), it can be said that there are some subjects who did not evaluate "glare is significantly noticeable" as being most unfavorable.

Fig. 3 Part-worth utilities of all subjects.

Fig. 4 Attribute importance of subjects(%).

As to cost, because part-worth utility in the condition "total cost is high" is 0, it can be said that all subjects evaluated this condition as being most unfavorable in the cost attribute. Part-worth utilities increase as the total cost shifts from high to low.

For lighting distribution, part-worth utilities increase as lighting distribution becomes more uniform. However, the difference between part-worth utility in "space is uniformly illuminated" and "space has slightly dark areas" is small. Moreover, because part-worth utility in "space has significantly dark areas" is not 0 (but 9.4%), it can be said that there are some subjects who did not evaluate this condition as being most unfavorable.

With regards to usage of daylight, recycling and design, because part-worth utilities change accordingly as the level of each attribute changes, consideration of these attributes will positively influence the evaluation of an office lighting environment.

Table 7 Comparison of part-worth utilities by segments of attribute importance.

levels of attributes	segments according to the most important attributes						
	illuminance N=93	ighting distribution N=9	glare N=76	design N=7	cost N=16	usage of daylight N=19	recycling N=9
Newspaper prints are highly readable and it feels extremely bright (1500 lx)	100.4	46.5	38.7	56.5	30.6	49.8	48.5
Newspaper prints are generally readable and it feels rather bright (750 lx)	129.1	54.0	53.8	27.0	43.4	41.3	33.8
Newspaper prints are generally readable (400 lx)	85.1	72.9	49.1	62.7	29.3	50.0	25.7
Newspaper prints are generally readable but it feels rather dark (200 lx)	5.2	24.1	8.6	4.9	6.6	17.8	17.5
The space is uniformly illuminated (minimum illuminance/average illuminance=0.8)	36.4	77.0	35.6	12.8	23.7	35.3	26.6
The space has slightly dark areas (minimum illuminance/average illuminance=0.5)	25.4	102.5	29.5	18.9	18.4	31.3	23.5
The space has significantly dark areas (minimum illuminance/average illuminance=0.2)	6.4	35.9	8.4	9.6	8.4	16.1	10.8
Glare is significantly noticeable (Glare caused by a ceiling mounted luminaire with naked fluorescent lamps)	7.8	14.4	1.2	6.3	10.6	9.1	8.6
Glare is somewhat noticeable (Glare caused by a recessed luminaire using fluorescent lamps with no louvers)	46.3	24.3	89.5	42.5	38.1	39.4	43.3
Glare is barely noticeable (Glare caused by a recessed luminaire using fluorescent lamps with white louvers)	57.9	43.1	111.9	54.7	42.7	46.5	41.3
Glare is not noticeable at all (Glare caused by a recessed luminaire using fluorescent lamps with mirror finished louvers)	52.4	42.4	121.3	58.9	44.8	44.5	56.1
A lighting environment that is well designed	16.8	39.5	27.1	134.0	18.0	39.3	53.7
A lighting environment without particular design features	5.2	7.5	4.1	0.0	5.5	0.6	0.0
Total cost is low compared to average offices (0.8 times the average cost)	39.4	34.8	40.8	51.9	171.6	50.5	48.7
Total cost is the same as average offices	26.2	11.3	27.7	44.7	126.6	28.9	27.0
Total cost is high compared to average offices (2 times the average cost)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aggressive use of daylight is considered as a distinctive feature	30.9	42.8	37.8	73.7	37.3	149.1	66.9
Usage of daylight is not particularly considered	2.6	4.6	2.0	0.0	4.1	0.0	2.2
High concern for recycling effects	22.5	18.2	30.0	32.6	37.4	41.3	165.8
No particular concern for recycling effects	4.0	4.0	3.0	8.1	2.8	9.1	0.0

Note: Figures in the table are part-worth utilities.

Table 8 Comparison of the levels of importance by segments of attribute importance.

attributes	segments according to the most important attributes						
	illuminance N=93	ighting distribution N=9	glare N=76	design N=7	cost N=16	usage of daylight N=19	recycling N=9
illuminance	37.6	20.0	18.2	15.9	13.3	16.0	12.1
lighting distribution	12.1	32.1	11.8	5.6	8.1	11.1	8.2
glare	19.5	14.6	34.7	16.3	14.8	14.6	14.7
design	5.5	10.0	7.6	27.6	5.3	8.1	10.3
cost	10.2	7.7	10.0	10.9	40.0	10.1	9.7
usage of daylight	8.4	10.6	9.7	15.1	9.3	30.0	13.3
recycling	6.7	4.9	8.0	8.5	9.2	10.1	31.8

4.4 Reviewing Evaluation Structure by Segmenting the Importance Level of Attributes

In this section, subjects are classified into segments according to their most influential attribute. Then, the difference in evaluation structure of each segment is reviewed. Table 7 shows the results of part-worth utilities of each level from each of the seven segments. Table 8 indicates the importance level of each attribute by the above segments. Part-worth utilities in Tables 7 and 8 are the average of part-worth utilities of subjects in the same segment.

The number (N) of subjects^{5*} comprising each segment, when ranking from top to bottom, is illuminance ($N=93$), glare ($N=76$), usage of daylight ($N=19$), cost ($N=16$), lighting distribution ($N=9$), recycling ($N=9$) and design ($N=7$). This order roughly coincides with the order of the composition ratio in the importance level of attributes of all subjects shown in Fig. 4. However, the number of subjects in the segment of lighting not as many as it can be expected from the ranking of the composition ratio of lighting distribution in the importance level of attributes of all subjects. The reason for this is thought to be that lighting distribution is the second or third most important attribute for many subjects.

Next, the importance level of each of the seven segments is reviewed.

For the segment whose most influential attribute is illuminance, because the importance level of illuminance for the subjects in this segment is higher than the level for all subjects (Fig.3 and 4), the importance level of each of the remaining attributes except for lighting evenly lower than that of all subjects. Generally, subjects in this segment can be said to place importance on illuminance, glare and lighting distribution. The difference in tendency of all subjects and this segment with regards to part-worth utilities of levels of each attribute can be seen when comparing part-worth utility for illuminance of 200 lx and that of 400 lx. Also for this segment, part-worth utility for illuminance of 1500 lx is greater than that of 400 lx, and part-worth utility for "glare is not noticeable at all" is smaller than that for "glare is barely noticeable", while they are not for all subjects.

For the segment whose most influential attribute is glare, similar to the case above, because the importance level of glare is higher for subjects in this segment than the level for all subjects, the importance level of each of the remaining attributes except for lighting distribution and design is evenly lower than that of all subjects. Generally, subjects in this segment can be said to place importance on glare, illuminance, and lighting distribution. The remarkable characteristics of this segment with regards to part-worth utilities of levels of each attribute are that part-worth utility for illuminance of 1500 lx is smaller than that for 400 lx, and that the difference of part-worth utilities between "glare is

significantly noticeable" and "glare is somewhat noticeable" is large. The latter indicates that the subjects of this segment are sensitive to the change in glare levels.

For the segment whose most influential attribute is cost, it can be assumed that the subjects are evaluating the lighting environment only by the level of cost. This assumption can be made due to the fact that part-worth utilities for "total cost is the same as an average office" and "total cost is low compared to an average office" are both exceeding 100. The characteristics of the subjects of this segment seem to be "practical", as their importance level of glare is higher than that of illuminance.

For the segment whose most influential attribute is usage of daylight, because the importance level of daylight usage is high, the importance level of each of the remaining attributes except for recycling and design is low. Particularly, the decrease in illuminance and glare is significant. Importance level of recycling is higher than that for all subjects and thus it can be assumed that subjects of this segment place importance on concern for global environment such as recycling. The features of this segment can be observed in the results of part-worth utilities of levels of each attribute. Namely, part-worth utility for 750 lx is smaller than those for 400 lx and 1500 lx, part-worth utility for "glare is not noticeable at all" is smaller than that for "glare is barely noticeable," and part-worth utility for 200 lx and part-worth utility for "glare is significantly noticeable" are both greater than those for all subjects. This indicates that the subjects of this segment are more tolerant toward lighting environments that are too dark, too bright or glary.

For the segment whose most influential attribute is lighting distribution, because the importance level of lighting distribution is high, the importance level of each of the remaining attributes except for design is low. Particularly, the decrease in glare and recycling is significant. The tendency of this segment is observed in the fact that part-worth utility for "the space has slightly dark areas" is greater than that for other levels of the same attribute, and that part-worth utility for 400 lx is greater than that for other levels of the illuminance attribute. Furthermore, part-worth utility for "space has significantly dark areas" and for 200 lx are great compared to that of all subjects. It can be assumed from these results that subjects in this segment do not prefer a too homogeneous nor too bright lighting environment, and place emphasis on design.

For the segment whose most influential attribute is recycling, because of the fact that part-worth utility for "taking account of recycling effect is considered as a distinctive feature" is exceeding 150, the subjects place extreme importance on the attribute of recycling when evaluating a lighting environment. It can also be said that recycling and usage of daylight possess aspects that are common in terms of value attached to global environmental concerns, as the importance level for the attribute of daylight

^{5*} The total of subjects in the segments is not equal to the total of all subjects since the subjects ($N=9$) whose number of attributes with highest level of importance was more than two are excluded.

Table 9 Comparison of part-worth utilities by characteristics of subjects.

levels of attributes	gender		characteristics of subjects occupation and function			educational background	
	male N=161	female N=68	designer N=35	engineer N=87	others N=29	architectural N=117	non-architectural N=112
Newspaper prints are highly readable and it feels extremely bright (1500 lx)	68.8	57.2	49.4	66.0	78.5	55.2	76.0
Newspaper prints are generally readable and it feels rather bright (750 lx)	84.9	71.8	74.3	87.2	78.3	72.0	90.5
Newspaper prints are generally readable (400 lx)	66.3	54.5	60.7	61.3	50.6	58.4	67.5
Newspaper prints are generally readable but it feels rather dark (200 lx)	8.6	8.9	10.2	6.0	8.5	8.2	9.2
The space is uniformly illuminated (minimum illuminance/average illuminance=0.8)	36.3	34.1	40.2	34.3	32.6	35.0	36.4
The space has slightly dark areas (minimum illuminance/average illuminance=0.5)	30.0	28.4	30.3	32.2	27.3	28.2	31.0
The space has significantly dark areas (minimum illuminance/average illuminance=0.2)	9.5	9.3	11.3	9.1	9.0	7.0	11.9
Glare is significantly noticeable (Glare caused by a ceiling mounted luminaire with naked fluorescent lamps)	5.3	8.3	5.2	2.1	13.6	4.7	7.7
Glare is somewhat noticeable (Glare caused by a recessed luminaire using fluorescent lamps with no louvers)	53.5	47.6	55.3	62.2	38.2	52.0	51.5
Glare is barely noticeable (Glare caused by a recessed luminaire using fluorescent lamps with white louvers)	71.9	74.0	71.1	79.6	51.0	74.3	70.6
Glare is not noticeable at all (Glare caused by a recessed luminaire using fluorescent lamps with mirror finished louvers)	67.3	89.9	82.3	73.0	74.3	77.0	70.9
A lighting environment that is well designed	27.6	29.2	40.1	27.1	28.0	34.8	21.0
A lighting environment without particular design features	4.2	4.1	2.3	4.1	4.7	3.8	4.5
Total cost is low compared to average offices (0.8 times the average cost)	50.7	50.3	43.9	44.4	58.5	58.7	42.1
Total cost is the same as average offices	34.4	32.9	27.4	31.6	40.5	40.3	27.3
Total cost is high compared to average offices (2 times the average cost)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aggressive use of daylight is considered as a distinctive feature	41.8	58.1	58.4	41.5	49.9	50.2	42.9
Usage of daylight is not particularly considered	2.8	0.9	0.8	2.1	4.7	1.4	3.1
High concern for recycling effects	31.4	37.8	34.1	31.2	48.4	36.1	30.4
No particular concern for recycling effects	4.6	2.6	2.9	5.0	3.4	2.6	5.4

Note: Figures in the table are part-worth utilities.

Table 10 Comparison of the levels of importance by characteristics of subjects.

attributes	gender		characteristics of subjects occupation and function			educational background	
	male N=161	female N=68	designer N=35	engineer N=87	others N=29	architectural N=117	non-architectural N=112
illuminance	26.8	21.8	21.8	26.1	24.2	22.1	28.7
lighting distribution	12.5	11.1	12.3	12.5	11.5	11.2	13.0
glare	22.6	25.0	23.9	24.4	21.4	23.4	23.2
design	7.4	7.6	9.7	7.5	7.0	8.8	6.1
cost	12.2	11.9	10.3	10.9	13.2	13.9	10.2
usage of daylight	10.3	13.3	13.6	10.1	11.6	11.8	10.5
recycling	8.3	9.1	8.4	8.5	11.2	8.9	8.2

usage for this segment is high compared with the results of all subjects.

For the segment whose most influential attribute is design, the importance level of the attributes of design and usage of daylight is high compared to the results of all subjects, and the importance level of the other attributes are low. The distinctive characteristic of this segment is that part-worth utility for 750 lx is clearly low compared to part-worth utilities for 1500 lx and 400lx, while part-worth utility for 750 lx is not for other segments. This may be describing their resistance toward a textbook-like thinking that "the standard illuminance level for offices is 750 lx."

4.5 Reviewing the Evaluation Structure by Subjects' Characteristics

In this section, it will be reviewed how characteristics of subjects, such as gender (male or female), occupation and function (designer, engineer or others) and educational background (architectural or non-architectural) affect evaluation. Table 9 shows the results of part-worth utilities by subjects' characteristics. Table 10 shows the results of the importance level by subjects' characteristics. Figures in these tables are the average of part-worth utilities for the subjects in the same group.

First, when observing gender difference, the most influential attribute is illuminance for males, whereas it is

glare for females. Part-worth utility for "glare are not noticeable at all" is smaller than that for "glare is barely noticeable" for males, but is greater for females. Furthermore, the results show that females tend to place more emphasis on values attached to global environmental concerns such as usage of daylight or recycling than males. This supports the past study¹⁷⁾, which clarifies the fact that females tend to take global environmental concerned actions on a daily basis more than males.

Next, with regards to occupational and functional differences (designer, engineer or others), the importance levels for both cost and recycling are high for others compared to engineers and designers, and the importance levels of both design and usage of daylight are high for designers compared to others and engineers. Also, part-worth utility for 1500 lx differs significantly according to occupation and function, such as, 1. part-worth utility for 1500 lx is almost equal to part-worth utility for 750 lx for others, 2. part-worth utility for 1500 lx is smaller than that for both 750 lx and 400 lx for designers, 3. part-worth utility for 1500 lx is smaller than that for 750 lx and greater than that for 400 lx for engineers. Furthermore, with regards to part-worth utility for "glare is not noticeable at all," it is greater than that for "glare is barely noticeable" for others and designers, while it is smaller for engineers.

Finally, in relation to educational background (architectural or non-architectural), it should be noted that the importance level of illuminance for architects is higher than for non-architects. Particularly, part-worth utility for 1500 lx is small for architects.

5. Conclusion

In this study, the evaluation of lighting environment for offices was attempted by using the conjoint analysis and by taking trade-offs relationships among evaluation perspectives into consideration. As the findings show, the evaluation structure of a lighting environment for offices, which consists of various attributes in terms of quality, was quantitatively clarified. It is believed that the study achieved the goal initially projected.

Here, future challenges for this study will be stated in order to make the information provided more universal.

First, the challenges relating to the conjoint analysis, is the selection of attributes and their levels. Through the conjoint analysis, analyses are conducted based on the evaluations subjects make against profiles created by a set of attributes and their levels. To obtain more precise information through this analysis, it is necessary to either increase the number of attributes and their levels or select more specific patterns of attributes and their levels. Increasing the number of attributes and levels, however, will be more of a burden on the subjects and that may affect reliability and appropriateness of evaluations made.

Therefore, the numbers of attributes and their levels cannot be increased to an unlimited degree. In the case of this study, seven attributes and twenty levels in total were used. It is not clarified how the unselected attributes and levels may affect evaluation of a lighting environment and how they are related to the attributes and levels used in this study. On the other hand, if attributes and their levels were specified, information obtained through the analysis could be more specific. However, this may cause the information to become too unique, or in other words, information is no longer applicable universally. To solve this problem, it is necessary to conduct a number of empirical studies applying a similar method used in this study.

Furthermore, in this study, in order to grasp the individual differences of evaluation structures for office lighting environment more precisely, subjects were classified into segments according to their most influential attribute, and the difference in evaluation structure of each segment was reviewed. It cannot be denied that smallness of the number of subjects in segments such as lighting distribution, usage of daylight, recycling and design compared to all subjects limits generalization of the results. In future, it is necessary to improve the weakness of statistical reliability due to the number of samples by implementing additional research with increased number of subjects.

The ultimate purpose of this study was to establish an evaluation of lighting environment that takes into consideration the diversity of evaluation perspectives. To this

end, an office setting, which has been evaluated most frequently in past studies, was chosen as the first stage. Yet, subjects' evaluations may have been influenced by the fact that office settings have public features. In other words, because the evaluation target is lighting environment for offices, a place shared by many people, in spite of the differences in values, the subjects may have been influenced by how they think their evaluations may affect others or what others may desire in an office setting. In our next study, residential lighting environment, which is a personal setting, will be reviewed and compared with the findings of this study, and we will probe into an ideal evaluation of lighting environment, which takes into account various evaluation perspectives.

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