SUBJECTIVE CRITERIA FOR LIGHTING SYSTEMS DESIGN USING A SCALE MODEL

by

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Last, but certainly not least, the author is very much indebted to his wife, without whose encouragement and support this graduate program may not have materialized. It is to her that this work is dedicated.

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INTRODUCTION

Light is defined as visually evaluated radiant energy. From a physical viewpoint, light can be regarded as that portion of the electromagnetic spectrum which lies between the wavelengths of 380 nanometers and 780 nanometers. There is a certain fundamemtal relationship between light, vision and seeing. The eye is our gateway to the world about us. Without light we cannot see; with inadequate or the wrong kind of lighting, seeing may be inefficient, uncomfortable, or hazardous. No single simple formula or procedure will solve all lighting problems. On the contrary, many factors need to be taken into consideration, and their relative importance can vary widely depending on the seeing requirements that exist or are imposed upon people. The visual demands may range from the difficult ones involving prolonged critical seeing of very fine assembly or precision machine work to what might be termed casual seeing of large objects. The time available for seeing may be short or long. The things to be seen may require color discrimination or merely the differentiation of black, gray and white.

Generally, in interior lighting design the three major emphases were: (1) to provide adequate amount of light to meet visual requirements for task performance, (2) to provide the right contrast of light for comfort and task efficiency, and (3) to provide economy in lighting system design. But with increasing number of people required to spend long periods of time in interiors like offices or factory buildings, lighting designers and architects are becoming more aware of the fact that spatially, they are dealing with something more complex than simple comfort.

> "Our modern buildings offer excellent protection against rain or physical cold; but none against emotional coldness, the sense of loneliness, isolation, lack of purpose... You (designers and builders) are treating our souls...so don't treat our souls so cheaply."
>
> Bruno Bettelheim
> (Psychologist)

This statement is a comprehensive view of the total response to a building or building space of which interior lighting is one of the components. So, in lighting design the designers are concerned with the way light affects the users' perception of the room. Hence the design decisions must include the effect of light on subjective impressions. So it seems that these more comprehensive psychological and perceptual priorities should be identified and recognized in determining the value of lighting systems.

All of this indicates a change in the definition of "functional design". The idea of functionalism can no longer be limited to ideas associated only with utility, task, and physiological needs. A functional design must now include the qualitative ideas of user impression, attitude, well-being, and motivation. It should be noticed that these later factors may dictate the primary functional value of a lighting system. For these reasons, in recent years designers and architects have been investigating in the aesthetic aspect of lighting design which has predominant bearing on the users impression and attitude in a particular lighted space.

Lighting Aesthetics

Light is an element of design which should be used not only for visual comfort but also to achieve predetermined emotional responses. Light has certain characteristics that affect the mood and atmosphere of the space influencing the emotional responses of the people who occupy the space. The definition and character of space is greatly dependent on the distribution and pattern of illumination. Luminaires themselves have dimensional qualities that may be used to strengthen or minimize architectural line, form, color, pattern and texture.

According to the IES Lighting Design Handbook (1966) higher levels of general lighting are cheerful, and stimulate people to alertness and activity. Lower levels tend to create an atmosphere of relaxation, intimacy and restfulness. Devices which control the level of illumination make possible changing the mood or tone of the room to suit its various uses. This provides psychological change.

Lighting can be "soft" or "hard". Soft or diffused lighting minimizes harsh shadows, and provides a more relaxing and less visually compelling atmosphere. The artful use of hard or directional light can provide highlights and shadows that emphasize texture and add beauty to form, as, for example, a shaft of sunlight.

Another characteristic is the brilliance or sparkle obtained from small unshielded sources such as a bare lamp or candle flame. Usually such sources are not used as the prime origin of illumination, but are decorative.

Thus the art and science of modern interior lighting is broad in scope and involves many factors. Light can influence an observers unconscious interpretation of a space - for his judgment is based not only on form, but on form as modified by light. So the importance of lighting as a design element can hardly be over-emphasized and in his design the designer should consider the aesthetic and psychological effects in addition to the fulfillment of seeing needs.

Several researchers investigated the aesthetic and psychological effects of lighting system designs in recent years. Designers are now becoming more aware of the aesthetic aspect of the lighting system design in addition to the aspect of economy of the lighting system.

Subjective Reactions to Lighting

Flynn (1973) suggested that light can be regarded as a vehicle that facilitates the selective process and alters the information content of the visual field. He further suggested that a lighting design should be evaluated, in part, for its role in adequately establishing cues that facilitate or alter the users' understanding of his environment and the activities around him. Flynn and his associates (1973) performed an experiment on lighting design in a lighting demonstration room at the General Electric Lighting Institute at Nela Park near Cleveland. They obtained ratings for six different lighting arrangements in this medium sized conference room. Ratings were analyzed from 12 groups of eight subjects each with a total of 96 subjects. These adult subjects were well distributed in age and educational background. The six lighting arrangements were:

1) Overhead downlight - low intensity
2) Peripheral wall lighting - all walls
3) Overhead diffuse - low setting
4) Combination - overhead downlight (1) + end walls
5) Overhead diffuse high intensity
6) Combination - Overhead downlight (1) + peripheral (2) + overhead diffuse (3)

The factor analysis resulted in identification of five factors or categories of impression and three of these showed significant difference in impression between two or more of the six lighting systems. These five factors of impression are:

1) General evaluative impression
2) Perceptual clarity
3) Spatial complexity
4) Spaciousness
5) Impression of style or fashion

The results showed that the sixth lighting arrangement, that is, the combination of overhead downlight, peripheral, and overhead diffuse was the most preferred one and so suggests that light should come from more than one direction.

Ali (1978) performed an experiment based upon Flynn and his associates. He used seven different variations of single and combination lighting systems using a scale model to simulate a living room and then a waiting room. Sixty Kansas State University students took part as subjects. The results of his study validated the study of Flynn and his associates and it also showed that scale models can simulate real conditions effectively.

A few other researchers, Rodman (1970), Howard, Mlynarski, and Sauer (1972), Lemons and MacLeod (1972), and Lemons and Cole (1977) investigated aesthetic responses to different lighting environments in different living spaces.

Thus the importance of aesthetics as an aspect of lighting design considerations can hardly be overemphasized. Modern lighting system designs for any kind of interior must consider the impressions and emotional responses of the users of the interior.

While investigating into the aesthetic aspect of light, researchers were also concerned about the color of light. Color is an additional dimension of lighting design. Human beings are emotionally responsive to their surroundings, and color is one of the chief factors that determine how these surroundings appear. Since color of light intensifies surface colors of the same color and changes the other towards more gray it can greatly affect the emotional responses.

Incandescent Vs. Fluorescent Lighting

Both fluorescent and incandescent light sources are very commonly used interior light sources. They have different characteristics which lead their use in differing environments. Incandescent light sources are typically round shaped small light sources. They are generally of warm colored light, yellowish or reddish. Incandescent sources in application appear both bare, used for general lighting, or are directional with reflecting opaque shades to produce non-uniform distribution of light or to give highlights and focus attention to certain areas of the luminous space. On the other hand, fluorescent sources are typically long and cylindrical in shape with closed ends and produce white light - mostly cool white. General application of fluorescent lights use luminous ceiling design where the lamps are installed in a cavity above a translucent medium of usually rectangular dimension.

In commercial spaces, like workshops, classrooms, merchandise handling places, emphasis is given to the quantity and economy rather than aesthetics of illumination in the spaces. Generally in such spaces, uniformly distributed fluorescent lighting is used. In other commercial spaces like restaurants, showrooms, lightings aesthetics is of much more concern. In such spaces traditionally non-uniformly distributed incandescent lighting is used. So it would seem that the use of a light source and the distribution of its light in a space mainly depends upon the activity (task) in that space.

Kruithof (1941) investigated the color aspect of fluorescent luminaires because of the great variety of tints which can be obtained by mixing different luminescent substances. He showed that at low levels of illumination most people prefer a "warm" light, whereas at high levels of illumination, a "cold" light is preferred. It is widely believed that this is because the people are used to high levels of illumination from the natural daylight, whereas in the interiors of homes long experience with warm light from the fire or from incandescent lighting sources such as candlelight or incandescent filament light, is related in their minds with low levels of illumination. Hence warm incandescent lighting, according to this study, would be preferred in non-utility areas like living rooms, waiting lounges, etc. and cooler fluorescent lights for commercial spaces and classrooms. This is, in fact, common lighting practice. However, Perecherla (1978) performed an experiment on lighting aesthetics with a scale model representation of a waiting room. His experiment with an illumination level of 28 fc showed no preference between fluorescent and incandescent lighting. This result is in fact startling in the sense that it does not validate the traditional practice of using "warm" colored incandescent sources with low illumination for waiting room or living room area instead of fluorescent. The present study would investigate this further.

Semantic Differential Scale

Aesthetics of lighting system involves the quality of the lighting system and not just the quantity. A combination of different factors determine the quality and in a complex fashion. "Quality" of lighting is used to describe the luminance ratios, diffusion, uniformity, and chromaticity of the lighting.

There are direct methods available for measuring the quantity of illumination but there has been no straightforward way to measure the aesthetics of lighting system on a numerical scale until recently. Lighting aesthetics totally depends on subjective evaluation of the lighting system.

Some research has been done on devicing a suitable subjective scale to measure users aesthetic responses to lighting systems. One phase of this work was IERI Project 92 (1972) of GE which attempted to develop a standardized research procedure for studying subjective effects of environmental lighting. This involved the use of "Semantic Differential" (SD) rating scales, such as "clear-hazy", "pleasant-unpleasant", etc. For the purpose of the present research "Semantic Differential" rating scales would be used for the measurement of subjective reactions to lighting.

The semantic differential is essentially a combination of scaling procedures. This method had its origin in research on synesthesia with Theodore Karwoski and Henry Odbert at Dartmouth College. Osgood, C.E. later developed semantic differential technique in his psychological researches and applied it widely.

But the most important work of employing semantic differential scale in measuring subjective impression in lighting was done by Flynn, Hendric, Spencer, and Martyniuk in the IERI Project 92 (1979).

The semantic differential scale consists of using sets of pairs of words that represent the meaning of a particular concept expressed on a linear scale. Each pair of words that are opposite in meaning to each other correspond to a linear scale and represent the extreme ends of the scale as shown in Figure 1. The scale is conveniently divided in to few segments that will be assigned numerical values in ascending or descending order. This facilitates measuring the subjective responses quantitatively.

The semantic differential can be employed (a) to discover relationships between the form of the physical environment and those who occupy it and (b) to provide a basis for understanding the WHY of the relationship. But the limitations of the semantic differential and similar adjectival descriptions should be recognized. The adjectives should not be too specific. The variations in the environment are infinite - and hence impossible to describe completely.

The semantic differential is a generalized technique in the measurement of meaning. So, there are no standard concepts and no standard scales. Rather the concepts and scales used in a particular study depend on the purposes of the research. The semantic differential yields quantitative

Distinct	___	___	___	___	___	___	___	Vague
	1	2	3	4	5	6	7	

The scale is defined as:

1. Very distinct
2. Distinct
3. Slightly distinct
4. Neutral
5. Slightly vague
6. Vague
7. Very vague

Figure 1: An Example of a Semantic Scale

data which are verifiable, in the sense that other investigators can apply the same sets of scales to equivalent subjects and essentially obtain the same results.

The development of the semantic differential involves (a) use of factor analysis to determine the number and nature of factors entering into the semantic description and judgment and (b) the selection of a set of specific scales corresponding to these factors which can be standardized as a measure of meaning. Factor analysis is a statistical procedure which produces correlation matrices of the semantic scales. Its purpose is to try to bring some order out of semantic chaos by isolating subsets of scales or dimensions of meaning. The subjective responses on the scales of a particular subset would be similar under a particular lighting design but have a maximal differentiating power between different lighting systems.

Flynn's research with such scales has identified several factors or broad categories of impressions that can be cued or modified by lighting systems. These categories of impression are:

1) Impressions of preference
2) Impressions of pleasantness
3) Impressions of visual clarity
4) Impressions of spaciousness
5) Impressions of spatial complexity
6) Impressions of color tone
7) Impressions of glare

8) Impressions of public vs. private space

9) Impressions of relaxing vs. tense space

Substantial research has been accomplished by Vielhaur (1965), Craik (1968), Collins (1969) and Hershberger (1972) on the use of semantic differential technique for measurement of meaning in the architectural environment.

Scale Model Technique

Scale models have been found to provide a basis for lighting system design evaluation and they offer the tool the designers need to determine and demonstrate quality aspects of a lighting system based on all aspects of a proposed environment rather than past experience or previous results in dissimilar environments. Scale models thus provide the tool to support and emphasize a lighting system design.

There are many advantages in simulated rather than real environments. Real or proposed physical spaces are difficult to model or manipulate experimentally. They are expensive, time consuming, and highly complex. Small scale representations, simulations and mockups of built spaces are the very "stuff" of architectural practice; in a sense, any time a designer sketches alternative forms and judges whether one is better than the others, he conducts a simulation experiment. Architects may represent their architecture by drawings, models, or slides of models, and measure people's responses to them before the buildings are actually constructed.

The disadvantage in using models is that our subjects may not respond to them as they would to the actual environments. Although the pattern of behavior elicited by slides or models is interesting in its own right, it may tell us little about the subjects responses when confronted with the actual building, room or landscape. In simulating a lighting system, great care must be taken to make sure that the characteristics of the lighting system being used are represented. There is no basis for comparison unless each simulated system is performing as nearly like the actual one as possible. So far scale models have been used by several researchers to evaluate lighting aesthetics and to demonstrate light system differences.

Rodman (1970) used slide-model techniques for study and evaluation of the luminous environment of interiors. He used a special kind of variable model made of cardboard. The study consisted of recording of model variation in slide form and the comparison and evaluation of these slides projected to a scale which approached full size. The researcher suggested that one of the most important uses of this technique may be that of a communication device, for architects, lighting designers, and their clients and it may make the design a cooperative and creative joint effort.

Lemons and MacLeod (1972) used a scale model in lighting system design and evaluation. They used a model of four feet by four feet by one and one-half feet made to a scale of 1:8. The model was put in a light chamber housing ten 300-watt reflector lamps, two, four, six, eight, or ten of which could be operated at a time. To provide indirect lighting from the side walls they used four-foot fluorescent units mounted on the backs of the walls. Light was directed through slots in the wall and was reflected into the room off curved reflectors mounted over the slots.

Lemon and MacLeod argue that it is impossible to determine lighting system performance without knowledge of the luminaire, the environment, and the viewing task. The lighting designer must have new tools to meet the challenge presented by meeting the quality consideration for lighting system design. The researchers also argued that scale models present a possible technique to answer the needs for such a design tool. They further stressed that scale models can provide quality evaluation of a system design prior to actually constructing the actual environment.

In a more recent study Lemons and Cole (1977) used a scale model to study the problem and potential solution to the lighting of open office systems. The researchers stressed that the design of office task lit systems furniture had been greatly benefited by the scale model study.

A few other researchers like Howard, Mlynarski, and Sauer (1972) and Seaton and Collins (1972) used scale models and other simulation techniques to evaluate luminous environment of interiors.

PROBLEM

Several researches have been done to determine optimum level of illumination for different environmental condition. Attempts have been made to measure subjective reaction to different lighting environment. This research is a similar attempt to determine which aspect or aspects of light determine preference of one system over the other. The present research mainly investigated which single aspect or combination among color of the light, luminaire size, luminaire shape, and distribution pattern of light creates the basis for preference of one lighting design over others from users' point of view. This study used a scale model of a waiting lounge instead of the real environment.

The following hypothesis will be tested for the present study.

1. Incandescent lighting will present a more visually clear, spacious and preferred luminous interior than fluorescent lighting.
2. Smaller luminaire size will present a more visually clear, spacious, and preferred luminous interior than large luminaire size.
3. Non-uniform distribution pattern of light will present a more visually clear, spacious, and preferred luminous interior than uniform distribution.
4. Circular luminaire shape will present a more visually clear, spacious, and preferred luminous interior than rectangular shape.

METHOD

In this study a scale model of a waiting lounge was used for measuring subjective impressions of light. This scale model had the provision of changing the ceiling type for different luminaire set up. Eight different ceiling patterns were used for the study with two kinds of lighting distribution, two sizes of luminaires and two shapes of luminaires. This model was set up in two different lighting booths. One booth had incandescent lighting and the other had fluorescent lighting. The subjects of the study observed the waiting lounge under these different lighting systems and made subjective judgment about the appearance of the room's interior under these different lighting environments.

Model

For the present study a model of the size 24" x 12" x 10" built to a scale of 1 inch = 1 foot was used to simulate a waiting lounge of dimension 24' x 12' x 10' (Figure 2). It was designed originally by a student in Architecture Department of KSU who had this as a class assignment. Certain modifications to the design were later incorporated to suit the purpose of the present study.

The model was made with white foam core on three side walls covered with blue colored hard paper sheet, of Munsell color matching designation of 10B6/6 (Hue 10B, Chroma 6, Value 6),

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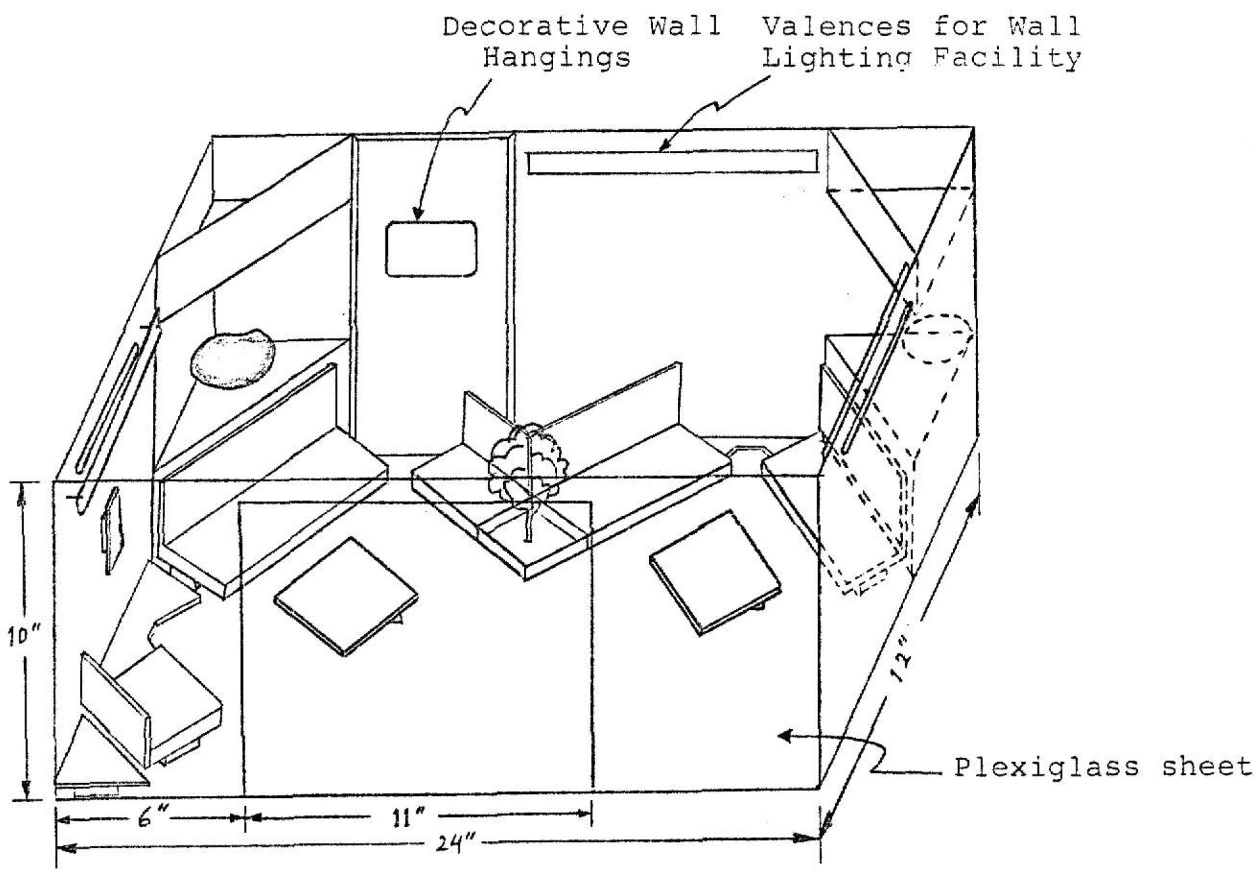
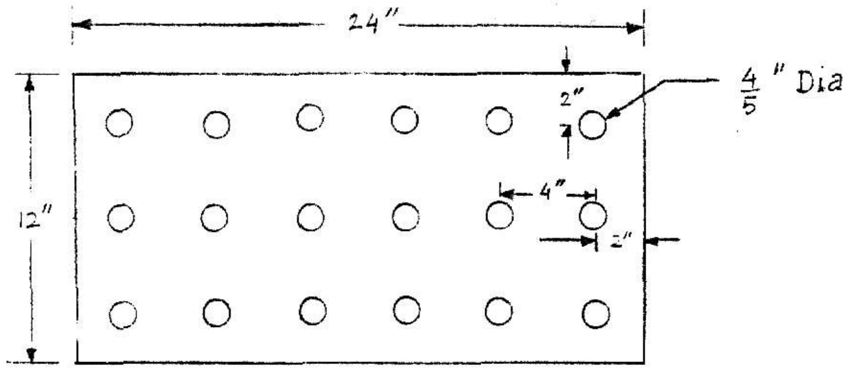


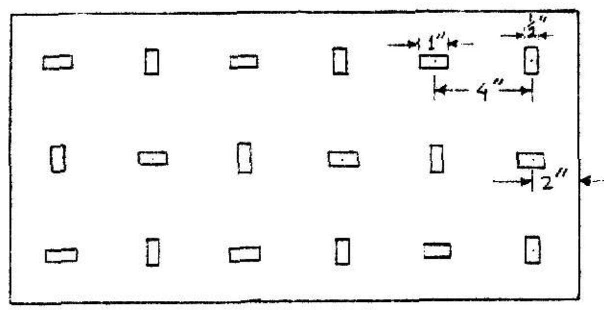
Figure 2: Three Dimensional View of the Scale Model

to give a light blue appearance to the interior walls. On the front was a transparent plexiglass sheet with an entrance. The floor was made of foam core with a dark blue (Munsell designation 7.5B 2/4) acrylic fabric covering to give the effect of a carpet. The furnishing of the room consists of sofas, tables, decorative plants and wall hangings.

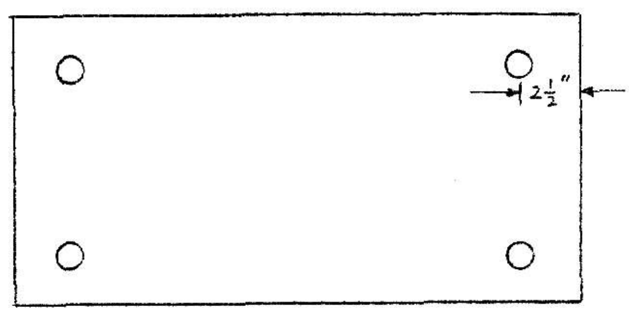
The model was provided with eight different ceiling types. Each ceiling consists of one particular type of luminaire system. The different luminaire patterns are shown in Figure 3.1 and Figures 3.1(a), 3.1(c), 3.2(e), 3.2(g) consist of circular luminaires and the other four consist of rectangular luminaires. In each shape category there are two sizes, small circular (dia-4/5"), bigger circular (dia-3 1/4"), and small rectangular (1" x 1/2") and bigger rectangular (2" x 4"). There were two different arrangements for each shape and size of luminaire. In one type of arrangement the luminaires were widely spaced to provide non-uniform distribution of light. These are in Figures 3.1(c), 3.1(d), 3.2(g), and 3.2(h). In the other arrangements the luminaires were more closely spaced to provide a more uniform distribution of illumination in the entire model. The size of the luminaires was so chosen that for a particular size category and distribution pattern the total luminaire surface area for rectangular and circular luminaires was the same. For smaller sources the size of circular luminaires were taken to be close to standard size of cylindrical opening of the fixture that is usually used with this type of luminaires, and the size of corresponding rectangular sources of small size had been chosen



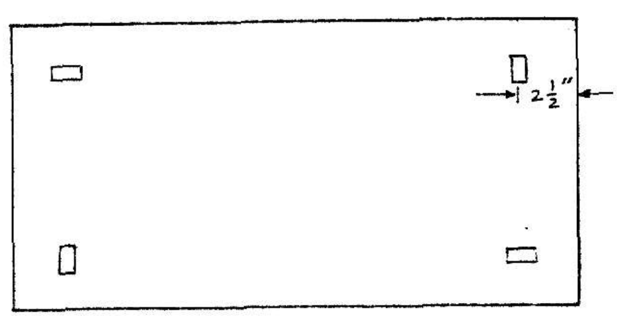
(a) Circular Sources with Uniform Distribution



(b) Rectangular Sources with Uniform Distribution

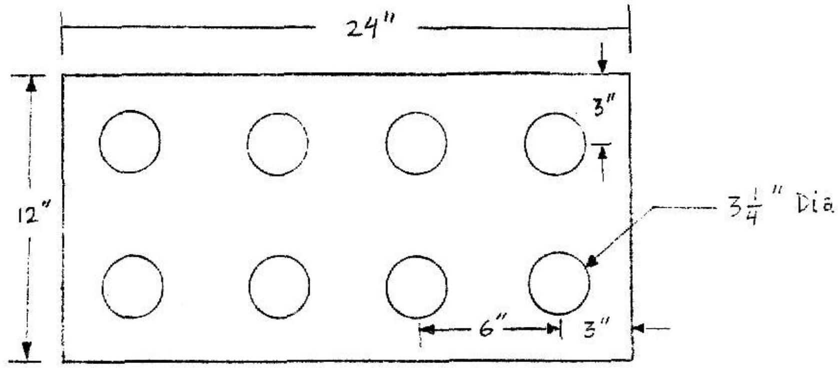


(c) Circular Sources with Non-uniform Distribution

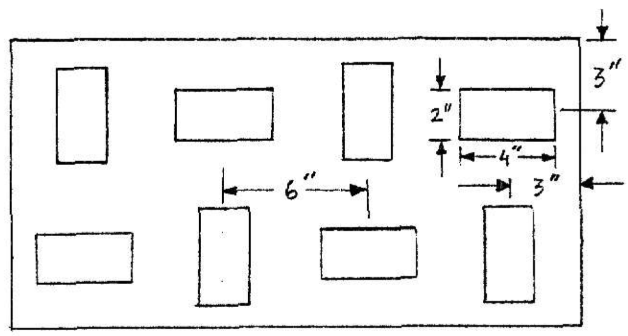


(d) Rectangular Sources with Non-uniform Distribution

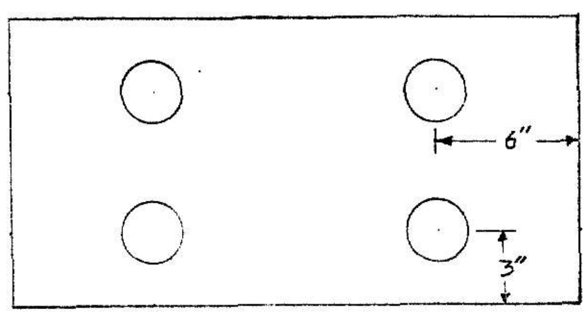
Figure 3.1: Ceiling Lighting Designs with Small Luminaire Sources



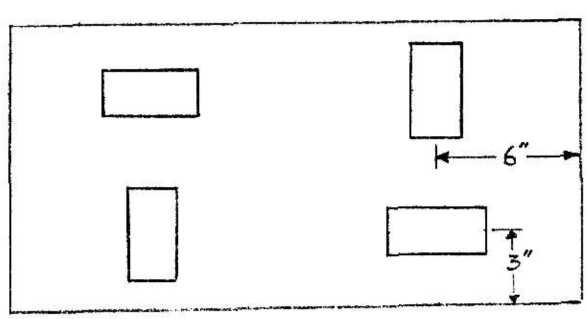
(e) Circular Sources with Uniform Distribution



(f) Rectangular Sources with Uniform Distribution



(g) Circular Sources with Non-uniform Distribution



(h) Rectangular Sources with Non-uniform Distribution

Figure 3.2: Ceiling Lighting Designs with Large Luminaire Sources

such that the total luminaire surface area remains same. In large luminaire sizes the rectangular luminaire pattern had the dimension of standard fixtures of 2 feet x 4 feet reduced to a scale of 1 inch = 1 foot. Again the size of the circular luminaires of bigger size was so chosen that for a particular distribution type total luminaire surface area for circular and rectangular patterns remain approximately the same. The rectangular sources of a particular ceiling type were arranged in a checker board pattern.

The total luminaire surface area for different ceiling patterns are as follows:

(a) Smaller luminaires with uniform distribution — 9 sq. inch.

(b) Smaller luminaires with nonuniform distribution — 2 sq. inch.

(c) Large luminaires with uniform distribution — 65 sq. inch.

(d) Large luminaires with nonuniform distribution — 32 sq. inch.

The ratio of luminaire surface areas for uniform and non-uniform distribution for smaller source size is 4.5:1 and the corresponding ratio for large luminaire size is 2.0:1.

All the eight different types of ceiling were observed under both incandescent lighting when the model was set in an incandescent light booth and under fluorescent lighting when the model was set in the fluorescent light booth. The incandescent light booth houses 15 incandescent light bulbs in the ceiling below which is a plastic diffuser. The illumination level can be varied by switching and operating a transformer. The flourescent light booth houses four cool white fluorescent tube lamps. The illumination level of the booth can also be varied continuously.

Experimental Design

The sixteen different treatments in the experiment are listed in Table 1. These treatments constitute the four independent variables of the study which are:

a) Color of light source (Incandescent and fluorescent)

b) Shape of source (Rectangular and circular)

c) Size of source (Small, large)

d) Distribution pattern of light (uniform and non-uniform)

The dependent variables are subjective impressions to the different lighting arrangements under the semantic scales of Table 2.

This study was an independent group design. Two independent groups of subjects, each group consisting of 20 subjects, viewed the eight different ceiling patterns (subjects run individually) in different random orders and judged them. Each subject of one group viewed all the ceiling patterns and the luminous interior of the scale model under fluorescent lighting and the subjects of other group under incandescent lighting only. In this way each subject was kept unaware of the designed comparison of measurements of reactions between the fluorescent and incandescent systems. The order of presentation of the ceiling patterns to the subject were randomized to confound any kind of serial effect.

TABLE 1

Sixteen Treatments or Ceiling Patterns

Color or Source of Light	Type of Distribution	Size and Shape of Luminaire
Incandescent	Uniform	Small Rectangular
		Large Rectangular
		Small Circular
		Large Circular
	Non-Uniform	Small Rectangular
		Large Rectangular
		Small Circular
		Large Circular
Fluorescent	Uniform	Small Rectangular
		Large Rectangular
		Small Circular
		Large Circular
	Non-Uniform	Small Rectangular
		Large Rectangular
		Small Circular
		Large Circular

TABLE 2

Semantic Scales for Evaluation of Lighting Systems

	Scales	
Pleasant	______	Unpleasant
Beautiful	______	Ugly
Like	______	Dislike
Clear	______	Hazy
Distinct	______	Vague
Bright	______	Dim
Large	______	Small
Spacious	______	Cramped
Horizontal	______	Vertical

Task

Every subject was given an Informed Consent and Instructions form, Figure 4, that described the task. Then every subject signed the Informed Consent Statement shown in Figure 5. The subjects then were handed the Evaluation Sheets (Figure 6) for rating the luminous environment of the scale model using one Evaluation Sheet for each treatment or lighting pattern. An adjustable chair was used to bring the eye level of the subject to a predetermined height so that each subject viewed the interior at the same level. Each subject was asked to observe the interior of the model for few minutes to try to associate the particular ceiling lighting design with his feeling of the model's interior appearance before rating that lighting system. After evaluating each lighting design and the interior appearance of the scale model the subject was asked to keep his or her eyes away from looking into the lighting booth. After each ceiling lighting pattern was set on the model the average illumination level in the model was adjusted to 11 foot candles which is within the recommended level of illuminance for waiting lounges by the Illuminating Engineering Society's Lighting Design Handbook (1966).

Each subject evaluated each lighting system design on the nine semantic differential scales as shown in Table 2.

INFORMED CONSENT AND INSTRUCTIONS

This study is designed to study "THE SUBJECTIVE CRITERIA FOR LIGHTING SYSTEMS DESIGN USING A SCALE MODEL".

Your task will be very simple. You will be asked to sit down in front of a scale model of a Waiting Lounge, lit by a particular kind of lighting. You will be shown this condition briefly. Then you will judge the lighting in an evaluation sheet. Altogether you will be exposed to eight light settings and make judgments in each case. For example, if you feel that for a particular lighting design the system appears very pleasant, very ugly, and is average in spaciousness circle the number close to your judgment on the sheet, as shown below

UNPLEASANT	1	2	3	4	5	6	(7)	PLEASANT
UGLY	(1)	2	3	4	5	6	7	BEAUTIFUL
CRAMPED	1	2	3	(4)	5	6	7	SPACIOUS

There will be no discomfort and no risk in this experiment. However, you are free to stop your participation at any time. Naturally, I would prefer that you continue until the end so that I can get all the data. If you have any questions, now or later, feel free to ask.

Now, if you are ready for the experiment, please sign the informed consent statement form given by the experimenter.

If you have any comments about the procedure and experiment, please feel free to write them at the end of the experiment in the space provided in the evaluation sheet.

Thanks for your cooperation.

Figure 4: Informed Consent and Instruction Form

INFORMED CONSENT STATEMENT

Having read the informed consent, I hereby agree to be a subject in the research entitled "SUBJECTIVE CRITERIA FOR LIGHTING SYSTEMS DESIGN USING A SCALE MODEL"

S. NO.	SIGNATURE	AGE(Yrs)	SEX (M/F)	DATE

Figure 5: Informed Consent Statement Form

EVALUATION SHEET

NAME: ____________________ TRT. NO. _____

BRIGHT	1	2	3	4	5	6	7	DIM
SPACIOUS	1	2	3	4	5	6	7	CRAMPED
DISTINCT	1	2	3	4	5	6	7	VAGUE
HORIZONTAL	1	2	3	4	5	6	7	VERTICAL
LARGE	1	2	3	4	5	6	7	SMALL
CLEAR	1	2	3	4	5	6	7	HAZY
LIKE	1	2	3	4	5	6	7	DISLIKE
PLEASANT	1	2	3	4	5	6	7	UNPLEASANT
BEAUTIFUL	1	2	3	4	5	6	7	UGLY

Comments: ____

____

Figure 6: Evaluation Sheet for Subjective Impressions

RESULTS

The data obtained in this experiment was collected in two sets. The first set was collected with the waiting lounge model under incandescent light sources. The second set was collected with the model under fluorescent light sources. The ratings of 20 subjects under incandescent lighting and the ratings of 20 subjects under fluorescent lighting, on nine semantic scales and the corresponding three factors, are shown in Appendix I. The correlation matrix among the nine semantic scales for all 320 observations appears in Table 3.

The subjective ratings were factor analyzed using the statistical analysis system computer program (User's Guide to SAS76, North Carolina, SAS Institute, Inc., 1976) to find relationships among the semantic scales. This factor analysis resulted in identification of three factors or "categories of impression". The factor pattern of these factors is shown in Table 4. The factors and the highest factor loadings (above 0.60) are shown in Table 5.

Univariate analysis of variance was performed on each of the three factors separately. The analyses was done to find if there were significant differences among the light colors (incandescent vs. fluorescent), sizes of luminaire surfaces (small vs. large), shapes of luminaire surfaces (circular vs. rectangular), and

TABLE 3

Correlation Matrix

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

NUMBER OF OBSERVATIONS=320

CORRELATION MATRIX

	S1	S2	S3	S4	S5	S6	S7	S8	S9
S1	1.00000	0.56340	0.55140	0.19520	0.16130	0.13490	-0.00800	0.05220	0.02310
S2	0.56340	1.00000	0.60730	0.11400	0.20810	0.13290	0.10880	0.09310	0.06790
S3	0.55140	0.60730	1.00000	0.11480	0.14840	0.06570	0.02370	-0.00700	0.06270
S4	0.19520	0.11400	0.11480	1.00000	0.50690	0.44690	0.18010	0.16690	0.17140
S5	0.16130	0.20810	0.14840	0.50690	1.00000	0.56620	0.08030	0.18920	0.08860
S6	0.13490	0.13290	0.06570	0.44690	0.56620	1.00000	0.07740	0.16950	0.08340
S7	-0.00800	0.10880	0.02370	0.18010	0.08030	0.07740	1.00000	0.63650	0.59960
S8	0.05220	0.09310	-0.00700	0.16690	0.18920	0.16950	0.63650	1.00000	0.68140
S9	0.02310	0.06790	0.06270	0.17140	0.08860	0.08340	0.59960	0.68140	1.00000

S1 - "Clear - Hazy"
S2 - "Distinct - Vague"
S3 - "Bright - Dim"
S4 - "Large - Small"
S5 - "Spacious - Cramped"
S6 - "Horizontal-Vertical"
S7 - "Beautiful - Ugly"
S8 - "Pleasant - Unpleasant"
S9 - "Like - Dislike"

TABLE 4.

Factor Patterns

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

FACTOR PATTERN

	FACTOR1	FACTOR2	FACTOR3
S1	0.00040	0.70288	0.12692
S2	0.07341	0.77578	0.11389
S3	0.00080	0.77750	0.04969
S4	0.13081	0.10010	0.60914
S5	0.05667	0.12932	0.79199
S6	0.05586	0.05381	0.70696
S7	0.74966	0.02760	0.05967
S8	0.83628	0.00944	0.16248
S9	0.79987	0.03521	0.05635

FACTOR 1 - Evaluation
FACTOR 2 - Visual Clarity
FACTOR 3 - Spaciousness

distribution patterns (uniform vs. non-uniform). Also any significant effect of the interactions among the four main effects were investigated. The results of the univariate analyses of variance are presented in Table 6 through Table 8. Duncan's multiple range test was also conducted for the above analyses and the results are shown in Table 9 through Table 20. The mean factor response of different combinations of source colors and luminaire sizes, source colors and luminaire shapes, source colors and distribution patterns, and luminaires shapes and distribution patterns, for each of the three factors is presented in Table 21. These mean responses show the interactions among the main effects.

All statistical tests were done at a 0.05 level of significance. A guide to the various symbols used in the analysis appear in Appendix II.

TABLE 5

Factors and Factor Loadings

		Loadings
Factor 1 - Evaluation		
Beautiful	Ugly	0.75
Pleasant	Unpleasant	0.84
Like	Dislike	0.80
Factor 2 - Visual Clarity		
Clear	Hazy	0.70
Distinct	Vague	0.78
Bright	Dim	0.78
Factor 3 - Spaciousness		
Large	Small	0.61
Spacious	Cramped	0.79
Horizontal	Vertical	0.71

TABLE 6

Evaluative Factor: Analysis of Variance for Color, Shape, Size and Distribution Effects

STATISTICAL ANALYSIS SYSTEM

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: FACTOR1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	53	962.91255257	18.16816133	35.29	0.0001	0.875456	18.9613
ERROR	266	136.93515597	0.51479382		STD DEV		FACTOR1 MEAN
CORRECTED TOTAL	319	1099.84770854			0.71749134		3.78397635

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUB	19	9.81398660	1.00	0.4574
COL	1	1.49126704	2.90	0.0899
SUB(COL)	19	10.02291815	1.02	0.4325
SHAPE	1	291.53714450	566.32	0.0001
SIZE	1	55.39217087	107.60	0.0001
SHAPE*SIZE	1	99.99516892	194.22	0.0001
DIST	1	244.44398368	474.84	0.0001
SHAPE*DIST	1	25.02228240	48.61	0.0001
SIZE*DIST	1	39.76547570	77.25	0.0001
SHAPE*SIZE*DIST	1	0.29288763	0.57	0.4513
COL*SHAPE	1	13.22329292	25.69	0.0001
COL*SIZE	1	69.86438054	135.71	0.0001
COL*DIST	1	44.20844375	85.88	0.0001
COL*SHAPE*SIZE	1	9.67946528	18.80	0.0001
COL*SHAPE*DIST	1	3.91751437	7.61	0.0062
COL*SIZE*DIST	1	44.22582106	85.91	0.0001
COL*SHAPE*SIZE*DIST	1	0.02634957	0.05	0.8212

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB(COL) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
COL	1	1.49126704	2.83	0.1091

TABLE 7

Visual Clarity Factor: Analysis of Variance for Color, Shape, Size, and Distribution Effect

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: FACTOR2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	53	116.77698146	2.20337701	4.10	0.0001	0.449769	25.0796
ERROR	266	142.85162462	0.53703618		STD DEV		FACTOR2 MEAN
CORRECTED TOTAL	319	259.63060610			0.73282753		2.92200583

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUB	19	11.15485390	1.09	0.3574
COL	1	27.42088415	51.06	0.0001
SUB(COL)	19	12.26973327	1.20	0.2546
SHAPE	1	2.91581151	5.43	0.0205
SIZE	1	3.54707252	6.60	0.0107
SHAPE*SIZE	1	2.80568776	5.22	0.0231
DIST	1	12.79589865	23.83	0.0001
SHAPE*DIST	1	5.09566581	9.49	0.0023
SIZE*DIST	1	15.53144555	28.92	0.0001
SHAPE*SIZE*DIST	1	0.18289374	0.34	0.5600
COL*SHAPE	1	0.76151930	1.42	0.2348
COL*SIZE	1	7.77216602	14.47	0.0002
COL*DIST	1	4.59623718	8.56	0.0037
COL*SHAPE*SIZE	1	3.15269581	5.87	0.0161
COL*SHAPE*DIST	1	4.16688478	7.76	0.0057
COL*SIZE*DIST	1	0.15290261	0.28	0.5941
COL*SHAPE*SIZE*DIST	1	2.45662893	4.57	0.0334

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB(COL) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
COL	1	27.42088415	42.46	0.0001

TABLE 8

Spaciousness Factor: Analysis of Variance for Color, Shape, Size, and Distribution Effect

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: FACTOR3

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	53	559.65136299	10.55945968	27.93	0.0001	0.847682	18.2491
ERROR	266	100.56221852	0.37805345		STD DEV		FACTOR3 MEAN
CORRECTED TOTAL	319	660.21358151			0.61486052		3.36527043

SOURCE	DF	ANOVA SS	F VALUE	PR > F
SUB	19	5.44864460	0.76	0.7556
COL	1	3.51154762	9.29	0.0025
SUB(COL)	19	10.45576435	1.46	0.1012
SHAPE	1	4.58768268	12.14	0.0006
SIZE	1	62.09093367	164.24	0.0001
SHAPE*SIZE	1	3.83975517	10.16	0.0016
DIST	1	398.20326153	1053.30	0.0001
SHAPE*DIST	1	2.33132092	6.17	0.0136
SIZE*DIST	1	0.11573840	0.31	0.5805
SHAPE*SIZE*DIST	1	1.21778024	3.22	0.0738
COL*SHAPE	1	0.48942549	1.29	0.2562
COL*SIZE	1	52.50323126	138.88	0.0001
COL*DIST	1	10.69132579	28.28	0.0001
COL*SHAPE*SIZE	1	1.37573689	3.64	0.0575
COL*SHAPE*DIST	1	1.25504188	3.32	0.0696
COL*SIZE*DIST	1	0.18740449	0.50	0.4820
COL*SHAPE*SIZE*DIST	1	1.34676799	3.56	0.0602

TESTS OF HYPOTHESES USING THE ANOVA MS FOR SUB(COL) AS AN ERROR TERM

SOURCE	DF	ANOVA SS	F VALUE	PR > F
COL	1	3.51154762	6.38	0.0205

TABLE 9

Evaluative Factor: Duncan's Test for Source Colors

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR1

ALPHA=0.05 DF=19 MSE=0.527522

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	COL
A	3.8522	160	I
A			
A	3.7157	160	F

TABLE 10

Visual Clarity Factor: Duncan's Test for Source Colors

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR2

ALPHA=0.05 DF=19 MSE=0.645775

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	COL
A	3.2147	160	F
B	2.6293	160	I

TABLE 11

Spaciousness Factor: Duncan's Test for Source Colors

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR3

ALPHA=0.05 DF=19 MSE=0.550303

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	COL
A	3.4740	160	F
B	3.2645	160	I

TABLE 12

Evaluative Factor: Duncan's Test for Luminaire Size

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR1

ALPHA=0.05 DF=266 MSE=0.514794

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SIZE
A	4.2000	160	L
B	3.3679	160	S

TABLE 13

Visual Clarity Factor: Duncan's Test for Luminaire Size

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR2

ALPHA=0.05 DF=266 MSE=0.537036

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SIZE
A	3.0273	160	L
B	2.8167	160	S

TABLE 14

Spaciousness Factor: Duncan's Test for Luminaire Size

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR3

ALPHA=0.05 DF=266 MSE=0.378053

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SIZE
A	3.3098	160	L
B	2.9288	160	S

TABLE 15.

Evaluative Factor: Duncan's Test for Luminaire Shape

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR1

ALPHA=0.05 DF=266 MSE=0.514794

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SHAPE
A	4.7385	160	R
B	2.8295	160	C

TABLE 16

Visual Clarity Factor: Duncan's Test for Luminaire Shape

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR2

ALPHA=0.05 DF=266 MSE=0.537036

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SHAPE
A	3.0175	160	R
B	2.8265	160	C

TABLE 17

Spaciousness Factor: Duncan's Test for Luminaire Shape

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR3

ALPHA=0.05 DF=266 MSE=0.378053

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	SHAPE
A	3.4890	160	R
B	3.2495	160	C

TABLE 18

Evaluative Factor: Duncan's Test for Distribution Pattern

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR1

ALPHA=0.05 DF=266 MSE=0.514794

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	DIST
A	4.6580	160	U
B	2.9100	160	N

TABLE 19

Visual Clarity Factor: Duncan's Test for Distribution Pattern

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR2

ALPHA=0.05 DF=266 MSE=0.537036

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	DIST
A	3.1220	160	U
B	2.7220	160	N

TABLE 20.

Spaciousness Factor: Duncan's Test for Distribution Pattern

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: FACTOR3

ALPHA=0.05 DF=266 MSE=0.378053

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	DIST
A	4.4848	160	U
B	2.2538	160	N

TABLE 21

Mean Factor Response Values for First Order Combinations of Shapes, Sizes, Distribution Patterns, and Source Colors

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

ANALYSIS OF VARIANCE PROCEDURE

MEANS

SHAPE	SIZE	N	FACTOR1	FACTOR2	FACTOR3
C	L	80	3.80451415	3.02546933	3.79956935
C	S	80	1.85445602	2.62762968	2.69950112
R	L	80	4.59554560	3.02910920	3.81995763
R	S	80	4.88138963	3.00581512	3.15805348

SHAPE	DIST	N	FACTOR1	FACTOR2	FACTOR3
C	N	80	2.23511157	2.75277170	2.21936952
C	U	80	3.42385860	2.90032730	4.27970096
R	N	80	3.58482804	2.69130405	2.28813099
R	U	80	5.89210720	3.34362028	4.68938013

SIZE	DIST	N	FACTOR1	FACTOR2	FACTOR3
L	N	80	2.97350792	2.60701297	2.71326130
L	U	80	5.42655183	3.44756557	4.90626569
S	N	80	2.84643168	2.83706279	1.79423921
S	U	80	3.88941397	2.79638201	4.06331540

COL	SHAPE	N	FACTOR1	FACTOR2	FACTOR3
F	C	80	2.96449944	3.07049584	3.39339837
F	P	80	4.46692181	3.35897382	3.55465220
I	C	80	2.69447073	2.58260317	3.10567211
I	P	80	5.01001342	2.67595051	3.42335891

COL	SIZE	N	FACTOR1	FACTOR2	FACTOR3
F	L	80	3.66451027	3.16417212	3.50945962
F	S	80	3.76691098	3.26529753	3.43859095
I	L	80	4.73554948	2.89040641	4.11066737
I	S	80	2.96893467	2.36814727	2.41896366

COL	DIST	N	FACTOR1	FACTOR2	FACTOR3
F	N	80	2.47001686	3.13461361	2.17572004
F	U	80	4.96140439	3.29485604	4.77233053
I	N	80	3.34992274	2.30946215	2.33178047
I	U	80	4.35456141	2.94909154	4.19725056

FACTOR 1 - Evaluation
FACTOR 2 - Visual Clarity
FACTOR 3 - Spaciousness

DISCUSSION

Factors

As a result of the factor analysis of raw data, three significant factors emerged. These factors were expected and are:

Evaluative (Factor 1). Under a particular lighting condition, if people rank it high, as beautiful, pleasant, and like means that the particular lighting condition is preferred. In this evaluative factor, three semantic scales "beautiful - ugly", "pleasant - unpleasant", and "like - dislike" have substantial loadings. All these scales are taken from Flynn's study where they were grouped to describe an "evaluative" impression of subjects or users. So the present analysis verifies the Flynn's study results. The mean response over all the 320 observations for Evaluative factor or Factor 1 was 3.78.

Visual Clarity (Factor 2). If a particular lighting condition creates a high impression of clearness, distinctness and brightness it means that high visual clarity is achieved. The three scales, "clear-hazy", "distinct-vague", and "bright-dim" have high loadings on this factor. These three scales were chosen from Flynn's grouping of scales to describe the impression of "visual-clarity" under a particular lighting condition. This analysis thus verifies Flynn's findings. The mean response over all the 320 observations for the Visual Clarity or Factor 2 was 2.92.

Spaciousness (Factor 3). When a lighting condition is considered to have created a feeling that the luminous space appears spacious, large, and horizontal then that lighting system is considered to have created an impression of "spaciousness" to the users' of the space or the subjects subjected to that environment. Three semantic scales were found to have high loadings on this factor. They are "spacious-cramped", "large-small", and "horizontal-vertical". These scales were also obtained from Flynn's study who grouped them to describe the impression of "spaciousness". So this finding in the present analysis also validates Flynn's identification of semantic scales to describe different categories of impressions. The mean response over all the 320 observations on the Spaciousness factor or Factor 3 was 3.37.

The identification of the above three categories of impressions or factors which were expected verifies the factors emerged in Flynn's research. Flynn used an actual or real conference room in his investigation but in the present research a scale model of a waiting lounge was used. This clearly suggests that the factors generalize over environments (type of space and whether it is real or simulated).

Color Effects

The analysis of variance with Factor 1 or the "evaluative" factor as independent variable showed no significant difference between fluorescent and incandescent lighting sources for the waiting lounge but the analysis with Factor 2 or the "visual clarity" factor and Factor 3 or the "spaciousness" factor showed that there is a significant difference between the effects of incandescent and fluorescent lighting for a waiting lounge. For the "visual clarity" factor the mean factor response for incandescent lighting is 2.63 and for fluorescent lighting it is 3.21. For the "spaciousness factor" the mean ratings for the source colors are 3.26 and 3.47 respectively. The Duncan's test on means for colors with these two factors showed that subjective ratings for incandescent lighting systems has a lower mean than the fluorescent lighting. For visual clarity factor the difference is small though statistically significant. A lower mean on the visual clarity factor implies that incandescent lighting systems were considered to present a considerably more visually clear luminous space than fluorescent lighting. This result agrees with the postulated first hypothesis. A slightly lower mean factor score for incandescent lighting systems on the spaciousness factor indicates that the luminous space appears more spacious with incandescent lighting than with fluorescent lighting. This result also agrees with the postulated hypothesis on color of light.

Since there was no significant differences of means for source colors on the evaluative factor the hypothesis on the preference of source color could not be confirmed. One reason for this failure of the hypothesis might be that the two groups of subjects evaluated the lighting systems separately under two different source colors. Neither group had any knowledge of a designed comparison between source colors. So the evaluation by two groups of different source colors overlapped. It may also be that there is really no difference between these source colors on the evaluative impression, and that "everyday" differences in liking is based on other expectations and not colors. In everyday viewing it is generally obvious which source type one is seeing (shape, size, and distribution), and fluorescent lighting has not generally been deemed as pleasant since it's introduction just before World War II. Rather, fluorescent has been deemed an efficient source (which it is).

The results obtained for the color effect agreed with the findings of Perecherla only for the evaluative factor. But his results on the visual clarity and the spaciousness factor did not find any significant difference between fluorescent and incandescent source colors. So the results of the present study did not agree fully with Perecherla's findings.

A similar investigation was performed by Gettu and Pravakaran (1982) which fully agreed with the findings of Perecherla on the visual clarity, spaciousness and evaluation factors for source colors. So the present results did not also agree fully with the findings of Gettu and Pravakaran.

Shape Effect

In the analysis of variance with each factor separately as the dependent variable it was found that there was a significant difference between the subjective impressions produced by circular lighting fixtures and rectangular lighting fixtures on all the factors. Duncan's multiple range test on the means for shape revealed that in each case the circular luminaire surface shape has a lower mean factor response than rectangular fixture design. The mean factor response values for shape has a large difference on Factor 1 or the evaluative factor. These means are 4.74 for rectangular and 2.83 for circular luminaires. A lower mean for circular shape of luminaire surface on this factor implies that the circular liminaire was preferred by the subjects and agrees with the second postulated hypothesis on preference based on source shape.

The mean factor response for Factor 2 or the visual clarity factor has a small difference for luminaire shape. But still it is statistically significant difference. The mean ratings are 3.02 for rectangular and 2.83 for circular shape. Here also the circular luminaire shape has a lower mean indicating that the circular luminaire shape presents a more visually clear luminaire space than rectangular luminaire surface shape.

On Factor 3 or the spaciousness factor the mean ratings are 3.49 for rectangular and 3.25 for circular shapes. Circular Luminaire shape has a slightly lower mean than rectangular shape, although the difference is statistically significant. It implies that circular luminaire shape presents a more spacious appearing luminous space. This agrees with the postulated hypothesis on spaciousness based on source shape.

On evaluative factor or impression the circular luminaire shape has a lower mean factor response value. This may be either cause or effect or both because of the association of circular luminaire shapes with incandescent lighting in everyday life. That is, preferred circular shapes may enhance incandescent lighting systems appearance, and/or circular luminaire shapes may be preferred because of their association with incandescent lighting. The former effect could be a transitory effect as preferred design elements of this sort change over the years.

The visual clarity and spaciousness findings are somewhat surprising as greater luminance is generally associated with greater clarity, spaciousness, but lesser luminance with incandescent lighting systems.

However, the results obtained for the shape effect in the present study agreed with the findings of Gettu and Pravakaran for the visual clarity factor and the spaciousness factor. On the evaluative factor they did not find any significant difference in subjective impressions between circular and rectangular luminaire shapes.

Size Effect

The analysis of luminaire surface showed that on each of the three factors there were significant differences in subjective responses between large and small luminaire size. The Duncan's test on means revealed that for each factor, evaluative, visual clarity, and spaciousness smaller luminaire size had a lower mean factor response than larger luminaire size.

For the evaluative factor or Factor 1, the difference in mean response was large. A lower mean for smaller sizes on this factor implies that subjects preferred smaller luminaire surface size. This might have similar interpretation as in the case of the preference of circular luminaire shape since smaller luminaire size is generally associated with incandescent lighting and circular luminaire shape in everyday lighting systems.

In the case of the visual clarity factor or Factor 2, the difference in mean response values between two sizes was small but statistically significant. A lower mean for smaller size indicates that it presents a more visually clear luminous space than large size. This finding was a little surprising since the average illumination level in every case was kept approximately the same. One reason might be that for the same luminance the brightness of sources reduced as luminaire size increased. So the subjects might have associated the brightness of the luminaire source with their experience of visual clarity in the space.

The mean response values were widely different in case of spaciousness factor. A lower mean for smaller sizes indicates that the luminous space appeared more spacious with the smaller sources than with the use of large luminaire surface.

The results of the present study for the size effect agrees with the findings of Gettu and Pravakaran for all the three factors. But of course the size of small and large luminaires in their study were different from present study.

Distribution Effect

The results of the analysis of variance for distribution effect shows that for all the three categories of impression there were significant differences between the two distribution patterns of light, uniform and nonuniform.

Duncan's test on mean factor responses showed that in each case the non-uniform distribution of light has a lower mean than uniform distribution patterns.

In case of Factor 1 or the evaluative factor, the difference in mean factor responses was large. A lower mean for the non-uniform distribution suggests that the non-uniform distribution was preferred over the uniform distribution by the subjects of the experiment.

For Factor 2 or the visual clarity factor, the difference in means was small relative to the difference in the case of Factor 1. However, a lower mean on this factor indicates that the non-uniform distribution presents a more visually clear space than uniform distribution. This result might be the outcome of the fact that in non-uniform distribution particular areas in the viewing field are given more emphasis or draws more attention. These areas are generally more illuminated and have a higher than average luminance. Also for the same average luminance the sources in non-uniform distribution are brighter than the sources with uniform distribution for the same shape and luminaire size. The reason for this is for the later system the number of sources increases to bring uniformity but the source brightness reduces. So subject's or user's aesthetic feelings might associate the source brightness with the feeling of visual clarity.

The mean response values on the spaciousness factor had a large difference. A lower mean for non-uniform distribution implies that the luminous space appears more spacious with non-uniform distribution of light. From this above result the last postulated hypothesis is confirmed for spaciousness factor.

Interactions

In the univariate analysis of variance, discussed in the previous section, considerable interactions were found among the four main effects, shape, size, distribution and color, for each of the categories of impression or factors.

The shape of luminaire surface was found to be in significant interaction with luminaire surface size for all the three factors. Duncan's test on main effects showed that circular luminaire shape and small luminaire size has a lower mean than large luminaire size. But the mean factor response values for the combinations of rectangular shape with large size and rectangular shape with small size for Factor 1 or the evaluative factor showed that the former has a lower mean than the later combination. This may be due to the fact that in existing lighting system designs rectangular shape uses fluorescent lighting and are usually large in dimension. This experience in viewing the association of large size with rectangular shape might have given rise to this interaction. For Factor 2 or the visual clarity factor the combination of circular shape with small size has a mean considerably lower than any other combination of shapes and sizes for this factor and the mean response values for other combinations of shapes and sizes are very close to each other. On Factor 3 or the spaciousness factor the mean response values for the combinations of circular shape with large size and rectangular shape with large size are very close to each other and might not give a statistically significant difference though circular luminaire shape has a lower mean than rectangular luminaire shape and was statistically significant on the spaciousness factor. This indicates that the shape of the luminaire effects the luminaire size in producing differing subjective impressions on lighting.

The shape of luminaire surface also interacted with the distribution pattern of light for evaluative factor, visual clarity factor, and spaciousness factor. For the evaluative factor the combination of circular size and uniform distribution was found to have a lower mean than rectangular size with non-uniform distribution. But from Duncan's test of main effects the non-uniform distribution pattern has a lower mean than uniform distribution pattern. So here the luminaire shape effected the subjective evaluation of distribution patterns of light. This might be due to the large difference in mean response values between the circular and rectangular shapes on the evaluative factor as revealed by the Duncan's tests on main effects.

For Factor 2 or the visual clarity factor, the mean response values for the combinations of circular shape with non-uniform distribution, circular shape with uniform distribution, and rectangular shape with non-uniform distribution were very close to each other and also the mean for the combination of rectangular shape with uniform distribution was slightly lower than the mean for circular shape and non-uniform distribution. So this reveals the reason for a significant interaction between shape and distribution on this factor.

For Factor 3 or the spaciousness factor, the mean response values for the circular non-uniform design and rectangular non-uniform designs were very close to each other and might have given rise to the significant interaction between shape and distribution on this factor.

The size of luminaire surface was found to interact significantly with the distribution pattern of light on the evaluative factor and the visual clarity factor. For the evaluative factor the mean response values for the combinations of large size with non-uniform distribution and small size with non-uniform were very close. It indicated that for non-uniform distribution the luminaire surface size has no effect on subjective evaluation of lighting systems.

For the visual clarity factor the mean response values for small size with non-uniform distribution and small size with uniform distribution were very close. This indicates that for smaller luminaire surface size the differing distribution patterns produce approximately same visual clarity in the luminous space. This result is intriging. However, the Duncan's test on means for distribution patterns showed that though the difference in means for uniform and non-uniform distribution was statistically significant yet the difference was small compared to the differences on the other two factors. Again the mean response values for the combination of large size with non-uniform distribution and small size with uniform distribution were very close. This indicates no difference in visual clarity for large size with non-uniform distribution and small size with uniform distribution. This might have been an overlapping effect since smaller size had a statistically significant lower mean than larger size and non-uniform distribution had a lower mean than uniform distribution. Of course in both of the above cases the differences in means were small though statistically significant.

Source colors and luminaire size were found to have significant interactions on all the three factors. Also source colors and distribution patterns of light were found to interact significantly on all the three factors.

These interactions give rise to the possibility of further research in this area. Further investigations into these patterns of interactions might be worthwhile.

Implications

The analysis of the data showed that there was no significant difference between incandescent and fluorescent lighting systems on the evaluative factor. A possible reason for this has been presented in the previous discussion. However, it leaves a possible area to investigate further. The experiment was done with independent groups of subjects rating the lighting systems under fluorescent and incandescent sources. This design strengthens the results obtained. Significant consistent results were obtained on all the factors. The factors that emerged from the factor analysis also agree with Flynn's study. So scale model representation in this experiment seems to have achieved its purpose

The interactions among the main effects are intriguing. Few of the first order interactions have been explained in the previous section. An in-depth investigation into these interactions might lead to new interesting results. The results obtained in the univariate analysis on main effects could be the basis for investigating subjective responses on different combinations of distribution pattern, lighting source color, luminaire shape and size. This might also explain some of the above mentioned interactions. However, there are many areas in which further research may be performed.

The present analysis suggests that circular luminaire shape, small size of luminaire surface, and non-uniform distribution of light would be preferred lighting elements. These results could be of help to designers who try to design and incorporate lighting environments, which are aesthetically pleasing.

Considering the energy efficiency of lighting systems design fluorescent lighting might be used in designing such spaces as waiting lounges and living rooms. Fluorescent light sources are now available in small sizes and circular shapes which can be arranged in the lighting design to present a non-uniform pattern of distribution of light. The present study indicates no difference in preference between fluorescent and incandescent lighting systems and even if there is some subtle difference with preference towards incandescent system this sort of preference changes over the years. Also fluorescent system offers different tints of light colors which can be brought closer to the tint offered by incandescent lighting.

All in all, by observing the results obtained in this study, it is obvious that quite a few interior lighting design decisions can be made at lower costs using scale models rather than real full scale environments.

CONCLUSIONS

1. Three dimensions which emerged as a result of factor analysis verify Flynn's study results. The factors are evaluation, visual clarity, and spaciousness.
2. Incandescent source color presented a more visually clear and spacious luminous space than fluorescent sources. The hypothesis that incandescent sources would be preferred over fluorescent sources could not be confirmed.
3. Circular shape of luminaire surfaces presented a more visually clear, spacious, and preferred luminous space than rectangular luminaire surface shape.
4. Smaller size of luminaire surface presented a more visually clear, spacious, and preferred luminous space than large size of luminaire surface.
5. Non-uniform distribution pattern of light presented a more visually clear, spacious and preferred luminous space than uniform distribution pattern of light.
6. Further research can be done as a continuation of the present study to investigate the interactions arising among the main effects by studying subjective responses to lighting conditions which are different combinations of the distribution patterns, source colors, luminaire surface sizes and shapes.

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APPENDIX I

SUBJECTIVE RATINGS

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

P-474

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
1	I	C	S	U	1	2	2	2	3	2	3	4	2	2	2.38465	1.18275	2.34521
2	I	C	S	U	2	3	3	3	2	2	2	2	2	2	1.88172	2.99557	1.78071
3	I	C	S	U	3	2	2	2	3	4	4	2	3	2	2.16104	1.76715	3.78153
4	I	C	S	U	4	2	2	2	3	3	4	2	2	2	1.76646	1.81965	3.24616
5	I	C	S	U	5	3	3	4	2	3	3	2	3	3	2.57312	3.25559	2.54294
6	I	C	S	U	6	3	3	3	2	4	3	1	1	1	0.67427	2.93554	3.17503
7	I	C	S	U	7	2	2	2	2	3	3	1	1	1	0.72833	2.16055	2.96319
8	I	C	S	U	8	4	3	3	4	2	2	2	1	1	1.06541	3.27657	2.24622
9	I	C	S	U	9	3	2	2	3	3	3	2	2	2	1.78635	2.13582	2.51777
10	I	C	S	U	10	3	3	3	2	2	2	2	1	1	1.08679	3.02117	1.79943
11	I	C	S	U	11	2	2	2	3	3	3	2	2	2	1.80055	1.85921	2.91793
12	I	C	S	U	12	1	2	2	3	2	4	2	1	1	1.04353	1.59103	2.75771
13	I	C	S	U	13	2	3	3	2	2	4	3	2	1	1.74751	2.63620	2.45140
14	I	C	S	U	14	3	2	2	2	2	2	2	2	2	1.88174	2.20875	1.85373
15	I	C	S	U	15	4	4	4	3	3	3	2	1	1	0.97687	4.01199	2.78030
16	I	C	S	U	16	3	2	3	4	4	4	2	2	1	1.33653	2.44355	3.98896
17	I	C	S	U	17	2	2	4	3	3	2	3	1	2	1.62334	2.71132	2.41575
18	I	C	S	U	18	2	2	4	3	3	3	2	2	2	1.76319	2.91820	2.80455
19	I	C	S	U	19	2	1	3	3	3	2	2	2	2	1.81225	1.89398	2.55849
20	I	C	S	U	20	3	3	2	3	4	3	1	2	2	1.47740	2.50854	3.43439
21	I	C	S	N	1	2	1	2	1	1	1	1	1	1	0.92199	1.63389	0.67407
22	I	C	S	N	2	2	1	2	2	1	1	1	1	1	0.91858	1.62329	1.09315
23	I	C	S	N	3	4	4	4	2	3	2	2	1	1	1.01477	4.00216	2.22399
24	I	C	S	N	4	1	2	2	1	1	1	1	2	2	1.74307	1.72807	0.83270
25	I	C	S	N	5	2	1	1	2	2	2	1	1	1	0.83824	1.16973	1.58833
26	I	C	S	N	6	2	2	2	1	1	1	1	1	1	0.93357	2.02588	0.85127
27	I	C	S	N	7	2	2	1	1	1	1	1	1	1	0.94518	1.65369	0.90588
28	I	C	S	N	8	2	2	2	1	1	1	1	1	2	1.27645	2.03437	0.80451
29	I	C	S	N	9	3	4	3	2	2	2	2	1	1	1.09837	3.41715	1.77653
30	I	C	S	N	10	3	2	2	1	1	2	1	2	1	1.33655	2.23723	1.20737
31	I	C	S	N	11	2	2	1	1	1	1	2	1	1	1.20830	1.67966	0.87318
32	I	C	S	N	12	1	1	1	1	1	1	1	1	1	0.94815	0.96609	0.92944
33	I	C	S	N	13	5	5	5	3	3	2	4	4	4	3.90765	5.04068	2.25233
34	I	C	S	N	14	1	1	1	1	2	2	2	1	1	1.11934	0.90420	1.73232
35	I	C	S	N	15	2	2	2	1	1	1	1	1	1	0.93357	2.02589	0.85127
36	I	C	S	N	16	1	2	1	2	2	2	1	1	1	0.86439	1.28911	1.96503
37	I	C	S	N	17	3	3	3	2	2	2	1	1	2	1.16657	3.02519	1.78537
38	I	C	S	N	18	3	1	2	2	2	2	1	1	1	0.81208	1.83753	1.93355
39	I	C	S	N	19	4	3	3	2	2	2	2	1	1	1.07223	3.29779	1.79927
40	I	C	S	N	20	3	1	1	2	2	2	1	3	3	2.41356	1.39594	1.95072
41	I	R	S	U	1	3	3	3	3	3	4	6	6	6	5.98414	2.73451	2.96231
42	I	R	S	U	2	2	2	2	4	3	4	6	5	6	5.54328	1.73982	3.23593
43	I	R	S	U	3	3	2	3	4	4	4	5	6	6	5.64857	2.35466	3.74922
44	I	R	S	U	4	2	2	2	4	4	4	5	5	5	4.87979	1.71205	3.82272
45	I	R	S	U	5	3	3	3	4	4	4	6	5	5	5.12835	2.77631	3.71184
46	I	R	S	U	6	3	2	2	5	4	4	6	6	5	5.57658	1.94884	4.04137
47	I	R	S	U	7	2	3	2	5	5	5	5	6	6	5.59057	2.00987	4.93963
48	I	R	S	U	8	4	4	3	5	5	5	6	6	6	5.82497	3.35074	4.72960
49	I	R	S	U	9	2	2	2	4	4	4	5	5	5	4.87979	1.71205	3.82272
50	I	R	S	U	10	3	3	3	4	4	6	5	6	7	5.93409	2.67600	4.33552
51	I	R	S	U	11	3	3	3	4	4	4	6	6	6	5.92329	2.75111	3.69312
52	I	R	S	U	12	4	4	4	4	3	4	5	5	6	5.25101	3.86692	3.11227
53	I	R	S	U	13	2	3	2	4	4	4	6	5	6	5.49742	2.11301	3.71986
54	I	R	S	U	14	3	2	2	5	4	5	6	6	6	5.88540	1.91377	4.32285
55	I	R	S	U	15	2	3	3	4	4	4	5	5	5	4.87978	2.49923	3.74470
56	I	R	S	U	16	2	2	2	3	4	4	6	5	5	5.59835	1.69343	3.59458

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
57	I	R	S	U	17	4	4	3	4	4	4	5	5	5	4.86225	3.44844	3.72097
58	I	R	S	U	18	3	2	3	5	5	4	5	5	5	4.79278	2.34645	4.45475
59	I	R	S	U	19	2	2	2	5	5	5	5	5	5	4.78445	1.63909	4.88176
60	I	R	S	U	20	2	3	3	4	5	5	5	6	6	5.59278	2.41167	4.56154
61	I	R	S	N	1	3	3	5	2	2	4	3	2	2	2.05267	3.69969	2.29526
62	I	R	S	N	2	3	3	3	2	2	2	2	2	2	1.88172	2.99557	1.78071
63	I	R	S	N	3	2	3	3	2	2	2	4	3	4	3.56038	2.69995	1.65000
64	I	R	S	N	4	3	3	3	2	2	1	4	4	4	4.03234	2.98603	1.34764
65	I	R	S	N	5	2	1	2	2	2	2	3	3	3	2.94277	1.51146	1.83088
66	I	R	S	N	6	2	2	2	3	2	2	5	3	4	3.82012	1.90228	1.71880
67	I	R	S	N	7	2	3	2	2	2	1	4	4	3	3.71555	2.31378	1.45117
68	I	R	S	N	8	4	4	4	2	2	2	3	4	5	3.37724	4.00533	1.67915
69	I	R	S	N	9	2	3	4	2	1	1	4	5	4	4.54477	3.09376	0.81589
70	I	R	S	N	10	1	2	2	1	1	2	4	3	3	3.29290	1.66471	1.04413
71	I	R	S	N	11	3	2	2	2	2	2	3	5	4	4.18676	2.12917	1.31662
72	I	R	S	N	12	2	2	2	1	1	1	3	3	4	3.39261	1.98451	0.70167
73	I	R	S	N	13	3	3	3	2	2	1	4	4	4	4.03234	2.96609	1.34964
74	I	R	S	N	14	1	2	2	1	2	1	4	3	5	3.95577	1.69047	1.12972
75	I	R	S	N	15	2	1	3	2	2	2	5	4	4	4.25236	1.87839	1.69215
76	I	R	S	N	16	3	2	2	2	2	1	3	4	5	4.11214	2.20292	1.41360
77	I	R	S	N	17	2	4	4	2	3	2	4	4	4	3.95495	3.43428	2.10735
78	I	R	S	N	18	1	3	2	3	3	3	5	4	5	4.54926	1.93409	2.71240
79	I	R	S	N	19	2	2	2	1	2	1	3	3	3	2.99225	1.95762	1.25576
80	I	R	S	N	20	2	2	1	2	1	1	4	4	3	3.77305	1.54940	1.02185
81	I	C	L	U	1	3	4	4	5	5	5	5	4	5	4.31784	3.51975	4.69753
82	I	C	L	U	2	4	5	4	6	5	5	4	5	5	4.50036	4.15157	4.95817
83	I	C	L	U	3	4	4	4	6	6	6	5	5	5	4.65556	3.69369	5.78444
84	I	C	L	U	4	3	3	4	5	5	6	4	4	5	4.00864	3.08372	5.08186
85	I	C	L	U	5	4	4	3	6	6	6	4	4	4	3.61350	3.32723	5.89047
86	I	C	L	U	6	4	3	4	5	5	6	5	4	4	3.91425	3.35631	5.09576
87	I	C	L	U	7	3	3	3	6	5	6	4	4	4	3.67392	2.67743	5.40671
88	I	C	L	U	8	3	4	4	5	5	5	4	4	4	3.71180	3.51478	4.77698
89	I	C	L	U	9	4	4	4	5	6	5	4	5	4	4.09182	3.73850	5.31219
90	I	C	L	U	10	2	3	3	5	6	6	5	5	5	4.69250	2.36390	5.63931
91	I	C	L	U	11	3	2	3	5	5	4	2	3	3	2.41353	2.39544	4.63428
92	I	C	L	U	12	4	4	2	6	5	5	3	3	3	2.65857	3.02314	5.16094
93	I	C	L	U	13	5	4	4	5	5	5	6	6	6	5.79831	4.01854	4.67382
94	I	C	L	U	14	3	3	3	5	4	5	4	4	5	4.11217	2.75490	4.30091
95	I	C	L	U	15	4	3	4	5	5	6	4	5	5	4.44610	3.33064	5.10774
96	I	C	L	U	16	3	5	5	5	6	6	4	4	4	3.61585	4.23955	5.53453
97	I	C	L	U	17	4	4	4	6	5	6	5	5	5	4.71741	3.71649	5.27711
98	I	C	L	U	18	4	4	3	5	5	6	4	4	3	3.33144	3.35614	5.20642
99	I	C	L	U	19	2	3	3	4	4	4	5	4	5	4.42776	2.52893	3.71667
100	I	C	L	U	20	3	3	3	4	5	5	5	4	4	3.97835	2.73868	4.59893
101	I	C	L	N	1	3	4	3	3	3	3	5	5	4	4.62524	3.24030	2.70885
102	I	C	L	N	2	2	2	2	4	4	4	5	5	5	4.87979	1.71205	3.82272
103	I	C	L	N	3	2	3	3	4	3	3	4	3	3	3.11872	2.61153	2.97727
104	I	C	L	N	4	1	2	2	3	3	4	4	4	4	3.89714	1.49358	3.14349
105	I	C	L	N	5	2	2	3	4	4	4	3	3	3	2.75207	2.15270	3.87094
106	I	C	L	N	6	2	1	2	3	3	3	4	4	4	3.90545	1.41377	2.83850
107	I	C	L	N	7	4	5	5	4	4	5	4	5	4	4.21011	4.58228	3.99603
108	I	C	L	N	8	2	2	2	4	4	4	3	3	4	3.10658	1.76601	3.67390
109	I	C	L	N	9	2	2	2	3	3	4	4	3	3	3.08765	1.79539	3.16205
110	I	C	L	N	10	2	3	3	3	4	3	2	2	2	1.74345	2.62355	3.34725
111	I	C	L	N	11	2	2	2	3	4	3	5	5	4	4.57478	1.75773	3.31777
112	I	C	L	N	12	3	4	3	3	3	3	4	4	4	3.91409	3.26453	2.71351

STATISTICAL ANALYSIS SYSTEM

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
113	I	C	L	N	13	3	2	3	4	3	3	5	5	5	4.94557	2.44222	2.93238
114	I	C	L	N	14	4	4	4	3	3	3	5	4	5	4.49397	3.94229	2.57924
115	I	C	L	N	15	3	3	3	4	3	4	5	5	5	4.92267	2.75864	3.22721
116	I	C	L	N	16	2	2	3	4	4	3	4	3	3	3.04968	2.19274	3.51001
117	I	C	L	N	17	2	2	2	3	3	3	4	4	4	3.91708	1.80975	2.81565
118	I	C	L	N	18	3	2	3	4	3	3	4	4	5	4.23042	2.47144	2.93704
119	I	C	L	N	19	2	3	3	3	4	4	5	5	4	4.54028	2.56534	3.56798
120	I	C	L	N	20	2	1	2	3	3	3	4	4	4	3.90549	1.41377	2.83850
121	I	R	L	U	1	4	3	4	6	5	6	6	6	7	6.10660	3.30027	5.20234
122	I	R	L	U	2	3	3	3	5	4	6	7	7	6	6.45116	2.58656	5.58307
123	I	R	L	U	3	4	4	4	6	6	6	7	7	7	6.77609	3.64423	5.68161
124	I	R	L	U	4	4	4	4	6	6	5	7	7	7	6.81058	3.68380	5.35537
125	I	R	L	U	5	4	4	5	5	5	5	7	6	6	6.06450	4.13359	4.59668
126	I	R	L	U	6	4	4	3	5	6	6	6	7	6	6.18506	3.25868	5.55220
127	I	R	L	U	7	5	5	5	6	6	6	7	6	7	6.30949	4.75772	5.57559
128	I	R	L	U	8	3	4	4	5	5	5	6	6	6	5.82793	3.45532	4.67414
129	I	R	L	U	9	4	4	4	5	5	5	6	7	7	6.60831	3.71673	4.65526
130	I	R	L	U	10	5	4	5	6	6	5	7	7	7	6.78442	4.35160	5.29860
131	I	R	L	U	11	4	4	5	5	6	6	7	7	7	6.76785	4.04603	5.40352
132	I	R	L	U	12	4	4	4	5	5	5	7	6	7	6.41941	3.74690	4.59452
133	I	R	L	U	13	5	3	3	6	5	5	6	6	7	6.13823	3.22526	4.52356
134	I	R	L	U	14	3	3	4	5	6	5	7	7	7	6.81696	3.02181	5.15346
135	I	R	L	U	15	5	5	5	5	5	5	7	7	6	6.51395	4.77650	4.59114
136	I	R	L	U	16	3	4	3	5	5	5	6	7	7	6.63447	3.04893	4.71003
137	I	R	L	U	17	3	3	2	5	5	6	7	6	6	6.06818	2.24736	5.10231
138	I	R	L	U	18	4	4	4	4	4	4	6	6	6	5.90871	3.81490	3.61494
139	I	R	L	U	19	3	4	4	6	6	5	6	6	7	6.10999	3.43642	5.35820
140	I	R	L	U	20	5	4	5	5	6	6	7	7	7	6.75334	4.32264	5.40336
141	I	R	L	N	1	3	2	3	2	2	5	3	2	1	1.68688	2.47726	2.60288
142	I	R	L	N	2	2	2	2	3	4	3	5	5	5	4.91765	1.76223	3.27101
143	I	R	L	N	3	2	2	3	4	3	3	5	5	4	4.61722	2.16111	2.57925
144	I	R	L	N	4	2	2	2	3	3	3	4	4	4	3.91708	1.80975	2.81509
145	I	R	L	N	5	4	3	4	3	3	3	5	4	4	4.13947	3.54181	2.64945
146	I	R	L	N	6	3	3	3	4	4	4	4	4	4	3.80716	2.80057	3.75596
147	I	R	L	N	7	3	3	3	4	5	4	6	6	6	5.86584	2.72832	4.20045
148	I	R	L	N	8	2	1	2	3	3	2	5	5	6	5.34095	1.43316	2.41269
149	I	R	L	N	9	2	2	2	4	3	3	4	5	4	4.36565	1.76945	3.06660
150	I	R	L	N	10	3	1	3	3	4	4	4	5	5	4.58233	1.99400	3.60357
151	I	R	L	N	11	2	2	2	4	3	3	5	5	5	4.97173	1.77442	2.98715
152	I	R	L	N	12	3	2	2	3	3	3	4	5	4	4.35454	2.05667	2.84297
153	I	R	L	N	13	4	4	4	3	3	3	6	5	6	5.55204	3.91756	2.52787
154	I	R	L	N	14	3	3	2	4	4	4	5	5	5	4.87682	2.38465	3.79915
155	I	R	L	N	15	2	3	2	3	3	3	5	4	4	4.19175	2.20621	2.75895
156	I	R	L	N	16	1	2	3	3	4	3	5	5	6	5.26356	1.98130	3.16780
157	I	R	L	N	17	2	3	3	4	4	4	4	5	4	4.27374	2.45427	3.82415
158	I	R	L	N	18	2	2	3	4	3	3	6	6	6	6.01819	2.14088	2.88112
159	I	R	L	N	19	3	2	2	4	4	3	5	5	4	4.55681	2.02374	3.54108
160	I	R	L	N	20	2	2	2	3	3	3	5	5	5	4.97514	1.76502	2.76368
161	F	C	S	U	1	3	3	3	5	4	5	3	3	3	2.71120	2.77513	4.39708
162	F	C	S	U	2	2	2	3	5	5	5	3	4	3	3.10675	2.05004	4.95302
163	F	C	S	U	3	2	3	3	6	5	5	3	3	2	2.32199	2.46062	5.17691
164	F	C	S	U	4	3	3	4	5	5	4	4	3	4	3.28268	3.18806	4.44412
165	F	C	S	U	5	3	3	2	5	5	5	2	2	3	1.95020	2.39037	4.96565
166	F	C	S	U	6	3	4	3	5	4	3	4	4	4	3.84983	3.22552	3.66775
167	F	C	S	U	7	4	3	4	5	4	6	3	3	3	2.65055	3.40337	4.67254
168	F	C	S	U	8	3	3	3	5	6	4	2	2	1	1.22982	2.78934	5.18369

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
169	F	C	S	U	9	2	2	2	5	5	6	3	4	3	3.03586	1.61928	5.34086
170	F	C	S	U	10	2	2	3	3	3	2	3	2	2	2.09656	2.29044	2.50235
171	F	C	S	U	11	2	2	2	5	5	6	3	3	3	2.63383	1.64956	5.31283
172	F	C	S	U	12	1	2	2	5	4	4	3	4	3	3.23643	1.84059	4.15382
173	F	C	S	U	13	2	3	3	4	5	5	2	2	2	1.61365	2.51106	4.73452
174	F	C	S	U	14	2	2	2	6	5	5	4	3	3	2.92804	1.67641	5.17537
175	F	C	S	U	15	2	2	2	4	5	6	3	4	3	3.08926	1.62589	5.11735
176	F	C	S	U	16	2	1	2	5	5	5	3	3	3	2.65674	1.25256	5.00800
177	F	C	S	U	17	3	3	3	5	4	6	3	2	3	2.22468	2.76526	4.65928
178	F	C	S	U	18	2	4	6	5	5	4	3	3	3	2.67958	4.08485	4.35110
179	F	C	S	U	19	4	4	3	3	4	4	3	3	3	2.74953	3.50850	3.60033
180	F	C	S	U	20	4	3	3	5	5	6	3	4	4	3.39964	2.96416	5.21577
181	F	C	S	N	1	2	3	4	2	2	2	2	1	2	1.43265	3.14024	1.69825
182	F	C	S	N	2	2	2	2	1	2	1	3	2	1	1.85441	1.97833	1.32124
183	F	C	S	N	3	3	3	4	2	2	1	2	2	2	1.90461	3.42673	1.39787
184	F	C	S	N	4	3	3	4	2	2	2	2	2	2	1.87012	3.38716	1.72610
185	F	C	S	N	5	3	3	3	3	2	3	2	1	2	1.39180	2.97545	2.30435
186	F	C	S	N	6	5	5	6	3	2	4	3	3	3	2.82665	5.40027	2.39327
187	F	C	S	N	7	3	3	3	2	2	1	3	2	2	2.17934	3.03600	1.41976
188	F	C	S	N	8	3	3	3	2	2	2	2	2	1	1.53881	2.75147	1.82747
189	F	C	S	N	9	3	4	4	3	2	2	3	2	2	2.14143	3.77301	1.89347
190	F	C	S	N	10	4	4	4	3	3	3	4	3	3	3.09300	3.96253	2.67746
191	F	C	S	N	11	3	3	4	2	2	3	2	2	2	1.83562	3.34759	2.05433
192	F	C	S	N	12	4	4	4	3	2	3	3	2	2	2.09238	4.01006	2.22155
193	F	C	S	N	13	3	4	3	3	3	2	3	2	2	2.09558	3.35902	2.45542
194	F	C	S	N	14	3	4	3	3	3	2	3	2	2	2.09558	3.35902	2.45542
195	F	C	S	N	15	2	3	3	2	1	1	2	1	2	1.53619	2.81142	0.91727
196	F	C	S	N	16	3	2	3	2	1	2	1	1	1	0.86952	2.64751	1.34820
197	F	C	S	N	17	3	3	3	3	3	2	2	2	2	1.82087	2.96257	2.51152
198	F	C	S	N	18	3	4	4	3	3	3	2	2	2	1.78636	3.71018	2.76174
199	F	C	S	N	19	3	3	4	2	2	3	2	1	2	1.38361	3.37729	2.02630
200	F	C	S	N	20	3	3	4	3	3	3	3	2	2	2.07239	3.35423	2.42421
201	F	R	S	U	1	4	5	4	6	6	6	7	7	7	6.78768	4.04022	5.65820
202	F	R	S	U	2	3	3	4	5	5	5	7	7	7	6.87440	3.04461	4.64613
203	F	R	S	U	3	5	5	4	6	6	6	7	7	7	6.77312	4.31683	5.65404
204	F	R	S	U	4	4	5	5	5	6	5	7	7	6	6.47106	4.47709	5.09864
205	F	R	S	U	5	4	3	3	6	6	5	6	7	7	6.54747	2.89615	5.46409
206	F	R	S	U	6	5	5	6	4	5	5	1	2	2	1.29522	5.30596	4.55605
207	F	R	S	U	7	3	3	3	5	4	4	6	5	6	5.46786	2.77020	3.88856
208	F	R	S	U	8	5	5	5	6	6	6	7	7	5	6.07565	4.65903	5.69694
209	F	R	S	U	9	5	5	5	6	6	6	7	6	7	6.30949	4.73772	5.57539
210	F	R	S	U	10	3	3	4	5	5	6	6	6	7	6.12476	3.03426	4.97303
211	F	R	S	U	11	4	4	3	6	5	6	7	6	7	6.39311	3.30554	5.20085
212	F	R	S	U	12	3	3	4	5	5	5	6	6	7	6.15925	3.07383	4.65079
213	F	R	S	U	13	4	4	4	6	5	5	7	5	6	5.62107	3.76149	4.83673
214	F	R	S	U	14	4	5	4	6	6	7	7	7	6	6.41027	3.95616	6.03319
215	F	R	S	U	15	4	3	3	6	5	6	7	7	7	6.83355	2.87986	5.25229
216	F	R	S	U	16	3	3	4	5	5	3	4	4	3	3.42628	3.19343	4.19068
217	F	R	S	U	17	4	5	4	5	6	6	7	7	6	6.44817	4.04633	5.49148
218	F	R	S	U	18	5	5	4	3	3	3	6	6	6	6.00109	4.56047	2.53233
219	F	R	S	U	19	3	5	3	4	4	4	5	5	6	5.23131	3.57231	3.65097
220	F	R	S	U	20	4	5	4	5	6	6	7	7	7	6.79108	4.05083	5.43473
221	F	R	S	N	1	3	4	4	3	3	2	5	4	5	4.54302	3.70525	2.25121
222	F	R	S	N	2	3	3	3	2	2	3	5	4	4	4.22649	2.90741	1.97341
223	F	R	S	N	3	3	2	3	2	2	2	4	4	4	3.98626	2.55052	1.70128
224	F	R	S	N	4	3	3	4	2	2	1	5	5	5	5.07880	3.35254	1.24361

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
225	F	R	S	N	5	3	3	4	3	2	2	5	6	5	5.49253	3.27267	1.92335
226	F	R	S	N	6	4	4	4	2	2	3	4	5	5	4.74372	3.94553	1.90921
227	F	R	S	N	7	4	4	4	3	2	2	5	5	5	5.03793	3.97496	1.77175
228	F	R	S	N	8	4	3	4	2	2	2	5	4	5	4.57773	3.61928	1.54365
229	F	R	S	N	9	3	4	3	4	3	4	5	5	4	4.59135	3.19013	3.26056
230	F	R	S	N	10	5	3	5	4	3	3	4	3	3	3.05184	4.22374	2.86957
231	F	R	S	N	11	4	4	4	3	2	2	5	5	6	5.38085	3.97946	1.72500
232	F	R	S	N	12	4	4	5	3	3	3	5	5	5	4.93439	4.30379	3.55271
233	F	R	S	N	13	3	3	3	2	2	2	4	5	5	4.79279	2.92131	1.65915
234	F	R	S	N	14	3	3	4	3	2	2	5	5	5	5.04050	3.30237	1.75532
235	F	R	S	N	15	4	4	4	3	3	3	5	4	5	4.49357	3.94229	2.57929
236	F	R	S	N	16	3	4	3	2	2	2	4	4	5	4.35235	3.34659	1.60771
237	F	R	S	N	17	3	4	3	3	3	3	4	4	4	3.91409	3.26953	2.71351
238	F	R	S	N	18	3	3	3	3	3	3	4	5	4	4.35453	2.84385	2.76495
239	F	R	S	N	19	3	3	3	4	5	4	4	4	5	4.09262	2.78227	4.25653
240	F	R	S	N	20	3	3	3	4	2	2	6	5	5	5.31223	2.96104	2.04071
241	F	C	L	U	1	3	4	4	5	5	6	6	6	6	5.79344	3.42576	5.00238
242	F	C	L	U	2	4	4	4	5	5	5	6	6	6	5.81337	3.74193	4.67398
243	F	C	L	U	3	4	4	4	5	6	6	5	5	5	4.66337	3.70430	5.56057
244	F	C	L	U	4	5	4	4	6	5	6	5	5	6	5.04576	3.95760	5.23019
245	F	C	L	U	5	3	3	4	5	5	5	5	4	6	4.64517	3.12826	4.67418
246	F	C	L	U	6	4	4	4	4	3	4	4	4	4	3.85003	3.48716	3.21345
247	F	C	L	U	7	3	3	2	4	5	5	5	5	6	5.12780	2.32678	4.58796
248	F	C	L	U	8	3	4	3	5	5	6	6	6	6	5.80504	3.03456	5.05659
249	F	C	L	U	9	4	4	3	5	6	6	5	5	5	4.67457	3.31311	5.61558
250	F	C	L	U	10	3	4	3	5	5	6	6	6	6	5.80504	3.03456	5.05659
251	F	C	L	U	11	3	3	3	5	5	5	7	6	6	6.09107	2.67862	4.71947
252	F	C	L	U	12	4	4	4	5	5	5	6	6	7	6.15628	3.74643	4.62723
253	F	C	L	U	13	3	3	3	4	4	4	5	5	5	4.86522	2.77584	3.74454
254	F	C	L	U	14	3	3	3	5	5	5	6	6	6	5.82754	2.67814	4.75216
255	F	C	L	U	15	3	3	4	6	5	5	7	6	6	6.07606	3.05920	4.88933
256	F	C	L	U	16	4	4	4	5	6	5	6	6	5	5.41301	3.71464	5.22807
257	F	C	L	U	17	3	3	3	5	4	4	5	5	6	5.20473	2.76573	3.92126
258	F	C	L	U	18	4	4	5	5	5	4	6	6	7	6.17917	4.17718	4.24433
259	F	C	L	U	19	4	4	3	4	5	5	5	6	6	5.56525	3.36088	4.53782
260	F	C	L	U	20	4	4	4	5	5	5	5	6	6	5.55024	3.74146	4.70668
261	F	C	L	N	1	2	3	2	2	2	3	2	2	3	2.21630	2.29310	2.11696
262	F	C	L	N	2	3	1	2	2	2	2	3	2	2	2.13327	1.81327	1.84944
263	F	C	L	N	3	4	3	3	2	3	2	2	2	2	1.80972	3.24978	2.28788
264	F	C	L	N	4	3	2	3	2	2	2	3	3	2	2.58525	2.57076	1.75946
265	F	C	L	N	5	3	3	3	2	2	2	3	3	3	2.93575	2.97124	1.72925
266	F	C	L	N	6	4	4	4	2	3	2	1	2	2	1.54658	4.03649	2.24256
267	F	C	L	N	7	2	2	2	2	3	3	3	4	4	3.65736	1.81989	2.62431
268	F	C	L	N	8	4	3	4	3	3	2	3	2	2	2.05783	3.63064	2.42405
269	F	C	L	N	9	3	3	3	4	4	4	2	2	2	1.69103	2.85003	3.89879
270	F	C	L	N	10	2	3	2	2	1	1	3	2	2	2.26295	2.39100	0.96722
271	F	C	L	N	11	3	4	3	2	2	2	2	1	1	1.09837	3.41715	1.77603
272	F	C	L	N	12	3	3	4	2	2	2	1	1	1	0.81206	3.41189	1.77752
273	F	C	L	N	13	4	4	3	3	3	2	1	2	2	1.55477	3.63469	2.52065
274	F	C	L	N	14	3	3	4	2	2	1	2	1	1	1.10967	3.45193	1.41659
275	F	C	L	N	15	4	4	4	3	3	2	2	2	1	1.46338	4.02186	2.48010
276	F	C	L	N	16	3	3	2	2	3	2	2	2	2	1.83588	2.58158	2.34266
277	F	C	L	N	17	3	4	5	3	2	3	2	2	3	2.17512	4.12866	2.15303
278	F	C	L	N	18	2	2	3	4	4	4	2	3	2	2.14603	2.14774	3.95039
279	F	C	L	N	19	3	4	3	2	2	2	1	1	1	0.63525	3.41668	1.80972
280	F	C	L	N	20	4	4	5	3	3	3	2	2	2	1.76020	4.37799	2.70696

STATISTICAL ANALYSIS SYSTEM

OBS	COL	SHAPE	SIZE	DIST	SUB	S1	S2	S3	S4	S5	S6	S7	S8	S9	FACTOR1	FACTOR2	FACTOR3
281	F	R	L	U	1	5	5	3	4	6	7	7	6	6	5.96211	3.93248	5.61266
282	F	R	L	U	2	4	4	4	5	5	6	6	6	6	5.77886	3.70237	5.60222
283	F	R	L	U	3	4	5	4	5	5	5	6	6	7	6.16787	4.14241	4.60382
284	F	R	L	U	4	5	5	4	5	6	6	7	6	6	5.98159	4.35264	5.45329
285	F	R	L	U	5	3	4	4	6	5	5	6	6	7	6.16743	3.45921	4.85087
286	F	R	L	U	6	3	2	3	4	4	5	6	6	6	5.87721	2.31556	4.04476
287	F	R	L	U	7	4	4	5	6	5	6	6	5	6	5.31185	4.11265	5.14305
288	F	R	L	U	8	4	5	4	6	6	7	6	6	5	5.35221	4.02565	6.08461
289	F	R	L	U	9	5	5	5	6	6	6	7	7	7	6.76152	4.70802	5.60343
290	F	R	L	U	10	3	3	3	4	5	4	6	5	6	5.41382	2.75801	4.17242
291	F	R	L	U	11	4	5	5	5	5	5	5	5	5	4.75529	4.55384	4.64758
292	F	R	L	U	12	3	4	4	5	6	5	6	7	6	6.22250	3.41283	5.20751
293	F	R	L	U	13	4	4	4	5	6	5	7	6	6	6.01905	3.71561	5.14862
294	F	R	L	U	14	4	4	3	6	5	5	6	6	6	5.82156	3.34014	4.95207
295	F	R	L	U	15	3	4	3	5	5	5	6	6	6	5.83955	3.07413	4.72176
296	F	R	L	U	16	5	6	5	4	4	4	6	6	6	5.90573	5.27468	3.51336
297	F	R	L	U	17	2	3	2	5	4	5	6	7	6	6.36357	2.00345	4.32762
298	F	R	L	U	18	4	3	3	6	5	5	6	6	7	5.15289	2.94865	4.92872
299	F	R	L	U	19	5	3	3	5	4	4	6	6	5	5.54785	3.28924	3.96103
300	F	R	L	U	20	3	2	3	4	5	5	6	6	6	5.81976	2.29276	4.55209
301	F	R	L	N	1	1	1	2	1	1	1	2	1	1	1.19967	1.35775	0.84214
302	F	R	L	N	2	2	1	2	2	2	2	3	3	2	2.59986	1.50657	1.87763
303	F	R	L	N	3	3	3	3	2	3	2	1	1	1	0.76621	2.95790	2.33946
304	F	R	L	N	4	3	2	3	2	3	2	2	2	1	1.46977	2.57269	2.35821
305	F	R	L	N	5	2	1	1	2	2	2	1	1	1	0.83824	1.16573	1.98833
306	F	R	L	N	6	2	3	2	3	2	2	2	1	2	1.45245	2.34726	2.03093
307	F	R	L	N	7	3	3	3	2	3	2	1	1	1	0.76621	2.95790	2.33946
308	F	R	L	N	8	4	3	4	3	3	3	2	2	2	1.76022	3.55090	2.78498
309	F	R	L	N	9	4	4	4	2	1	1	1	2	2	1.69556	4.12165	0.85566
310	F	R	L	N	10	2	3	2	3	3	3	3	3	2	2.52769	2.22597	2.88936
311	F	R	L	N	11	2	2	2	4	4	4	2	2	2	1.70560	1.78624	3.97697
312	F	R	L	N	12	3	2	2	2	3	3	1	1	1	0.73173	2.17116	2.74571
313	F	R	L	N	13	3	3	3	2	2	2	1	1	1	0.82366	3.02070	1.83213
314	F	R	L	N	14	2	3	3	3	4	4	2	2	2	1.70960	2.58463	3.67548
315	F	R	L	N	15	4	4	5	3	3	2	1	1	1	0.73663	4.44227	2.43015
316	F	R	L	N	16	2	2	3	2	1	2	1	1	2	1.22699	2.37539	1.30161
317	F	R	L	N	17	3	3	3	2	2	2	1	1	1	0.82366	3.02070	1.83213
318	F	R	L	N	18	2	2	2	3	3	3	2	2	1	1.45804	1.85472	2.56469
319	F	R	L	N	19	2	3	3	1	2	2	4	4	4	4.01581	2.68050	1.45456
320	F	R	L	N	20	4	5	4	3	3	3	2	2	2	1.78339	4.38277	2.73817

APPENDIX II

DESCRIPTION OF SYMBOLS

Semantic Scales

S1 - "Clear-Hazy"
S2 - "Distinct-Vague"
S3 - "Bright-Dim"
S4 - "Large-Small"
S5 - "Spacious-Cramped"
S6 - "Horizontal-Vertical"
S7 - "Beautiful-Ugly"
S8 - "Pleasant-Unpleasant"
S9 - "Like-Dislike"

Factors

FACTOR 1 - Evaluation
FACTOR 2 - Visual Clarity
FACTOR 3 - Spaciousness

General

COL - Source Color
DIST - Distribution Pattern
SUB - Subjects
OBS - Observations
I - Incandescent Light Source
F - Fluorescent Light Source
C - Circular Luminaire Shape
R - Rectangular Luminaire Shape
S - Small Luminaire Size
L - Large Luminaire Size
N - Non-uniform Distribution
U - Uniform Distribution

SUBJECTIVE CRITERIA FOR LIGHTING SYSTEMS DESIGN USING A SCALE MODEL

by

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ABSTRACT

The main objective of this study was to try to determine the aesthetic aspects of lighting systems designs that create preference of a particular lighting system design over the others using a scale model representation of a waiting lounge.

A model of a waiting lounge, of dimensions 24" x 12" x 10", was made to the scale of one inch equals to one foot. Sixteen lighting conditions (two source colors, two luminaire surface shapes, two luminaire surface sizes, two distribution patterns) were considered in this experiment. Each subject was exposed to eight different ceiling luminaire patterns under one of the source colors only, either incandescent or fluorescent. A total of 40 subjects evaluated the lighting conditions in two groups, each of 20 subjects, on nine semantic scales. Subjects in a particular group were exposed to only one particular source color.

The data was factor analyzed and three factors, evaluation, visual clarity, and spaciousness emerged. Further analysis showed that luminaire shapes, sizes, and distribution patterns did effect the subjective reactions significantly. Source color did not effect the evaluative factor.

The circular luminaire surface shape, smaller luminaire size, and non-uniform distribution achieved more visual clariety, spaciousness, and were preferred. Incandescent source color achieved more visually clear and spacious luminous space but incandescent and fluorescent both were equally preferred.