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LIGHTING CUES TO VISUAL CLARITY

by

SHYAM N. GETTU

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INTRODUCTION

In the development of electric lighting in the 20th century the year 1973 was a significant turning point. Lighting design priorities have always been discussed and considered, but not with the social urgency that accompanied the "energy-crisis" of 1973 nor with the economic urgency that has accompanied the rising power costs that have characterized the period since 1973.

The post-1973 period has therefore produced many questions regarding the value of lighting. Unfortunately, however, the question, "What does lighting contribute to a building interior?", has too often resulted in simplistic discussions that are limited to task visibility and immediate task performance. Without downgrading the obvious importance of lighting in task visibility, it seems equally obvious that light contributes in other ways to the visual quality of the room and to the sense of well-being felt by the users of that room.

Thus lighting has two main effects namely on:

- (a) Visual performance in a space
- (b) Subjective impressions of a space .

Measurements of visual performance involve physical measurements and task performance whereas subjective impressions of a space may not require a visual task. There are positive and negative aspects to the influence of lighting on

impressions. The positive effects involve pleasure and the negative effects involve complaints of discomfort. Lighting can give an interior a character and has the capacity to communicate impressions of invitation, boredom, relaxation and interest. Thus, lighting can be a vehicle that facilitates the selective process and alters the information content of the visual field. These themes of information content suggest that some aspects of a lighted space can be recognized and documented if one is prepared to discuss and study lighting design as an exercise in visual communication. This suggests that when the designer changes the lighting modes (ie. the patterns of light, shades and color in the room), he changes the composition and relative strength of visual signals and cues. This in turn alters some impressions of meaning for the room occupant or user. In contrast the designer may use all of the technical material available to him and yet be unable to create an environment that is aesthetically pleasing.

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

Bruno Bettelheim (psychologist)

In this sense, one may note that many lighting systems are designed merely to function in a "permissive" way (ie.

simply to permit performance or participation in some activity that involves vision, without attempting to influence user impressions or other behaviors).

A number of investigators have studied the relation of visual performance to the level of illumination, usually in terms of speed and accuracy. Some have dealt with specific practical tasks in typical work situations. Others have conducted laboratory investigation of the basic factors which influence visual performance. Guth, S.K., et al (1951) showed that visual ability, evaluated with respect to contrast and size discrimination and speed of vision, improves with task luminance or illumination. The illumination must be adequate in quantity, direction and spectral quality.

Lighting Aesthetics

Bennett (1977) indicated in order of importance the ergonomic criteria applicable to all objects of human use including lighting systems:

- (1) Health and Safety
- (2) Performance
- (3) (Dis)comfort
- (4) Aesthetics

Aesthetics, in its narrow sense refers to beauty, in a broader sense it refers to all subjective impressions.

The term aesthetics of a lighting environment is con-

cerned with its quality rather than the quantity of illuminance (illumination). Quality of lighting is a term used to describe all factors in a lighting installation not directly concerned with the quantity of illumination (lux or footcandles). It is obvious that if a given room is alternately lighted with a bare bulb and with a luminous ceiling, both giving the same average quantity of illumination, there is a vast difference in the effects of the two lighting systems. The difference is in the quality of the lighting, a term which describes the luminance ratios, uniformity and chromacity of the lighting. Aesthetics of a lighted space are complex phenomena to explain as they are the combined effects of various things that describe the quality of lighting. Aesthetic measurement has generally been subjective.

Semantic Differential Technique

A tool to evaluate the aesthetics of lighting is the semantic differential technique. Each semantic rating scale consists of two words, one on each end of a scale. These words are opposite in meaning. The scale is divided uniformly from one end to the other into a convenient number of segments, the segments convey degrees between the two anchor words in an ascending or descending order. For example, the scale shown below is a semantic differential rating scale.

DIM 1 2 3 4 5 6 7 BRIGHT

This 1 to 7 scale may be defined as

1. Very dim
2. Moderately dim
3. Slightly dim
4. Neutral
5. Slightly bright
6. Moderately bright
7. Very bright

The semantic differential technique was developed by Osgood et al (1957). It is the most widely used technique in the study of subjective responses to the built environment. The scales correspond to the verbal mode by which occupants most often express their perceptions, thoughts, feelings, attitudes and behaviors concerning their environment. An advantage of the semantic differential scale technique is that it can be applied to a wide area of situations. It can be employed to discover the relationships between the form of the physical environment and the reactions of those who occupy it. One may have a large number of scales which convey the same meaning or a similar meaning. This is why factor analysis is used; factor analysis reduces the data of a large number of scales which are to some degree correlated, to that of a smaller number of factors or dimensions which are independent.

Several studies have been conducted on the use of semantic scales for measurement of meaning in the architectural environment; some of the recent studies were by Vielhaver (1965), Canter (1968), Craik (1968), Collins (1969), Brittell (1969) and Hershberger (1972). There was noteworthy agreement between all of the above researchers on the first factor, which is usually labeled "aesthetic evaluation". This factor had substantial loadings of such scales as pleasant, cheerful, colorful, bright, impressive, gay, etc. A second factor "organization" was also found to be common to all the research. It had substantial loadings of such scales as neat, orderly, tidy, organized, clear, calm, etc. A third "space" factor was evident for four of the researchers with loadings of such scales like roomy, large, wide, flexible, spacious, open, etc. A "potency" factor was also found by three researchers with loadings of such scales like rough, coarse, rugged, strong, etc.

Flynn et al (1973) attempted to develop a standardized research procedure for studying subjective effects on environmental lighting. They did important work employing semantic differential scales in measuring subjective impressions in lighting. Their research with such scales had identified several factors or broad categories of impressions that can be cued or modified by lighting systems. Three categories of impressions found are :

1. Impressions of pleasantness

2. Impressions of visual clarity.
3. Impressions of spaciousness.

For the purpose of the present research "semantic differential" rating scales will be used for the measurement of subjective reactions to lighting.

Scale Modeling Technique

One major problem is how to represent a designed environment before it is built. The question, therefore is how a lighting system can be evaluated as a part of the total environment prior to actually creating the environment. Perhaps even more important is how different lighting systems can be evaluated to establish a system of design.

One can attempt to experiment with structures, either in full scale or real time or in terms of simulated settings abbreviated in time or space. Full scale, real time simulations are relatively rare, they are expensive to create realistically. Accordingly in some cases lighting researchers have turned to small scale simulations which allow them to make evaluations of real lighting environments.

Small scale representations, simulations or mockups of built spaces can be used for lighting design study. Some simulations can be effective for some purposes but not for others; thus, in experimentation the simulation technique one uses will vary with the kinds of forms and spaces to be

represented. Although one cannot say with certainty whether responses to a simulated lighting environment using scale models will be the same as when expressed in full scale, it would not be unreasonable to say that scale models to a large extent realistically represent lighting systems. Scale models have been used by lighting designers to evaluate the luminous environment to demonstrate system performance differences.

Lemons and MacLeod (1971) did a study of scale models for lighting systems design and evaluation. In this study the researchers used a scale model to arrive at the quality evaluation of a lighting systems design prior to actually constructing the real environment. From the research, it was found that the quality of lighting within the environment is more dependent upon luminance ratios than quantity per se (horizontal footcandles). The luminance ratios are dependent upon the brightness of the luminaires, ceiling, walls and floors. The model according to the authors could provide unlimited variations to reproduce any lighting system and environment.

Subjective Reactions to Lighting.

Flynn, Spencer, Martynirk and Hendrick (1973) have done a very important study entitled "Interim study of procedures for investigating the effect of light on impressions and behavior". The study was conducted at the General Electric

Lighting Institute at Nela Park near Cleveland in a room set up as a conference room. The room was rectangular in shape with a rectangular conference table and ten chairs around it. The room had six lighting arrangements that permitted significant variation in the visual character of the space without changing any of the other conditions. Ratings were analysed from 12 groups with a total of 96 subjects in groups of eight

The six arrangements of the study were as follows:

- (1) Overhead down lighting, low illuminance, 10 fc
- (2) Peripheral wall lighting, all walls 10 fc
- (3) Overhead diffuse, low setting 10 fc
- (4) Combination: Overhead downlighting (1)
+ end walls 10 fc
- (5) Overhead diffuse, high intensity 100 fc
- (6) Combination: Overhead down lighting (1)
+ peripheral (2) + Overhead diffuse (3) 30 fc

The principal subjective factors of the semantic scales used in the study were a general "evaluative" factor which had scales like pleasant..... unpleasant, a "perceptual clarity" factor which had scales like clear.....hazy and a "spaciousness" factor which had scales like spacious.....cramped. The results showed that the highest condition on evaluation was the combination arrangement: Overhead down lighting (1) + peripheral lighting (2) + overhead diffuse (3). For perceptual clarity overhead diffuse and

high intensity was the best. Impressions of spaciousness resulted from peripheral rather than overhead lighting. This study has contributed useful information on how lighting environments should be designed and what particular features of lighting arrangements will have positive reinforcements for the inhabitants.

Flynn (1976) performed a study with subjective responses to low -energy and non-uniform lighting systems. He used three factors of subjective impressions; evaluative, visual clarity and spaciousness. Each of these factors was based on appropriate semantic scales. He used seven lighting arrangements with variation in levels; central down lighting, peripheral (wall) lighting and central diffuse lighting. Flynn found that when impressions of general clarity are important, bright uniform overhead lighting was preferred. Cool white fluorescent lamps were rated as being "clear" but the high pressure sodium discharge lamp installations were considered as "hazy" and "vague". This supported Flynn's concept that lighting provides a number of cues which people use to interpret or "make sense" of a space. Flynn's basic point is correct but until a much wider set of interiors and lighting conditions have been examined, the generality of the cues must be open to question.

Ali (1978) performed an experiment based upon that of 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 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 also showed that scale models could effectively simulate real lighting conditions.

Spaciousness

Inui and Matsuda, (1971) carried out work on "spaciousness" at the Building Research Institute, Tokyo. Observations in scale models differing in spaciousness under an artificial sky had been carried out by Inui and Matsuda. From these studies spaciousness for different sky luminances was shown to be a function of interior luminance, room size and window size. Observations in full scale interiors were also made to confirm the results. From additional experiments it was found that a lower limit of just acceptable spaciousness did exist. This was a criterion for design. One of the aims of their experiment was to establish the relationship between spaciousness and physical room factors and to find an empirical formula for the prediction of spaciousness.

The physical variables used were window size (W), room size (R), average illuminance (L) and sky illuminance (S). Power relations between spaciousness and the three experimental variables for three different levels of sky luminance

were obtained. Interactions between the physical variables were studied and the correlations between spaciousness and physical variables were determined.

The empirical spaciousness formula developed was written as

$$\text{Spaciousness, } Sp = C \cdot L^{\alpha} \cdot R^{\beta} \cdot W^{\gamma}$$

where the coefficient C , varies according to the choice of the units, is determined by the method of least squares.

The authors suggested that the spaciousness formula could be of use as an index to evaluate the visual environment.

Illuminance Vs Luminance

A light source produces a quantity of luminous flux (lumens, ϕ , lm-metric and -English) which falls on a surface as illuminance (also, illumination, E , footcandles-English, lux-metric, $fc = 10.76 \text{ lx}$). The illuminance may be reflected from a surface (reflectance, ρ , dimensionless, 0 to 1) or transmitted through a surface (transmittance, τ , dimensionless, 0 to 1). The reflected or transmitted light is luminance (photometric brightness, L , footlamberts- English, candellas/square meter or nits, cd/m^2 -metric, $fl = 3.43 \text{ cd/m}^2$). Brightness or luminance is what people see so that in terms of physical characteristics the effectiveness of the lighting system depends on upon the flux of the source, the relation of the surface to the source and the character of the surface: $E = d\phi/da$, where A is the area, ft^2 . Also, L

= (E) (ρ) or (E) (τ).

While luminance is what people see, quality electronic photometers are used to measure it. Illuminance is measured by means of a lightmeter.

Visual Clarity

Generally in utilitarian spaces, like workshops, class rooms, and offices uniformly distributed fluorescent lighting is used. That is because of the emphasis given to the quantity and economy rather than the aesthetics of illumination in the spaces.

The lighting industry offers to purchasers a range of fluorescent lamps suitable for use in interiors. The range is classified according to the Luminous Efficacy (lumens/watt) and Color Rendering Index. Luminous efficacy defines the efficiency of the lamp at turning electric power into light. The color rendering index is a measure of how accurately the lamp reveals color compared with some (incandescent) reference source. There is a trade-off between luminous efficacy and color rendering index. As it turns out the higher the luminous efficacy the lower the color rendering index. This trade-off provides a problem for the designer. Should he save operating expense by using a high efficacy lamp to provide the required illuminance, thereby minimizing running costs or should he seek to provide a better quality lighting installation by using the good color rendering

lamps although this will increase the capital and running costs, or should he compromise and use the good color rendering lamps at a lower illuminance? Usually the problem has been solved intuitively by the designer in terms of what he thinks is desirable or most probably by the client requiring the most economical installation. However, in recent years evidence has appeared that the most appropriate criteria for judging the performance of a light source are yet to be found. For example a phenomenon called "visual clarity" is emerging as a criterion one cannot afford to ignore.

Aston and Bellchambers (1969) have aided the decision by quantifying the illuminances that are required for equal satisfaction in similar interiors lit by different fluorescent lamps. Specifically, it was found that with two colored interiors, one lit by a high efficacy lamp and the other by a good color rendering lamp, the illuminance of the good color rendering lamp was 20% lower than the high efficacy lamp when matched for equal satisfaction. Aston and Bellchambers used the term "visual clarity" in the sense of satisfaction. This finding considerably narrows the economic gap between the various lamps.

Bellchambers and Godby (1972) extended the original study to room size enclosures, using 60 observers. They found that "delux" lamps required about 25% less illuminance level to produce visual clarity equal to that of standard lamps. In

this study the percentage difference between matched illuminances for equality in satisfaction increased as the standard illuminance increased.

Boyce (1975) validated and extended the studies by Aston, Bellchambers and Godby. He found that the trade-off between illuminance and lamp color properties occurred over a wide range of interior colors and was independent of the illumination over a range of 300-600 lux. Variations in illuminance were achieved by mechanical means. This was necessary since the alternative of electric dimming produces changes in spectral emission of the lamps. He used two identical scale models lit to the same illuminance. The only difference between them was that one was lit by a high efficacy lamp and the other by a good color rendering lamp. Four fluorescent lamps were used; "white" color, "natural" lamp, "kolor-rite" lamp and "grolux" lamp (British lamps). The study was conducted for three levels of illumination, three levels of colorfulness of the interior and four combinations of lamp type. The two offices were furnished as mirror images with model desks, chairs and people. The experiment was designed so that each subject made adjustments to the illuminance level until the visual appearance of the two offices looked equally satisfactory. This was done for all the treatment combinations of the independent variables. Care was taken to emphasize that the two offices would not look the same. Boyce supports Bellchamber's work that the illuminance level

of a good color rendering lamp was 25% lower than the high efficacy lamp when matched for equal clarity. This result was extended to work areas of varying colorfulness. Boyce also found that with high illumination levels, the clarity, colorfulness and pleasantness was greater.

Chowdhury (1982) carried out an experiment to investigate which single aspect or combination of his experimental variables would present a more visually clear, spacious and preferred luminous interior. The four experimental variables were types of lamps (incandescent and fluorescent), luminaire size (small and large), luminaire shape (circular and rectangular) and distribution patterns of the lamp (uniform and non-uniform). A scale model of a waiting lounge instead of a real environment was used. The sixteen treatment combinations were evaluated at an average illumination level of 11 footcandles at table level.

The result of this experiment showed that the smaller luminaire size presented a more visually clear luminous space. The experimenter found that when a lighting design with a smaller luminaire area was studied, the brightness of the luminaires had to be increased to maintain the constant illumination level of 11 footcandles. This increase in the brightness (luminance) of the luminaire had a positive influence on the subjects evaluation of visual clarity and possibly explains the reason why a smaller luminaire area produced more clarity. Thus the effect of the luminaire area

on visual clarity was not independently studied, and a further investigation was suggested. In a similar study by Gettu and Prabhakar (1982) the same results were obtained.

Most of the studies done so far on visual clarity were performed in complex colorful interiors and dealt with the color properties of the lamp. The results of Boyce's studies conclude that bright uniform cool-white fluorescent lamps create impressions of high visual clarity.

The phenomenon of visual clarity needs to be investigated further. Quantitative and operational attributes need to be defined. Proof of existence and usefulness of visual clarity could lead to recommendations for lower light levels for specific tasks and functions resulting in energy savings. (IES/NBS Illumination Roundtable II, January 1981.) plane luminance was not considered.

Visual clarity is the perceived ability to perform a visual task (C.A. Bennett). This indicates that visual clarity relates to the luminance on the work plane. Since illumination cannot be seen, it would seem reasonable to hypothesise that the luminance on the workplane has an effect on visual clarity. As resulted from past studies, the illumination on the workplane has an effect on visual clarity. Again, since visual clarity deals with one's perception, another hypothesis that the luminaire luminance has an effect on visual clarity is suggested. Visual clarity is of importance in

spaces involving a performance of a task, and normally these spaces do not involve complex colorful interiors. For these reasons a simple achromatic interior would be of interest to investigate the effect of the lighting intensity factors on visual clarity.

PROBLEM

Research has been carried out to investigate the visual clarity in office interiors over a range of interior colorfulness for different fluorescent lamps.

The object of the present research is an attempt to investigate quantitatively how certain lighting intensity factors create an impression of high visual clarity. The three lighting factors chosen were luminaire luminance, workplane luminance and luminaire area. This study used a scale model with an achromatic interior instead of a real environment.

The main aim of this experiment was:

To establish the relationship between visual clarity and luminaire luminance, workplane luminance, luminaire area; and to find an empirical formula for the prediction of visual clarity.

The following hypotheses would be tested:

1. Larger luminaire luminances will present a more visually clear interior.
2. Larger workplane luminances will present a more visually clear interior.
3. Larger luminaire areas will present a more visually clear interior.

METHOD

In this study a scale model was used for investigating three lighting factors presumed to affect Visual Clarity. The lighting conditions were varied and subjective judgments were made by the subjects for these different lighting designs on semantic differential rating scales. The ceiling luminaire area and the reflectance of the three walls could be changed. This model was set up in a cool white delux fluorescent lighting booth (Figure.1). The illumination level could be varied by means of a dimmer. The subjects in the study observed the scale model under the different lighting systems and made subjective judgments of the workplace on various rating scales for the combinations of the independent variables.

Model

For the present study a model of the size 24"x12"x10" representing a scale of 1 inch = 1 foot was used to simulate a room of dimension 24'x12'x10'. The model was made with white "foam core" on three side walls. The walls and the ceiling of the model were white and the floor had a dull grey surface simulating a carpet. Above the ceiling was the lighting arrangement; it consisted of four 40 watt cool white delux fluorescent lamps. The achromatic interior was furnished with a chair and a desk, on the desk a piece of white paper (to scale) was placed to simulate a 11"x 8 1/2"

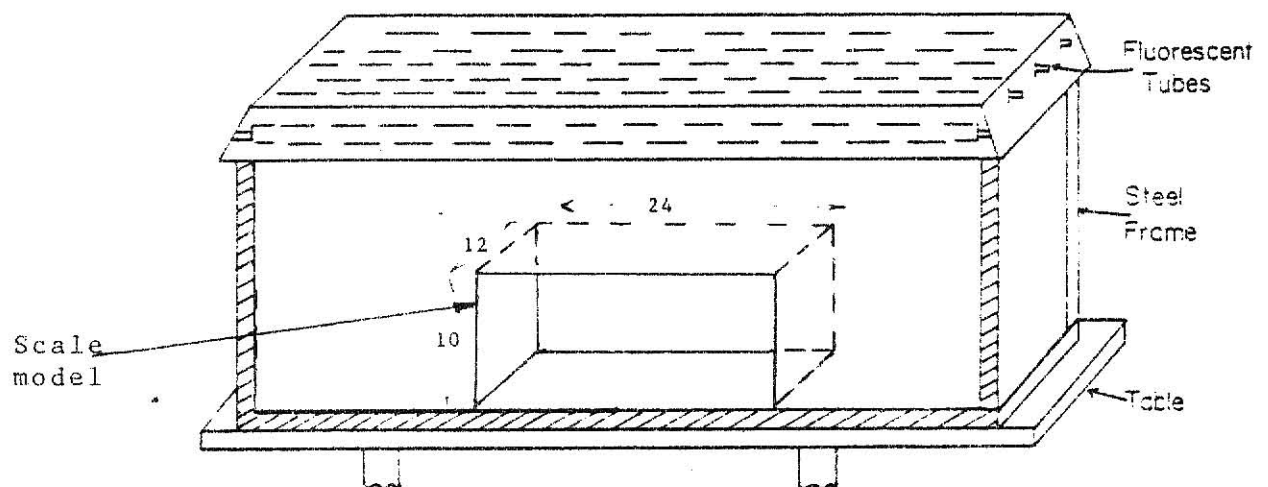


Figure 1. Structure of the lighting booth and scale model.

paper. This was done to aid the subject in his/her judgment of clarity on the working plane.

The model was provided with three different ceiling types. Each ceiling consisted of a certain percentage of area devoted to lighting. A luminous ceiling represented the extreme case (occupying 100% of the ceiling area). Survey of classrooms and other fluorescent lighted spaces at Kansas State University showed uniformly spaced luminaires occupying 10% of the ceiling area as typical. An intermediate luminous area of 50% was also selected. These layouts are shown in Figure 2. The light enters the model through a diffuser mounted on the ceiling.

The workplane was at a height of thirty inches above the floor level. Assuming the reflectance of the workplane to be 50% and referring to the recommended ranges of illumination on the workplane for various office type activities (Figure 2.); five luminance values ranging from 10 to 100 fL were potentially of interest in this study. Luminaire luminances and areas limited the five levels to 10, 20, 30, 40 and 50 fL. By surveying the classrooms at Kansas State University it was seen that the luminaire luminance was between 1000 and 4000 fL. The five luminaire luminance levels used in the study were 4000, 3560, 2500, 1440 and 1000 fL. The intermediate levels were required by the experimental design (Table 2).

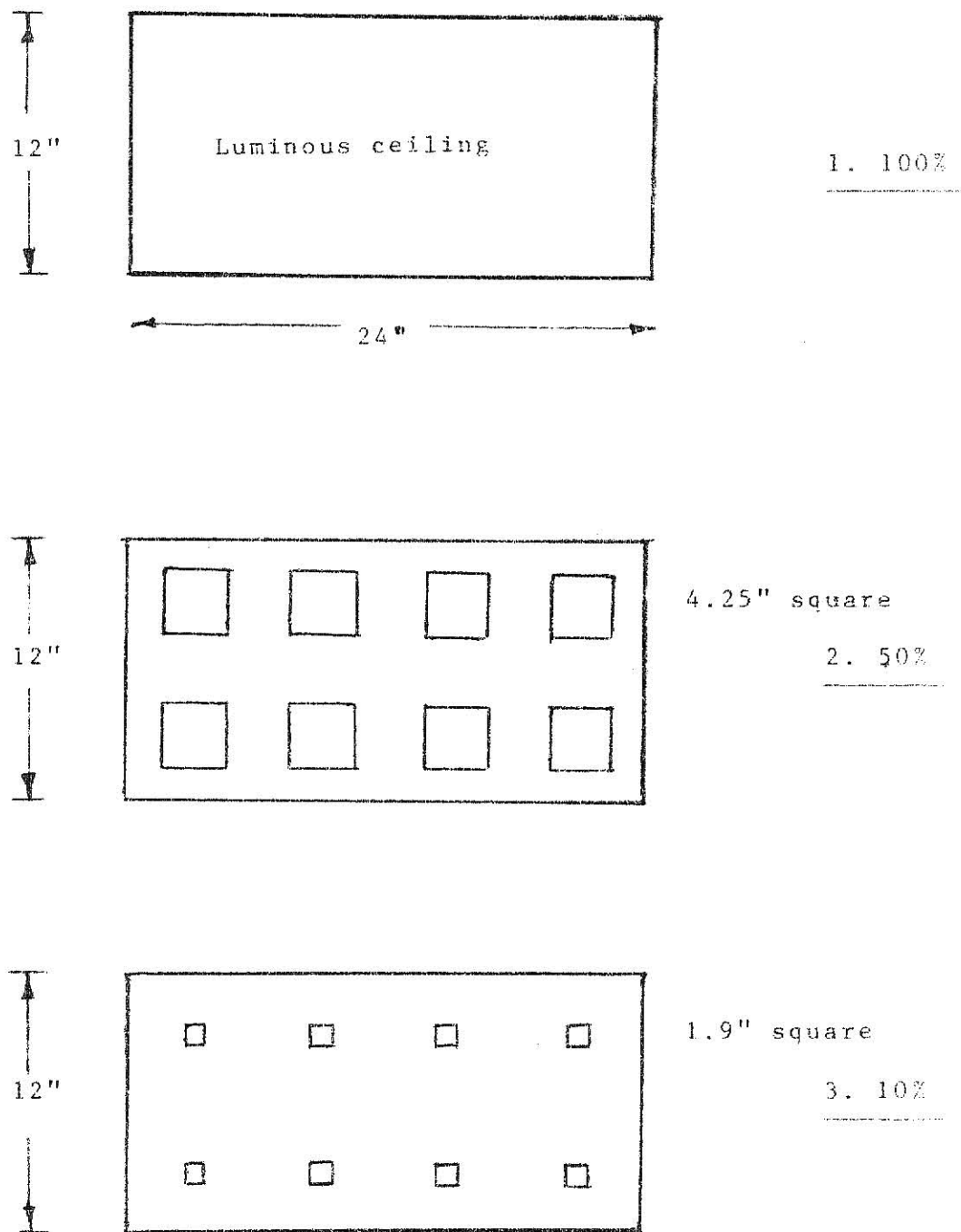


Figure 2. Layout of the three ceilings.

TABLE 1

Recommended Ranges of Illuminance on the Working Plane

Range of Illuminances in footcandles (lux)	Type of Activity-Area
10-15-20 (100-150-200)	Working spaces where visual tasks are only occasionally performed
20-30-50 (200-300-500)	Performance of visual tasks of high contrast or large size, for example, reading printed or typed materials, handwriting in ink.
50-75-100 (500-750-1000)	Performance of visual tasks of medium contrast or small size, for example, reading medium pencil handwriting, poorly printed or reproduced material.
100-150-200 (1000-1500-2000)	Performance of visual tasks of low contrast or very small size, for example, reading hard pencil on poor quality and very poorly reproduced material.

TABLE 2

Intermediate luminance levels of luminaires

Luminaire Luminance fL	Conversion Factor
4000	Max
3560	$\frac{\text{Max} + \text{Min}}{2} + \left(\text{Max} - \frac{\text{Max} + \text{Min}}{2} \right) \frac{1}{2}$
2500	$\frac{\text{Max} + \text{Min}}{2}$
1440	$\frac{\text{Max} + \text{Min}}{2} - \left(\text{Max} - \frac{\text{Max} + \text{Min}}{2} \right) \frac{1}{2}$
1000	Min

The illumination levels on the working plane for all combinations of the five luminaire luminances and the three luminaire areas are shown in Table 3. A luminance level greater than 50 fL on the workplane could not be obtained for some of the treatment combinations of the study. For example, for treatment combinations having low luminaire luminance and low luminaire area, a luminance greater than 50 fL on the working plane was not possible to obtain. Thus the upper workplane luminance level was chosen as 50 fL.

To obtain the five workplane luminances at a fixed luminaire luminance the reflectance of the table surface had to be changed. That is, it was desired to "un-tie" the luminaire luminance and the workplane luminance and make them independent of each other. Whenever the reflectance of the desk surface was changed, the reflectance of the three walls was changed to a same value. The various reflectance values of the modelling paper used are shown in Table 4. The reflectance of the table surface and the three walls was changed each time by using shades of white, black and grey modelling paper. The reflectance of the walls was changed by sliding the paper into the model such that only the three walls were covered by the modelling paper.

TABLE 3

Illumination on the Working Plane for Combinations
of the Independent Variables

Luminance of Luminaires, fL	Illuminance on the Working Plane, fc		
	100% Area	50% Area	10% Area
4000	400	266	120
3560	356	237	106
2500	250	166	75
1440	144	96	43
1000	100	66	32

TABLE 4.

Reflectance values of the modeling paper used.

Shade	Reflectance value
-----	-----
Black	0.06
Dark grey	0.13
Grey	0.20
Light grey	0.30
light grey	0.44
Dull white	0.65
White	0.94

Experimental Design

The three independent variables of the study and their levels were:

- a) luminance of the fixtures (4000fL, 3500fL, 2500fL, 1440fL and 1000fL)
- b) luminance on the working plane (50fL, 40fL, 30fL, 20 fL and 10fL)
- c) area of the luminaires (100%, 50% and 10%)

Thus a factorial design would mean $(5 \times 5 \times 3)$, seventy five experimental conditions. Such a design would approximately take five hours per subject so that multiple day sessions would have been required, and this introducing a day to day variation into the experimental error. Also such an approach meant using a relatively small number of subjects. This is undesirable due to the large individual differences in subjective reactions and the desire to sample these. Consequently a Quadratic Response Surface Design (G.M. Cox and W.G. Cochran) was selected using twenty seven of the possible seventy five conditions in a balanced fashion so that regression analysis of the entire space could be carried out. Table 5 shows the selected experimental design. The asterisks indicate the twenty seven conditions selected.

TABLE 5

Steps and combinations of the variables

LUMINAIRE LUMINANCE (fL)	AREA (%)	WORKPLANE LUMINANCE (fL)				
		10	20	30	40	50
4000	100			*		
	50			*		
	10			*		
3560	100		*		*	
	50		*		*	
	10		*		*	
2500	100	*		*		*
	50	*		*		*
	10	*		*		*
1440	100		*		*	
	50		*		*	
	10		*		*	
1000	100			*		
	50			*		
	10			*		

The dependent variables are subjects' impression of the different lighting designs in the semantic differential scales of Table 6.

For this experiment 20 students from disciplines of science and engineering of Kansas State University participated as subjects. There were twelve males and eight females whose mean age was 23 years with a range of 19 to 32 years. The subjects were given extra credit in a course for their participation. The subjects each viewed the 27 different combinations of the independent variables making judgments on the semantic scales. The order of presentation of the of the twenty seven treatments was randomized to avoid any kind of serial effect.

Task

Every subject was given an Informed Consent and Instructions form, Figure 3, that described the task. Each subject signed the Informed Consent Statement shown in Figure 4. The subjects were then handed the Evaluation Sheets (Figure 5) for rating the luminous environment of the scale model using one evaluation sheet for each treatment.

TABLE 6

Semantic Differential Scales for Evaluation of Lighting
Systems.

BRIGHT	1	2	3	4	5	6	7	DIM
CLEAR	1	2	3	4	5	6	7	UNCLEAR
LIGHT	1	2	3	4	5	6	7	DARK
SHARP	1	2	3	4	5	6	7	DULL
SPACIOUS	1	2	3	4	5	6	7	CRAMPED
VERY WELL	1	2	3	4	5	6	7	POORLY
PLEASANT	1	2	3	4	5	6	7	UNPLEASANT
ROMANTIC	1	2	3	4	5	6	7	UNROMANTIC

INFORMED CONSENT AND INSTRUCTIONS

Thank you for coming to help

This experiment is designed to study the physical lighting factors involved in the subjective assessment of an interior. Your task will be very simple. You will be asked to sit down in front of a scale model with a particular kind of lighting. You will be asked to judge the lighting. Frank opinions are needed from you. It will help if you try to forget all you have ever heard about light. Please just give your impressions of what you see. Altogether you will be exposed to twenty seven lighting conditions in a random order and make judgments in each case.

For example,

If you feel the space appears very clear for a particular lighting design then circle the number closest to your judgment as shown below

CLEAR 1 2 3 4 5 6 7 UNCLEAR

If you feel that your response is entirely neutral then circle the central position, number 4.

CLEAR 1 2 3 4 5 6 7 UNCLEAR

While giving your impressions of each lighting design pay more attention to the surface of the table. Imagine that you are performing a visual task on the table, for example,

reading printed or reproduced material, handwriting in ink;ordinary inspection or rough assembly. Please keep this in mind while evaluating each of the twenty seven lighting designs.

There will be no discomfort or 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 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 3. Informed Consent and Instructions form

INFORMED CONSENT STATEMENT

Having read the informed consent, I hereby agree to be a subject in the research entitled " Lighting Cues to Visual Clarity ".

<u>S. No.</u>	<u>Signature</u>	<u>Age (yrs)</u>	<u>Sex (M/F)</u>	<u>Date</u>
---------------	------------------	------------------	------------------	-------------

Figure 4. Informed Consent Statement Form

EVALUATION SHEET

NAME: _____

TREATMENT # _____

BRIGHT	1	2	3	4	5	6	7	DIM
CLEAR	1	2	3	4	5	6	7	UNCLEAR
LIGHT	1	2	3	4	5	6	7	DARK
SHARP	1	2	3	4	5	6	7	DULL

How spacious do you think the room looks?

SPACIOUS	1	2	3	4	5	6	7	CRAMPED
----------	---	---	---	---	---	---	---	---------

How well would you perform a visual task in this lighting?

VERY WELL	1	2	3	4	5	6	7	POORLY
-----------	---	---	---	---	---	---	---	--------

How pleasant do you think the room looks?

PLEASANT	1	2	3	4	5	6	7	UNPLEASANT
----------	---	---	---	---	---	---	---	------------

Does the lighting appear to be romantic?

ROMANTIC	1	2	3	4	5	6	7	UNROMANTIC
----------	---	---	---	---	---	---	---	------------

Comments: _____

FIGURE 5. Evaluation Sheet

An adjustable chair was used to bring the eye level of each subject to a predetermined height of about two and a half inches above the desk surface so that each subject viewed the interior at the same level. Each subject was asked to observe the interior of the model to try to associate that particular lighting design with his perception of visual clarity before rating the lighting system.

As seen in the evaluation sheet a few scales are present not pertaining to visual clarity, this was done to study the effect of this simple achromatic interior on impressions of pleasantness and spaciousness. Most of the past studies dealing with impressions of pleasantness, spaciousness and visual clarity were performed in complex colorful interiors.

After evaluating the lighting system the subject was asked to keep his/her eyes away from the lighting booth. Then the next combination of the independent variables was viewed. This was done until all the 27 different lighting designs were evaluated on the semantic differential scales. Each subject spent approximately an hour and a half to complete the experiment.

RESULTS

The subjective reactions of the 20 subjects for each lighting condition on each scale are given in Appendix A. The corresponding factor scores are also given. The luminaire luminance is specified by "LUM", the luminance of the working plane is specified by "WP" and the area of the luminaires by "A". "LUM" and "WP" levels are numbered from 1 to 5 and "A" levels are numbered from 1 to 3, these are listed in Figure 6. The letters BD, CU, LD, SD, SC, VP, PU, and RU used are the eight semantic differential scales listed in Figure 7.

Table 6 shows the correlation matrix for the semantic scales. Factor analysis of the eight scales was carried out using the Statistical Analysis System computer program (User's guide to SAS 82.2B, North Carolina, SAS Institute Inc., 1982). Three factors were extracted.

Table 7. shows the three factors found on the scales with their loadings. Loadings greater than 0.62 were considered to be high. In this respect loadings on Factor 1 occur with scales bright-dim, clear-unclear, light-dark, sharp-dull and very well-poor; Factor 1 was named "Clarity".

BD	bright - dim
CU	clear - unclear
LD	light - dark
SD	sharp - dull
SC	spacious - cramped
VP	very well - poorly
PU	pleasant - unpleasant
RU	romantic - unromantic

Figure 6. Symbols of the eight semantic scales.

Luminaire Luminance (fL)	Luminaire Area (%)	Workplane Luminance (fL)
-----	-----	-----
LUM0 - 4000	A0 - 100	WP0 - 50
LUM1 - 3560	A1 - 50	WP1 - 40
LUM2 - 2500	A2 - 10	WP2 - 30
LUM3 - 1440		WP3 - 20
LUM4 - 1000		WP4 - 10

Figure 7. Levels and symbols of variables.

TABLE 7

Correlation Matrix for the Semantic Scales

	BD	CU	LD	SD	SC	VP	PU	RU
BD	1.00	0.50	0.64	0.54	0.23	0.36	0.18	-0.22
CU	0.50	1.00	0.55	0.57	0.28	0.54	0.26	-0.16
LD	0.64	0.55	1.00	0.50	0.30	0.47	0.22	-0.25
SD	0.54	0.57	0.50	1.00	0.24	0.42	0.19	-0.14
SC	0.23	0.28	0.30	0.24	1.00	0.28	0.44	-0.14
VP	0.37	0.54	0.47	0.42	0.28	1.00	0.39	-0.13
PU	0.18	0.26	0.22	0.19	0.44	0.39	1.00	-0.22
RU	-0.22	-0.16	-0.25	-0.14	-0.14	-0.13	-0.22	1.00

TABLE 8

Factor Patterns

	FACTOR1	FACTOR2	FACTOR3
BD	0.86	-0.09	0.09
CU	0.86	-0.05	0.17
LD	0.89	-0.10	0.08
SD	0.82	-0.12	0.30
SC	0.54	0.40	-0.62
VP	0.82	0.07	0.12
PU	0.42	0.80	-0.10
RU	-0.44	0.69	0.50

FACTOR 1 - VISUAL CLARITY

FACTOR 2 - PLEASANTNESS

FACTOR 3 - SPACIOUSNESS

High loadings on Factor 2 occur on scales pleasant-unpleasant and romantic-unromantic; Factor 2 was named "Pleasantness". The only high loading on Factor 3 was scale spacious-cramped; Factor 3 was named "spaciousness".

Since the study mainly involved subjective impressions of visual clarity, the scores of the scales corresponding to visual clarity factor were added and their total score corresponded to "visual clarity". Table 9. shows the correlation matrix for visual clarity, luminaire luminance, work-plane luminance and luminaire area.

In the next part of the analysis regression analysis was carried out for the experimental variables and visual clarity. Because the experimental design was a "Quadratic Response Surface Design", with only twenty seven of the possible seventy five ($5 \times 5 \times 3$) combinations studied directly, mean or median values of the various combinations of conditions are not too meaningful. Rather, the multiple regression analysis, where a least squares best-fitting equation is fitted to predict visual clarity from the experimental variables, takes into account all of the conditions studied and gives the best description of the nature of the relationships among the variables. The correlation coefficients (R) associated with the regression model describe its goodness of fit.

TABLE 9

Correlation Matrix for Visual Clarity and the
Experimental variables

	Visual Clarity	Luminaire Area	Luminaire Luminance	Workplane Luminance
Visual Clarity	1.00	0.30	0.38	0.28
Luminaire Area	0.30	1.00	0.00	0.00
Luminaire Luminance	0.38	0.00	1.00	0.00
Workplane Luminance	0.28	0.00	0.00	1.00

Because of the heuristic nature of regression analysis, preliminary analyses was carried out and these analyses enabled selection of the transformations to be used on the variables.

Visual clarity, workplane luminance (WP), luminaire luminance (LUM), and luminaire area (A) were each subjected to a logarithmic transformation before fitting linear regression equations. Upon retransformation subsequent to regression analysis, the following power relations result:

$$VC = K1 (A)^{K2}$$

$$VC = K3 (WP)^{K4}$$

$$VC = K5 (LUM)^{K6}$$

$$VC = K7 (A)^{K2} \cdot (WP)^{K4} \cdot (LUM)^{K6}$$

Table 10. gives the results of these regression and correlation analyses. Reading down the left hand side of the table is a pair of rows showing the number of observers and the number of observations. The regression results, the specific values for the empirical constants K1 to K7 and the coefficients of determination (R^2) are given. Finally the coefficients of determination (R^2) due to experimental variables and due to observers are totalled and shown. Regression curves for all the twenty seven experimental conditions are shown in figures 8 to 22, also the mean observed values of visual clarity are shown on each of the plots.

TABLE 10

Regression and Correlation Results

Number of Observers	20		
Number of Observations	540		
<u>Empirical Constants</u>		<u>Coefficients of Determination R^2</u>	
Area effect:	K1	2.78 ± 0.09	0.11
	K2	0.10 ± 0.02	
Workplane			
Luminance			
effect:	K3	2.57 ± 0.17	0.07
	K4	0.18 ± 0.04	
Luminaire			
Luminance			
effect:	K5	1.27 ± 0.38	0.15
	K6	0.24 ± 0.05	
Overall			
effect:	K7	1.34	0.32

Coefficients of Determination: Due to physical parameters= 0.32

Due to observers = 0.25

Total = 0.57

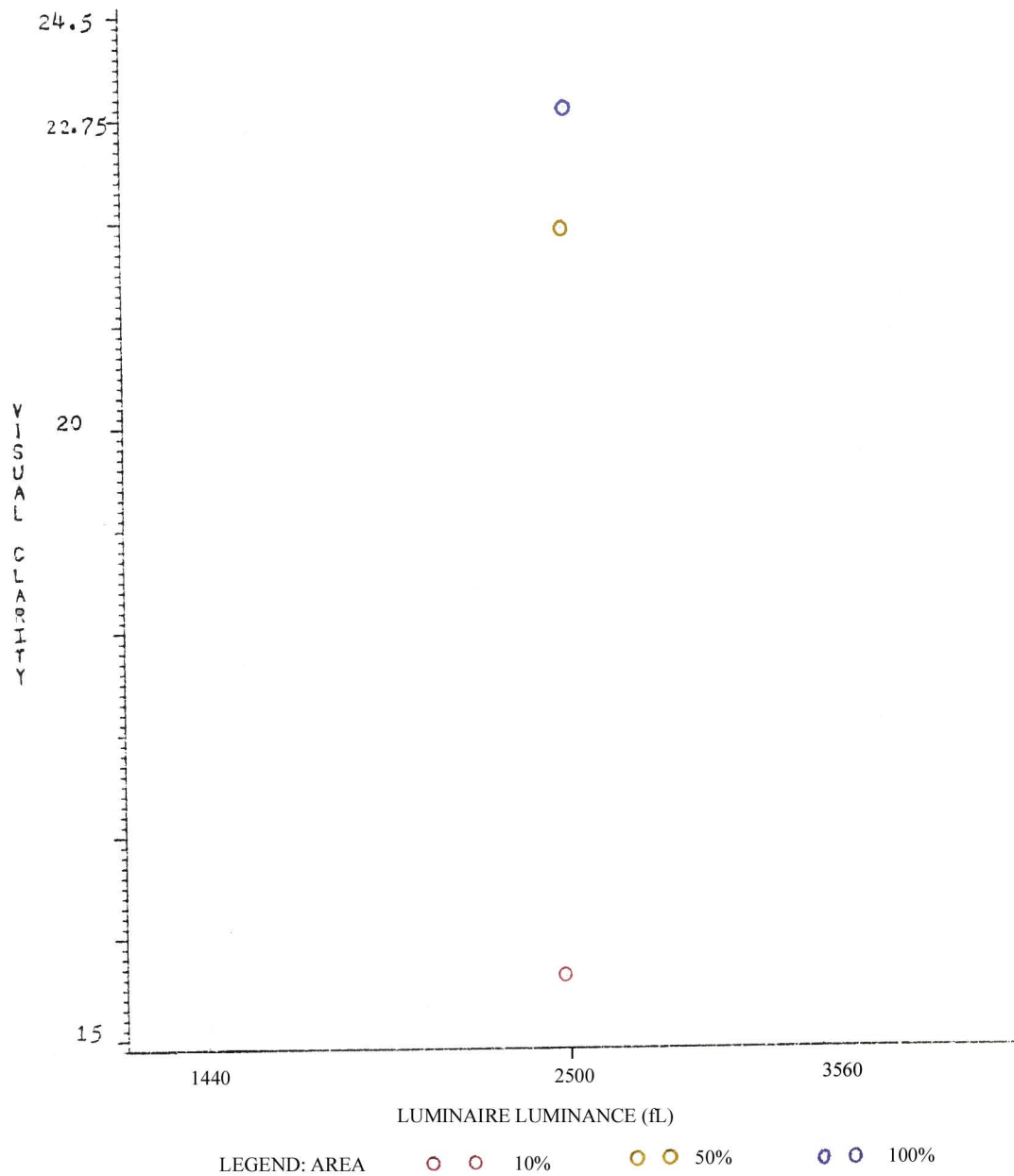


Figure 3 . Luminaire area curves for luminaire luminance at workplane luminance of 10fL on log-log co-ordinates.

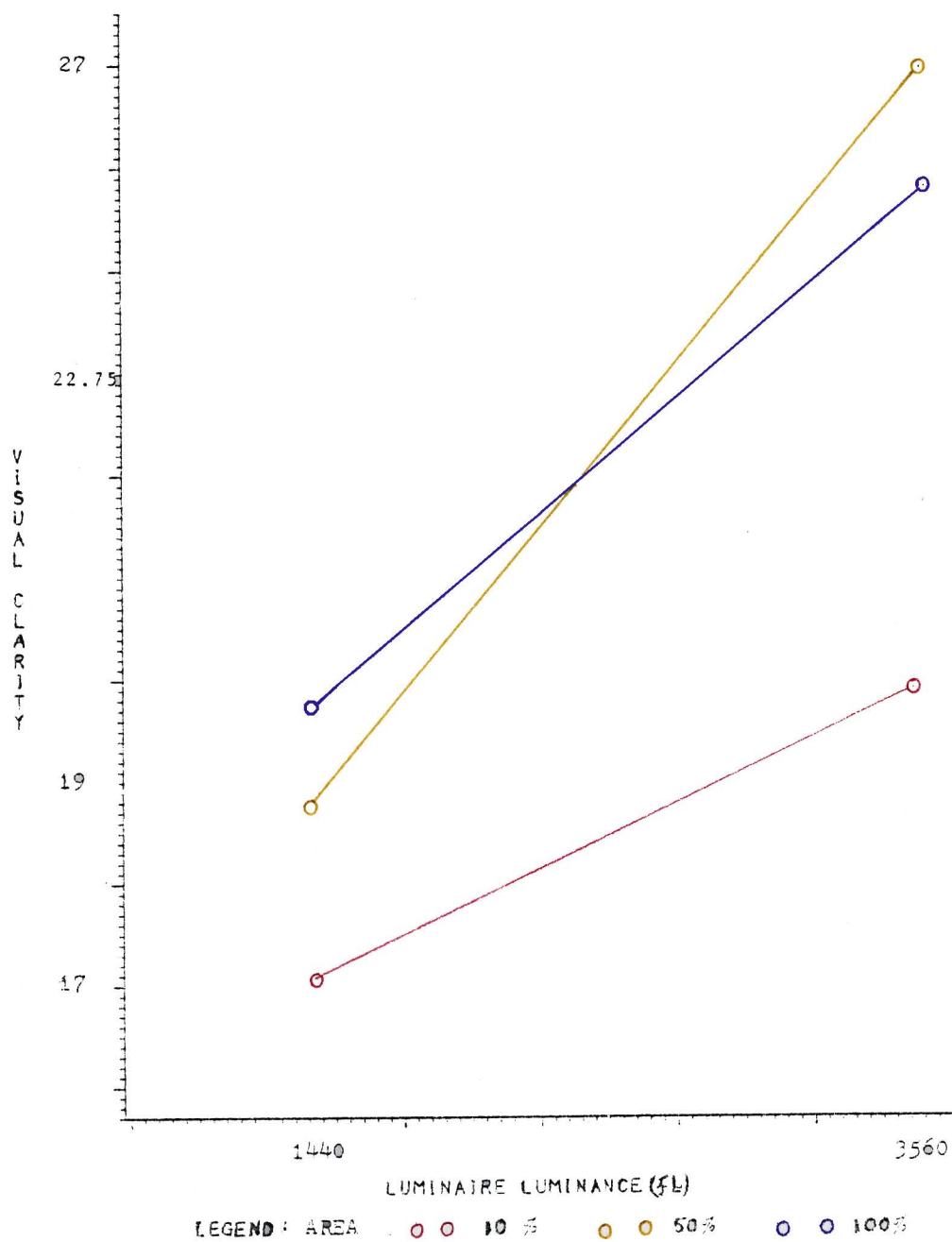


Figure 9 . Luminance area curves for luminance luminance at workplane luminance of 20fL on log-log co-ordinates.

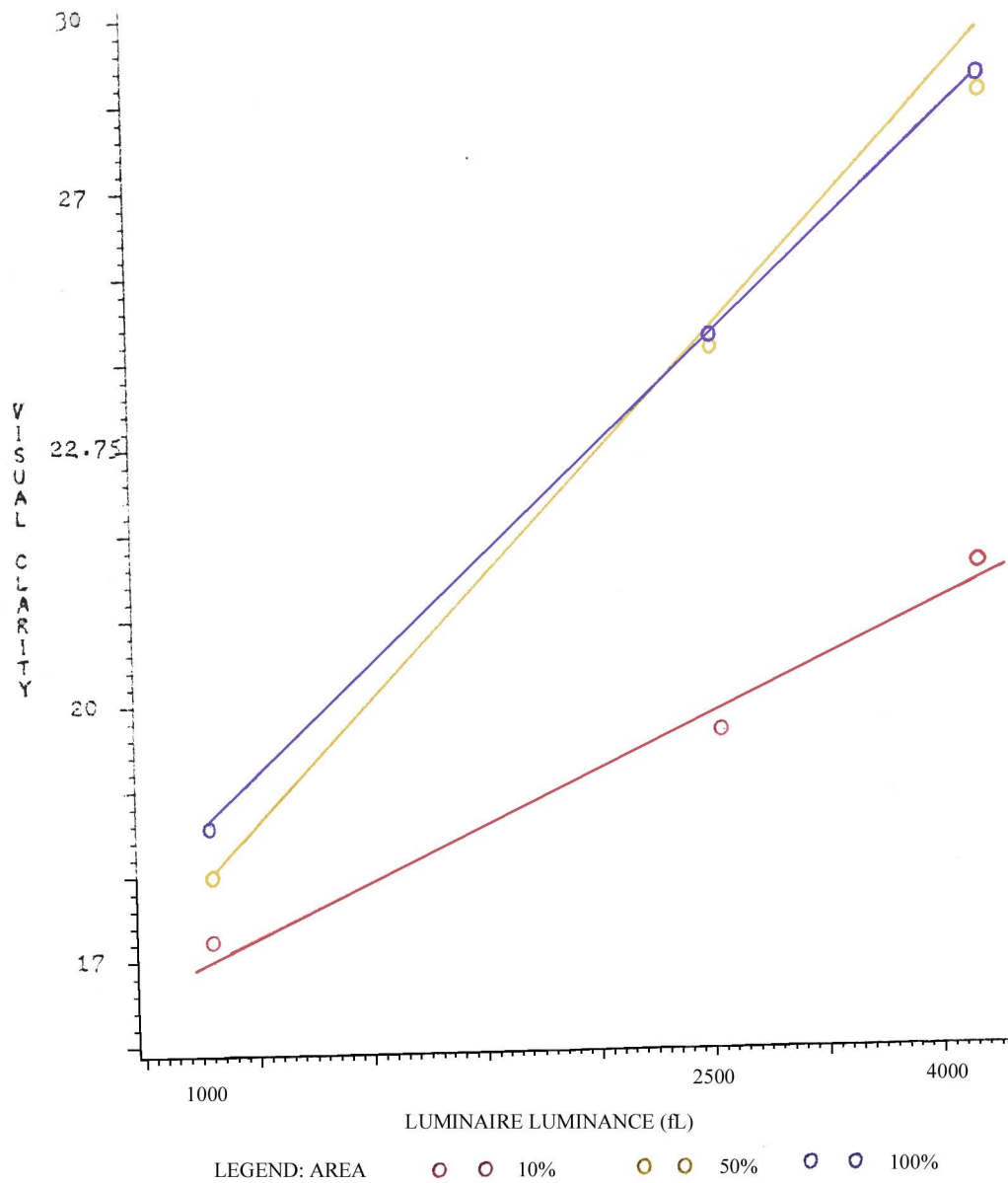


Figure 10. Luminaire area curves for luminaire luminance at workplane luminance of 30 fL on log-log co-ordinates

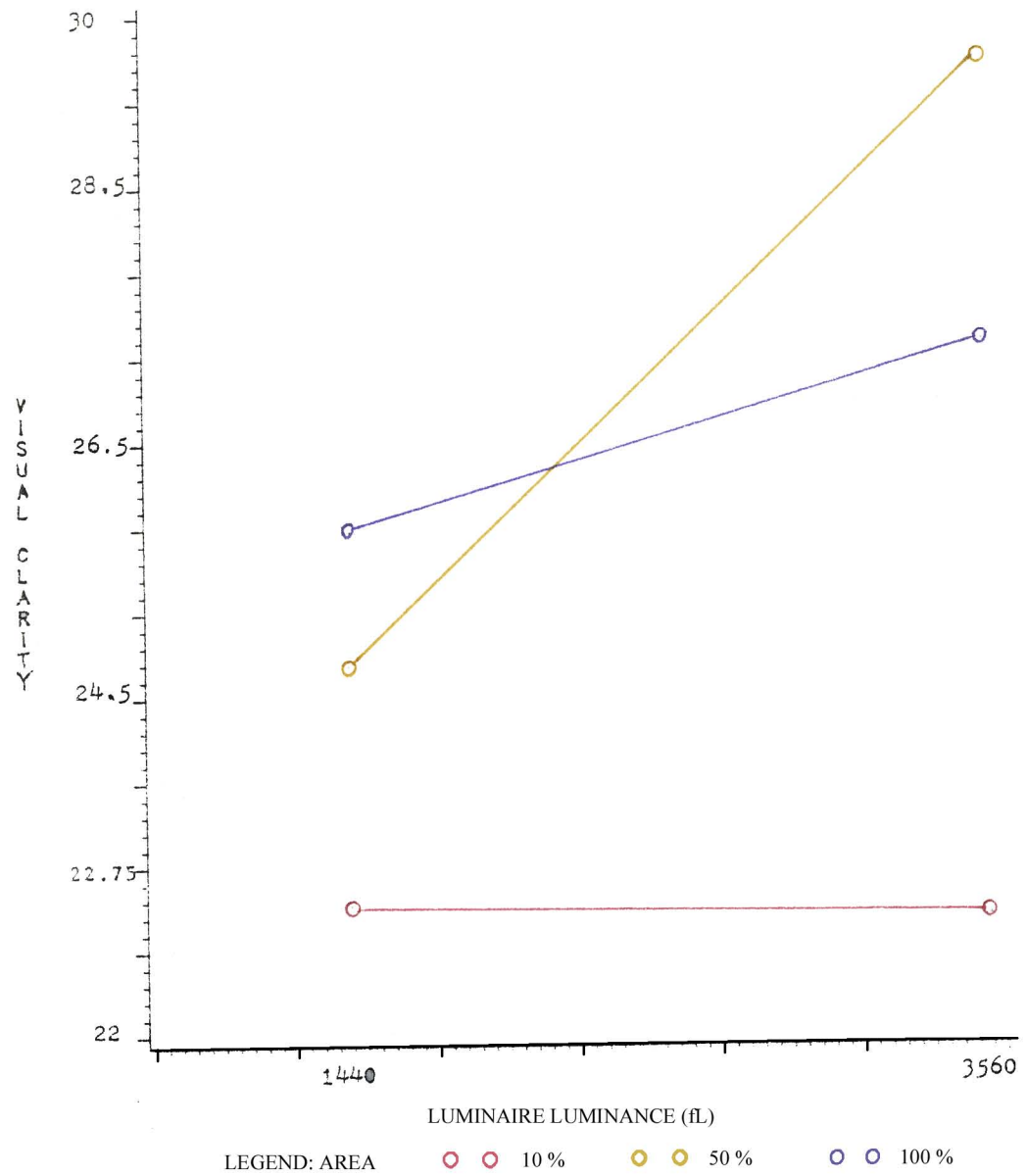


Figure 11. Luminance area curves for luminance at workplane luminance of 40 fL on log-log co-ordinates.

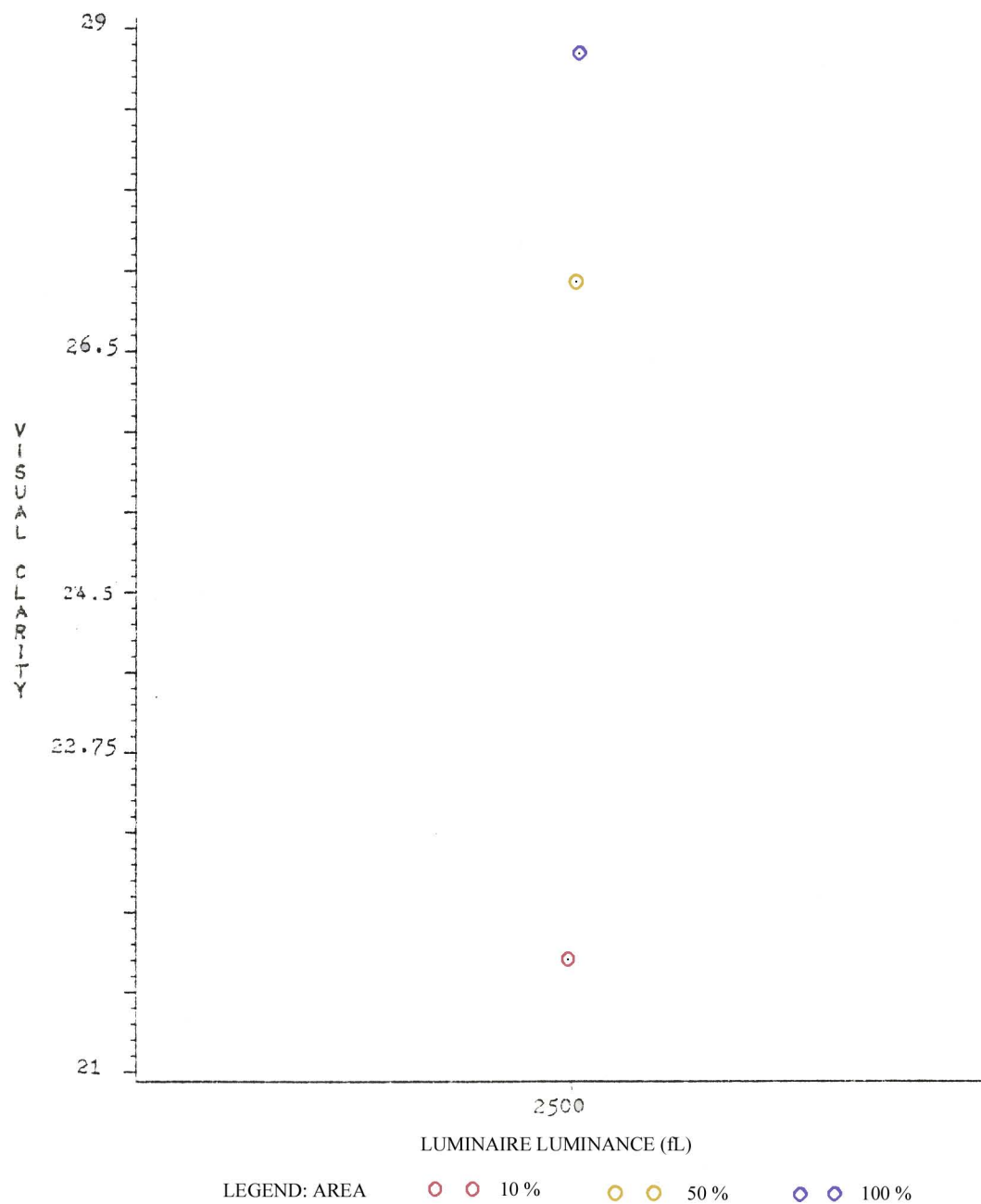


Figure 12 Luminaire area curves for Luminaire luminance at workplane luminance of 50 fL on log-log co-ordinates.

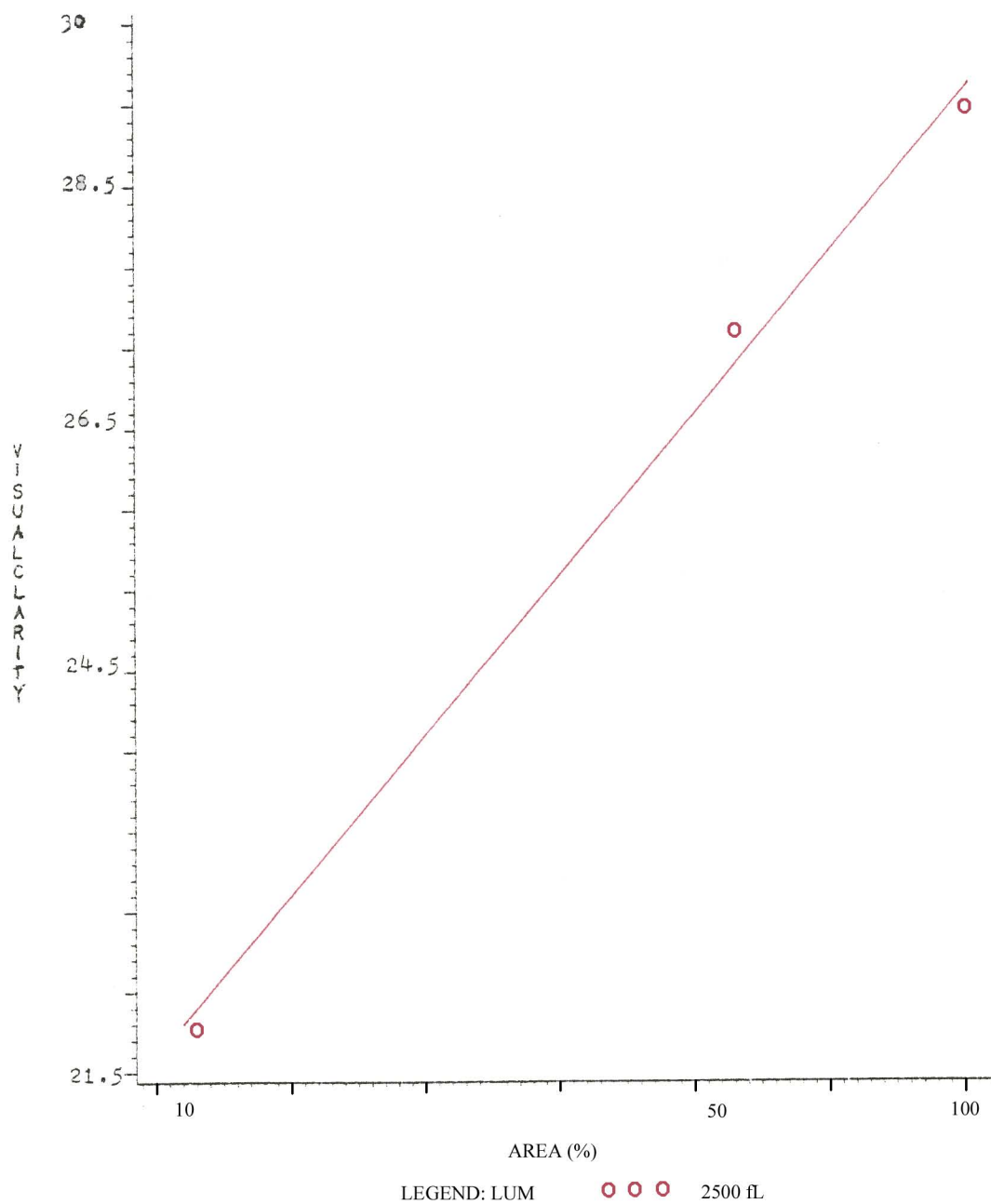


Figure 13. Luminaire luminance curves for luminaire area at workplane luminance of 50fL on log-log co-ordinates.

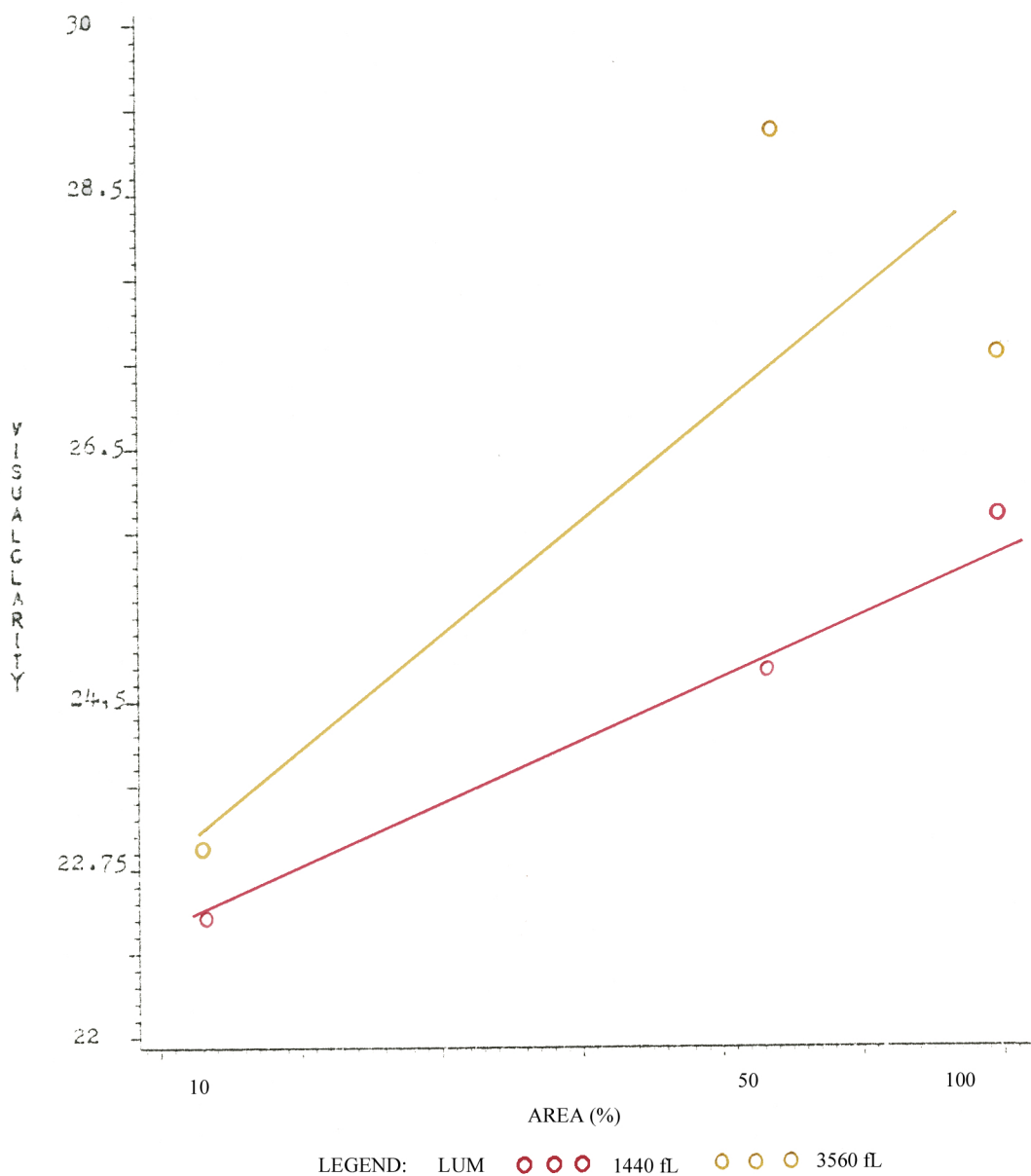


Figure 14. Luminaire luminance curves for luminaire area at workplane luminance of 40 fL on log-log co-ordinates.

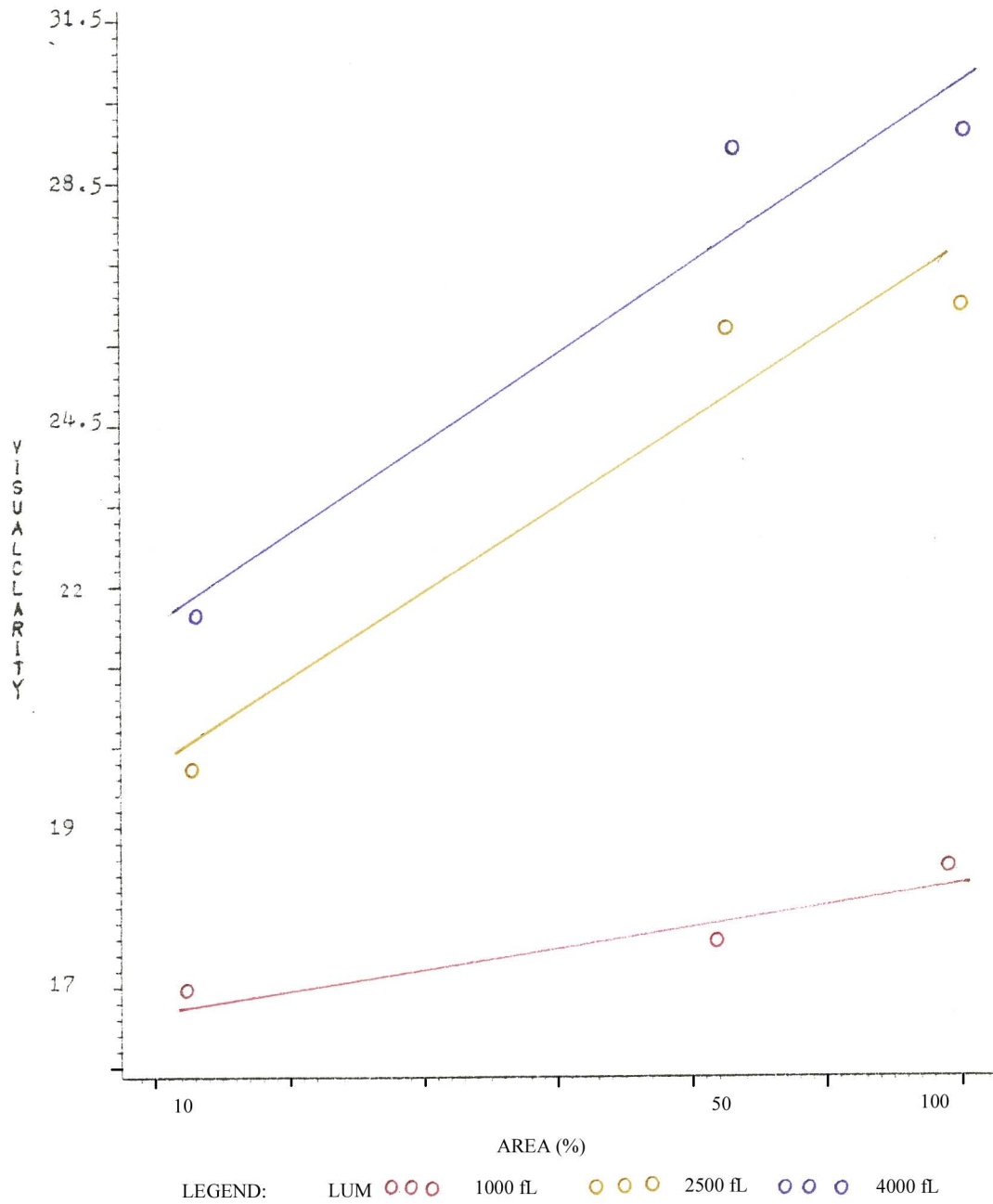


Figure 15. Luminaire luminance curves for luminaire area at workplane luminance of 30fL on log-log co-ordinates.

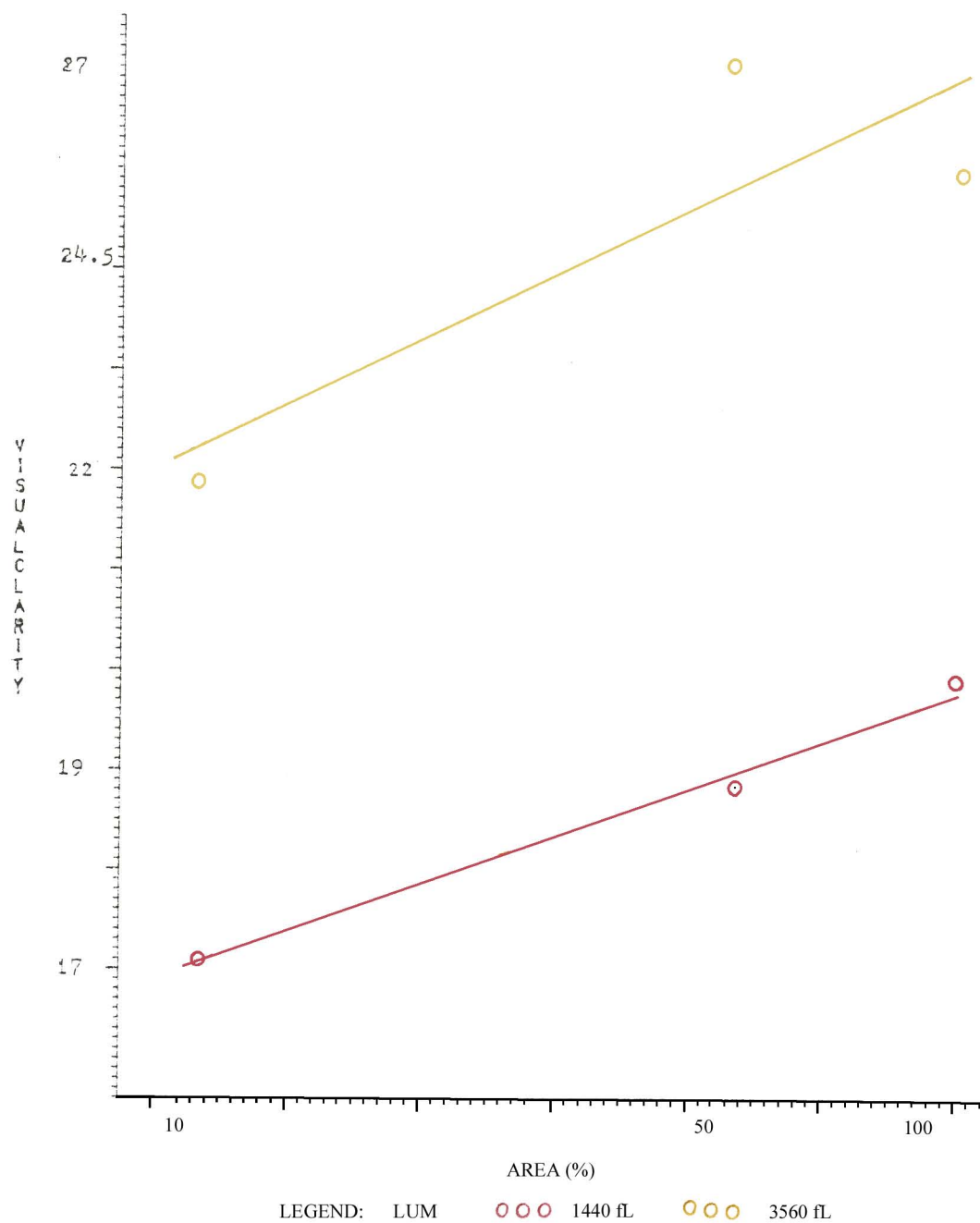


Figure 16. Luminaire luminance curves for luminaire area at workplane luminance of 20fL on log-log co-ordinates.

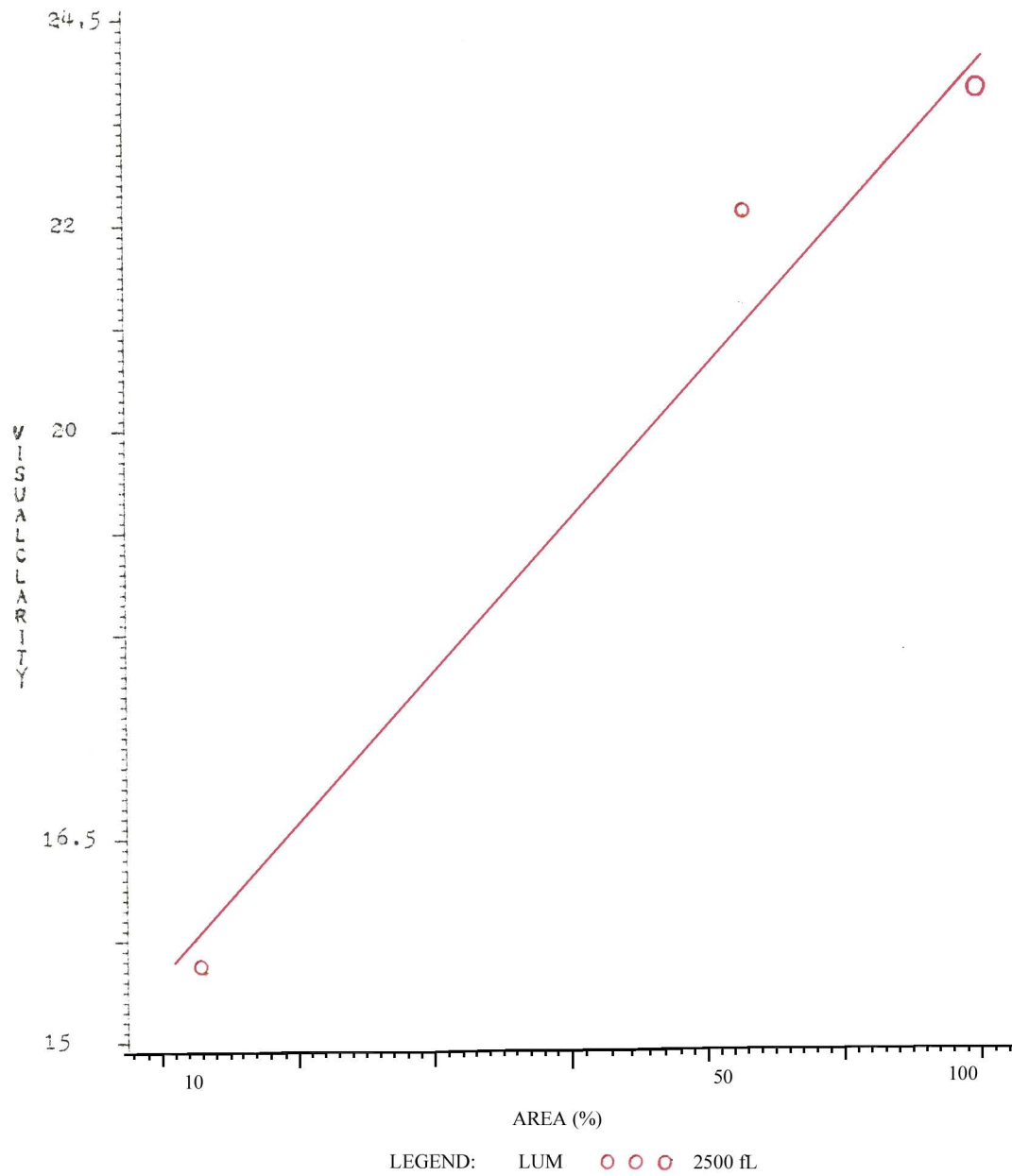


Figure 17. Luminaire luminance curves for luminaire area at workplane luminance of 10fL on log-log co-ordinates.

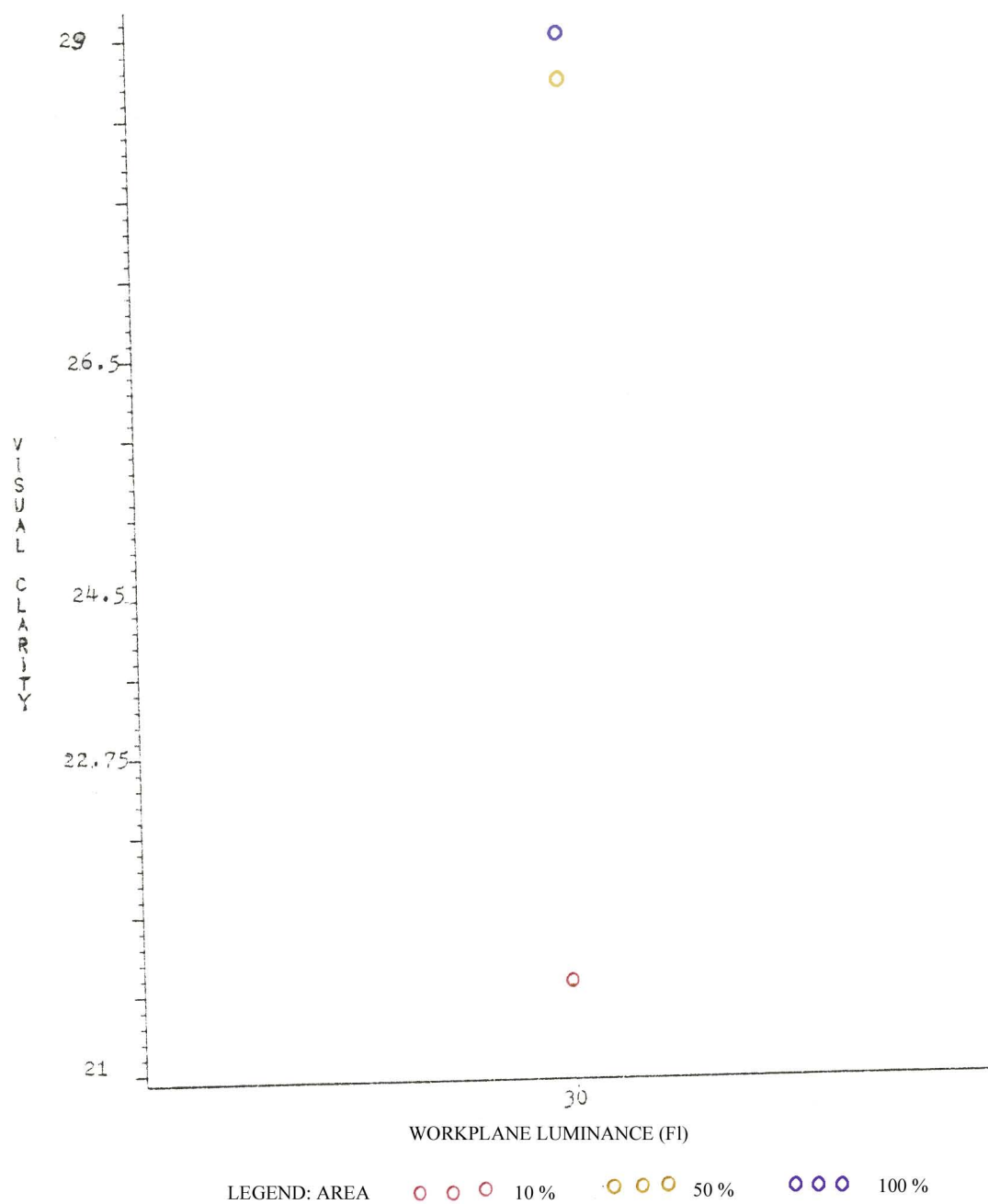


Figure 18. Luminaire area curves for workplane luminance at luminaire luminance of 4000 fL on log-log co-ordinates.

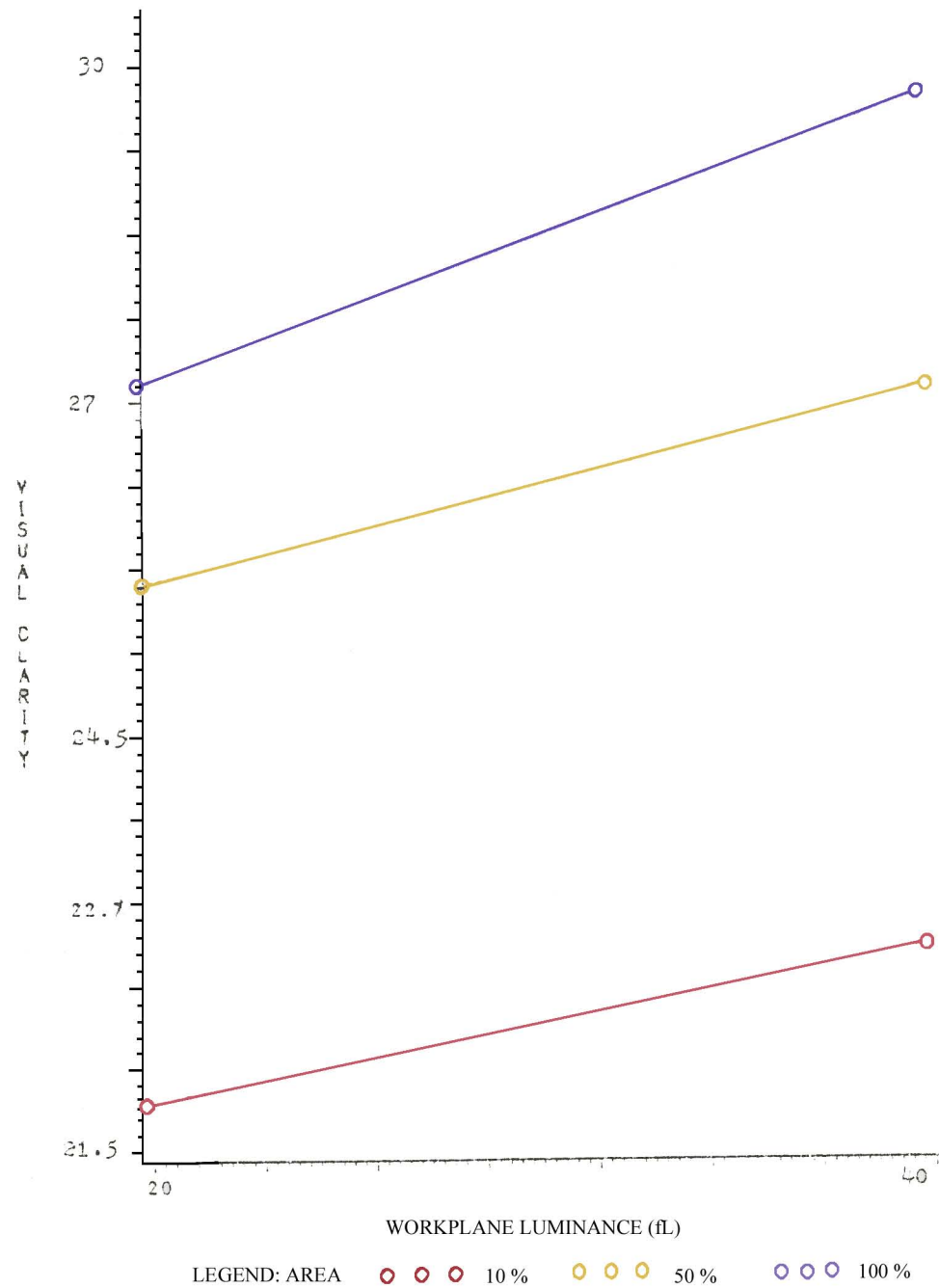


Figure 19. Luminaire area curves for workplane luminance at luminaire luminance of 3560 fL on log-log co-ordinates.

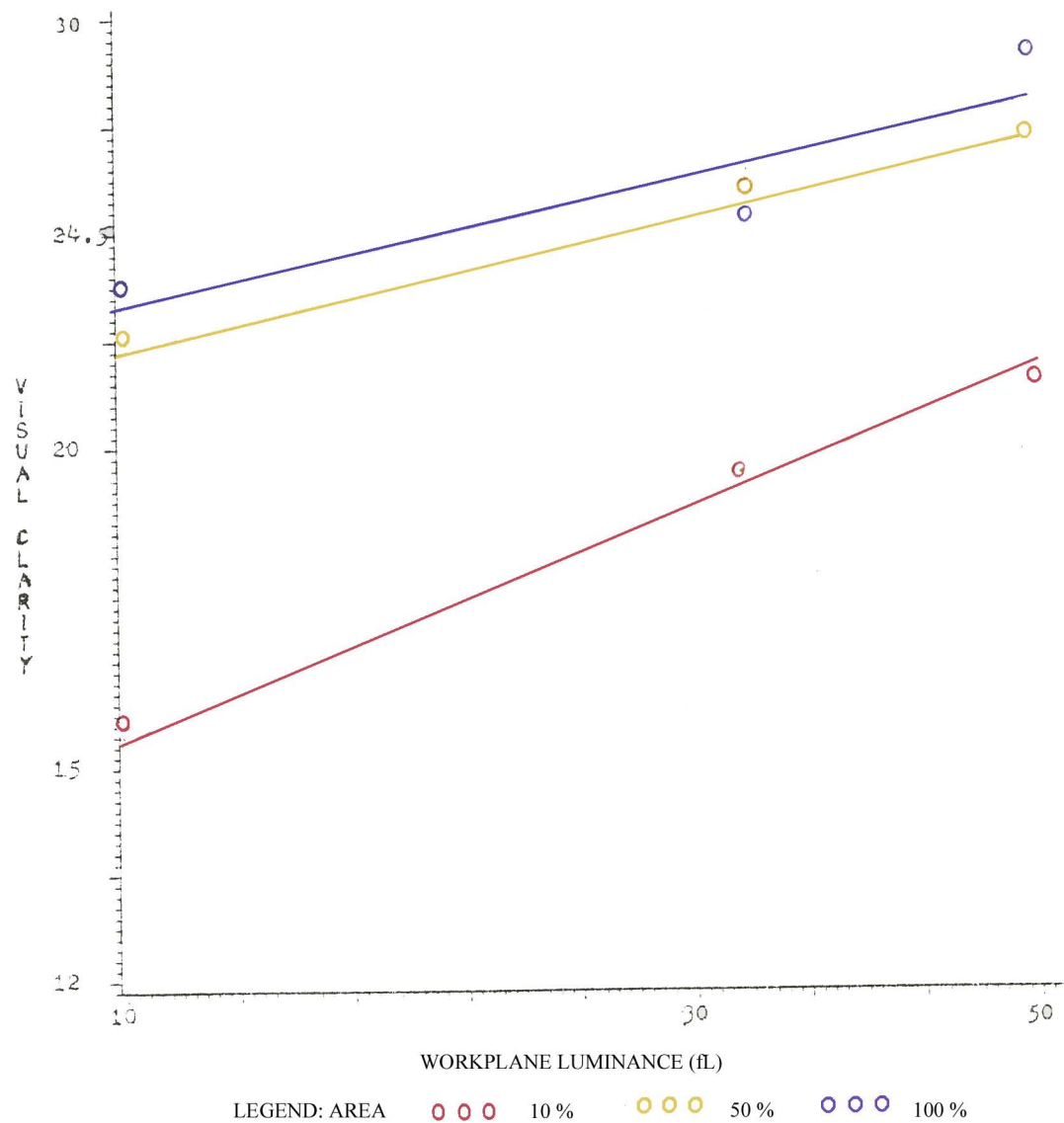


Figure 20. Luminaire area curves for workplane luminance at luminaire luminance of 2500 fL on log-log co-ordinates.

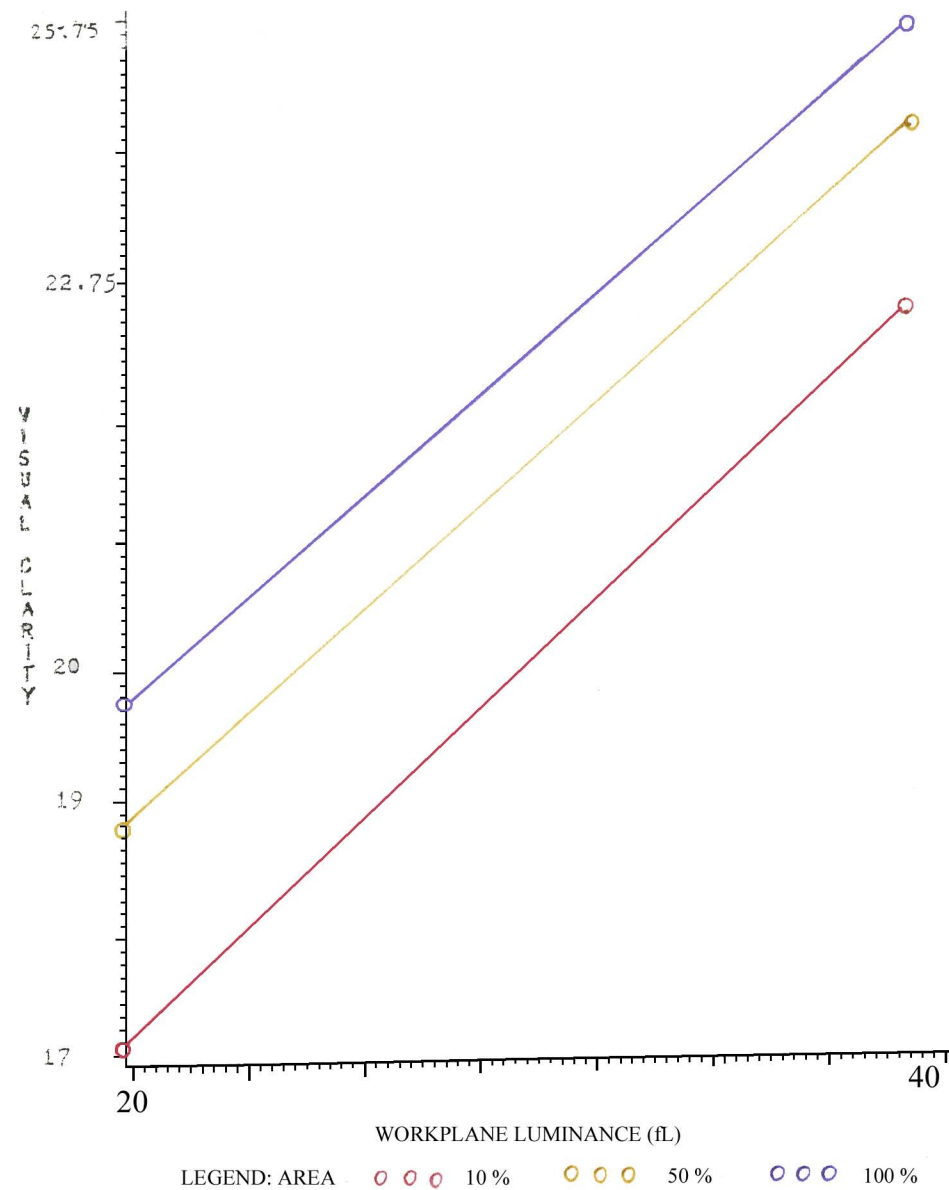


Figure 21. Luminaire area curves for workplane luminance at luminaire luminance of 1440 fL on log-log co-ordinates.

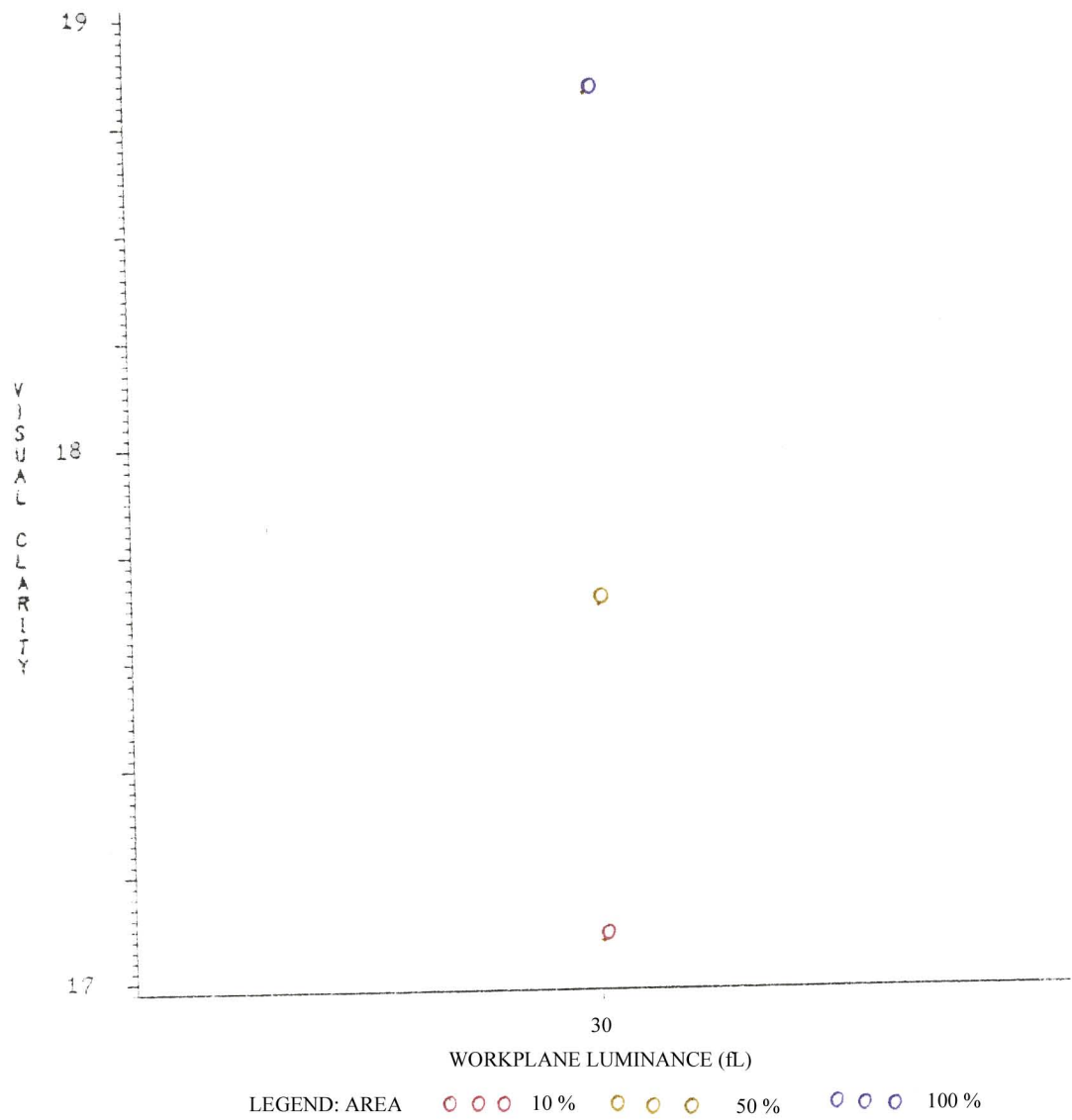


Figure 22. Luminaire area curves for workplane luminance at luminaire luminance of 1000 fL on log-log co-ordinates.

DISCUSSION

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

Visual Clarity (Factor 1)

If a particular lighting condition creates a high impression of clearness, brightness, sharpness it means that high visual clarity is achieved. In this clarity factor, five semantic scales "bright-dim", "clear-unclear", "light-dark", "sharp-dull" and "very well-poorly" have substantial loadings. These scales were taken from Flynn and Boyce's studies to describe the impressions of "visual clarity" under a particular lighting condition.

Evaluative (Factor 2)

Under a particular lighting condition, if people rank it high for evaluation, it means that the particular lighting condition is preferred. Two semantic scales "pleasant-unpleasant" and "romantic-unromantic" have substantial loadings. The first scale was taken from Flynn's study, under evaluative factor. The "romantic-unromantic" scale was chosen in this experiment to see if it would fall under the evaluation factor. It seemed that a pleasant lighting design was closely associated to romantic lighting.

Spaciousness (Factor 3)

When a lighting condition is considered to have created a feeling that the space appears spacious, then that lighting system is considered to have created an impression of "spaciousness" to the users of that space or the subject subjected to that environment. The semantic scale "spacious-cramped" was found to have a high loading on this factor. This scale was obtained from Flynn's study to obtain impressions of "spaciousness".

In the most of the past studies dealing with subjective impressions in lighting design, colorful interiors were used and the above three categories of impressions or factors emerged. In the present study, an achromatic interior was used and the same factors emerged. This suggests that the factors generalize over colorful as well as achromatic interiors.

In the following discussion, the relation between visual clarity and the experimental variables are dealt with. The scores of all the scales under Factor 1 (visual clarity) were summed up, this represented the score corresponding to visual clarity.

Experimental Parameters

For the entire data, the coefficient of determination R^2 due to the parameters was 0.32. This means that 32% of the

variance in visual clarity can be attributed to the range of variation which existed for the luminaire luminance, workplane luminance and the luminaire area in this experiment.

The specific (simple, first order) correlations may be seen to be 0.38 for luminaire luminance, 0.28 for workplane luminance and 0.30 for luminaire area. While there is a temptation to interpret these correlations as indicating the relative importance of the three parameters in determining visual clarity, this is misleading. For example, early in the experimental design it was intended to have a workplane luminance of 100 fL as the maximum luminance level. However, it was found that a workplane luminance of 100 fL (or higher than 50 fL) was not possible for some combinations of luminaire luminance and luminaire area. At low levels of luminaire luminance and luminaire area, a working plane luminance greater than 50 fL could not be obtained. If a workplane luminance higher than 50 fL could have been achieved then the correlation between visual clarity and workplane luminance probably would be greater.

Further the total R^2 for experimental parameters has meaning only in the context of this particular experiment. The range of values of luminaire luminance and workplane luminance were selected to cover the range of what might be deemed practical values. To the extent that these ranges are representative of some practical situation, these correlations have some meaning.

Putting the three experimental parameters into an equation with rounded values for their coefficients and exponents gives :

$$\text{Visual clarity} = 1.34 (A)^{0.10} (WP)^{0.18} (LUM)^{0.24}$$

where A is the percentage devoted to luminaires, WP (in foot lamberts) is the workplane luminance, LUM (in footlamberts) is the luminaire luminance.

When the relationship between values assessed by observers and values calculated from the visual clarity formula for the twenty seven treatments (averaged over the twenty subjects) were plotted there was seen to be a good correlation between them. Figure 23. shows this relationship. Points on the straight line represent conditions when the predicted clarity is equal to the observed clarity. Visual clarity covers a range from 16 to 30. Most points are near to the straight line in a range of error of $\pm 18\%$; the direction of the error is not biased.

From the regression equation it can be seen that all the three lighting variables had a positive effect on visual clarity. This agrees with the hypotheses on visual clarity. Of the three lighting factors, the luminaire luminance had the greatest effect on visual clarity. It is likely that higher luminaire luminance levels can be achieved by using a lens capable of creating high luminaire luminances from almost any viewing position.

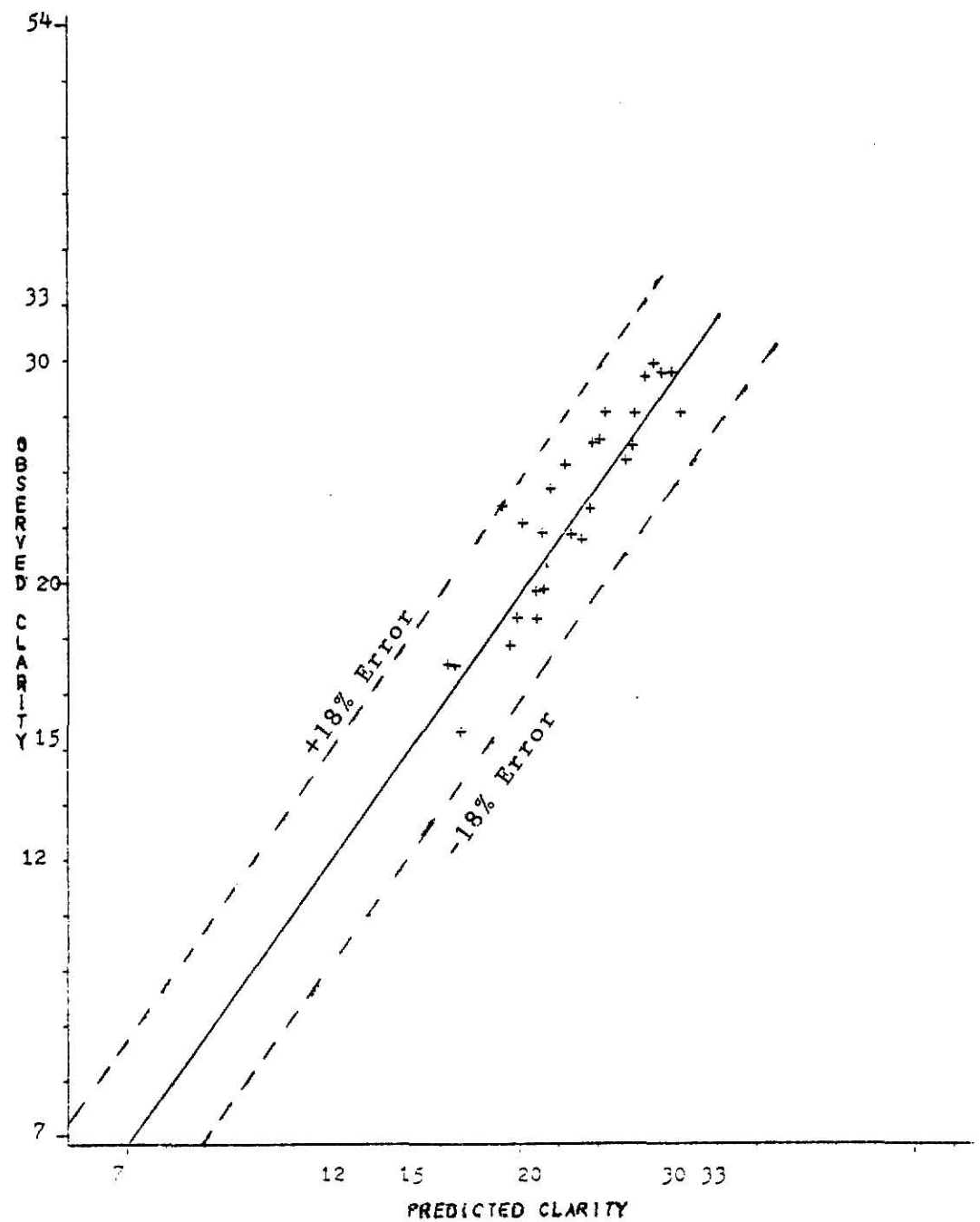


Figure 23. Predicted visual clarity versus observed visual clarity on log-log co-ordinates.

The surprising findings of Chowdhury, Gettu and Prabhakar that a smaller luminaire area presented higher visual clarity ratings than a larger luminaire was explained by the results of this study. In order to maintain a constant illumination for different luminaire sizes, the brightness of the luminaires reduced as the luminaire size increased. The subjects associated the brightness of the luminaire source with visual clarity. Thus it was seen from the previous study that a smaller luminaire area presented higher visual clarity.

It has been established by researchers that smaller light sources create impressions of pleasantness. The results of the present study show that larger light sources present higher visual clarity. Thus the designer should trade off between visual clarity and pleasantness at the expense of cost.

En passant, since the brightness of the workplane depends on its reflectance and affects visual clarity, the reflectance of the desk should be about 50% so that there is not much contrast between the paper and the desk surface.

It would be interesting to study the effect of these lighting factors on visual clarity in a real time environment. It is suggested that experiments be carried out in office rooms with the existing lighting conditions. A correlation study could be done to analyse the data. Further

research including other lighting factors is also recommended since the R^2 value is not remarkably high.

CONCLUSION

An experiment involving 20 subjects, each experiencing all the twenty seven lighting treatments resulted in the following:

1. Three factors which emerged as a result of the factor analysis were similar to Flynn's study. The factors are evaluation, visual clarity and spaciousness.

2. A model predicting visual clarity from luminaire luminance, luminaire area and workplane luminance was established.

3. There were large individual differences among observers of nearly equal importance in predictiveness to the physical parameters.

4. The overall predictability of visual clarity from physical and subjective parameters was substantial ($R = 0.75$) and the statistical analysis was adequate.

In addition to the extension of this research in a real environment, higher workplane luminance levels are recommended.

Individual differences.

The coefficient of determination R^2 demonstrates the importance of individual differences which have been recog-

nized by previous research dealing with subjective impressions. The indication of the importance of individual differences is the coefficient of determination R^2 due to observers, 0.25. This is almost equal to the coefficient of determination due to physical parameters, 0.32. Thus the total R^2 , 0.57, giving a correlation of 0.75 with visual clarity is more than half due to the physical parameters, and less than half due to the subject variation. This, illustrates the importance of using a large number of observers in this research.

APPENDIX I

SUBJECTIVE RATINGS

SAS												
OTC	SUB	LUM	EP	A	BD	CU	LD	SD	SC	VP	PU	RU
1	1	0	2	0	4	5	4	3	4	3	6	5
2	2	0	2	0	5	6	6	6	3	6	4	2
3	3	0	2	0	6	6	6	7	6	7	3	2
4	4	0	2	0	6	6	6	7	3	5	3	1
5	5	0	2	0	7	7	7	6	6	6	6	1
6	6	0	2	0	7	7	7	7	1	7	1	1
7	7	0	2	0	7	7	7	7	3	6	5	4
8	8	0	2	0	6	5	6	5	4	4	3	2
9	9	0	2	0	5	5	5	6	3	5	4	3
10	10	0	2	0	5	6	5	6	3	5	4	2
11	11	0	2	0	5	6	5	4	3	5	2	2
12	12	0	2	0	7	7	6	7	4	7	2	1
13	13	0	2	0	7	6	6	6	4	5	4	1
14	14	0	2	0	6	7	6	6	4	5	5	3
15	15	0	2	0	7	7	6	7	2	6	1	1
16	16	0	2	0	7	7	6	7	4	5	5	3
17	17	0	2	0	6	6	6	6	7	7	6	6
18	18	0	2	0	6	6	6	7	5	6	5	6
19	19	0	2	0	6	7	7	7	7	6	5	6
20	20	0	2	0	7	7	7	7	7	7	1	1
21	21	0	2	0	4	6	4	4	3	6	3	3
22	22	0	2	1	5	5	6	5	3	6	4	2
23	23	0	2	1	6	6	5	6	5	6	5	4
24	24	0	2	1	6	6	6	6	5	6	5	2
25	25	0	2	1	6	6	6	6	5	6	3	2
26	26	0	2	1	6	6	6	6	5	6	3	2
27	27	0	2	1	7	7	7	7	4	7	2	2
28	28	0	2	1	7	7	7	7	4	7	7	1
29	29	0	2	1	7	7	7	7	3	6	5	3
30	30	0	2	1	6	7	6	6	6	6	5	1
31	31	0	2	1	5	5	5	6	3	6	5	2
32	32	0	2	1	5	5	5	6	3	6	5	2
33	33	0	2	1	6	7	6	6	6	6	4	2
34	34	0	2	1	6	7	6	6	6	6	5	1
35	35	0	2	1	7	7	7	7	7	7	3	1
36	36	0	2	1	7	7	7	7	7	7	3	3
37	37	0	2	1	4	6	5	4	4	5	6	1
38	38	0	2	1	5	6	6	6	6	6	6	1
39	39	0	2	1	5	6	6	6	6	6	6	1
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41	41	0	2	2	4	4	4	4	5	4	5	4
42	42	0	2	2	4	4	4	4	5	4	5	4
43	43	0	2	2	5	5	5	5	5	5	5	4
44	44	0	2	2	5	5	5	5	5	5	5	4
45	45	0	2	2	5	5	5	5	5	5	5	4
46	46	0	2	2	5	5	5	5	5	5	5	4
47	47	0	2	2	6	6	6	6	6	6	6	4
48	48	0	2	2	6	6	6	6	6	6	6	4
49	49	0	2	2	6	6	6	6	6	6	6	4
50	50	0	2	2	5	5	5	5	5	5	5	4
51	51	0	2	2	5	5	5	5	5	5	5	4
52	52	0	2	2	4	4	4	4	4	4	4	3
53	53	0	2	2	4	4	4	4	4	4	4	3
54	54	0	2	2	4	4	4	4	4	4	4	3
55	55	0	2	2	5	5	5	5	5	5	5	4
56	56	0	2	2	4	4	4	4	4	4	4	4

FACTOR1	FACTOR2	FACTOR3
3.15431	3.21454	4.18191
4.81575	1.69009	2.72253
4.94478	2.72417	1.92934
5.02626	1.18065	1.92254
4.94741	3.98149	1.86485
6.17694	-0.67259	2.13743
5.79014	1.67219	4.31737
4.16463	1.93475	1.92993
4.62490	1.62489	3.20396
4.10454	1.21246	1.97863
5.60633	1.28151	1.62393
4.65583	2.61274	1.71091
4.07576	2.36624	1.57053
4.90836	2.41616	3.29175
5.70369	-0.15653	1.83232
3.89136	4.15396	2.89385
4.91154	4.22315	4.68939
5.66059	2.55948	5.03635
5.21186	2.47023	0.64963
4.01660	1.59255	2.90615
4.30136	1.85280	2.48351
4.73677	2.94543	3.68283
4.72066	2.32198	1.99271
5.78240	1.20135	2.23140
5.16347	4.76637	2.03185
3.89528	2.51147	3.06541
5.10794	3.45106	1.74745
4.88395	3.04626	2.50792
4.82298	0.95916	4.68132
4.14890	0.96757	1.38503
5.75820	2.34942	2.92251
4.10632	3.50126	1.81805
4.46366	3.63216	1.52242
4.33013	3.69168	2.07534
5.99996	0.61659	2.35025
3.36047	2.11324	2.40243
2.97213	3.18593	0.03952
4.58341	4.11478	1.88911
5.35657	2.71181	1.35835
4.17275	2.23467	3.46492
3.29043	3.31421	3.28069
3.37776	3.42517	3.13895
4.00304	3.14117	3.44731
2.34248	1.51344	2.75502
3.31919	4.00237	2.16787
2.08891	4.28947	4.13085
4.69552	3.97546	2.42141
4.52512	3.12845	2.39898
3.08437	2.72555	2.52609
3.11500	3.07720	1.84626
4.33752	4.16273	2.86095
3.27524	3.04444	2.87944
3.30433	3.78255	4.13520
3.47913	1.68803	2.64992
3.84327	2.96799	2.44705
3.42585	4.61113	3.55065

ORD	SOF	LUM	MP	A	EP	CH	LD	SP	SC	VP	PU	RU	FACTOR1	FACTOR2	FACTOR3
57	17	0	2	2	5	4	3	5	7	5	5	6	3.37507	4.10634	4.14072
58	18	0	2	2	3	4	3	4	3	4	3	3	3.02433	1.67390	2.67194
59	19	0	2	2	5	7	7	4	5	6	5	2	4.41036	3.35639	2.27103
60	20	0	2	2	3	3	4	3	5	2	2	2	2.37934	1.48955	1.50897
61	1	1	3	0	3	4	4	4	5	4	5	5	3.03854	3.30817	3.83725
62	2	1	3	0	5	6	5	6	4	5	5	4	4.57657	2.42852	3.86273
63	3	1	3	0	4	5	5	5	5	2	2	2	3.66736	2.18645	1.54480
64	4	1	3	0	6	6	6	6	5	6	4	3	4.80866	2.62451	2.83055
65	5	1	3	0	7	6	6	5	7	7	6	2	4.46334	4.65850	2.14296
66	6	1	3	0	6	5	6	6	1	7	1	1	5.25720	-0.39123	1.93355
67	7	1	3	0	6	5	6	6	3	5	3	3	4.80651	1.20917	2.97004
68	8	1	3	0	4	4	3	3	4	4	3	3	2.79955	2.31241	2.30741
69	9	1	3	0	4	5	3	6	3	5	5	5	4.48553	1.89869	4.66727
70	10	1	3	0	6	7	7	6	4	6	3	2	5.06092	1.75708	2.29515
71	11	1	3	0	3	5	3	3	3	4	2	2	2.88327	1.47802	1.77559
72	12	1	3	0	5	5	4	4	5	5	3	1	3.33940	2.78241	1.06560
73	13	1	3	0	5	5	6	6	6	6	5	2	4.19573	3.68529	2.15455
74	14	1	3	0	5	7	5	5	6	7	6	2	4.30662	4.17806	2.46694
75	15	1	3	0	5	5	6	5	3	5	5	1	3.90163	1.20436	1.44416
76	16	1	3	0	4	4	4	4	6	5	6	3	2.99054	4.36809	2.67276
77	17	1	3	0	7	6	6	3	7	5	3	1	3.62153	3.83382	0.47517
78	18	1	3	0	4	5	6	5	6	6	4	2	3.80278	3.48338	1.81476
79	19	1	3	0	7	7	7	5	7	7	1	1	4.74691	2.76572	0.42363
80	20	1	3	0	6	6	6	5	5	6	5	3	4.56813	3.15494	2.94794
81	1	1	3	1	5	6	6	5	3	6	3	2	4.64134	1.45515	2.37923
82	2	1	3	1	5	4	6	5	3	5	3	3	3.90628	1.46783	2.83501
83	3	1	3	1	6	6	6	5	5	5	3	2	4.33569	2.44359	1.80811
84	4	1	3	1	6	6	7	7	6	6	6	4	5.12013	3.66739	3.74934
85	5	1	3	1	5	6	7	5	4	5	7	2	4.13584	3.50197	2.99555
86	6	1	3	1	7	6	7	5	4	6	3	1	4.88141	1.97465	1.50225
87	7	1	3	1	6	5	6	6	3	5	3	5	4.99864	1.04885	4.18499
88	8	1	3	1	5	6	6	4	4	5	4	3	3.86373	2.43988	2.81337
89	9	1	3	1	3	6	5	6	3	6	5	4	4.55283	1.99692	4.18944
90	10	1	3	1	5	6	6	6	5	6	2	2	4.09524	2.26781	1.53993
91	11	1	3	1	7	7	7	7	5	7	5	3	5.69342	2.79306	3.28201
92	12	1	3	1	7	6	6	7	7	3	3	1	4.24642	3.19057	0.78384
93	13	1	3	1	6	5	5	6	6	7	6	4	4.54094	3.91915	3.68238
94	14	1	3	1	6	5	7	5	7	6	7	2	4.11473	5.07079	2.23636
95	15	1	3	1	5	5	6	5	3	5	3	2	4.30943	1.47011	2.25314
96	16	1	3	1	5	4	5	4	5	5	6	5	3.59196	3.33001	3.27986
97	17	1	3	1	6	6	5	4	7	4	6	5	3.55372	4.57989	3.60105
98	18	1	3	1	5	5	5	6	6	6	5	2	4.37514	3.64414	2.20403
99	19	1	3	1	3	6	7	5	7	7	1	1	3.89333	2.93895	0.38341
100	20	1	3	1	4	6	4	4	4	5	5	4	3.78319	2.77544	3.65476
101	1	1	3	2	5	5	5	4	3	4	5	3	3.84450	2.29533	3.15113
102	2	1	3	2	5	6	4	5	5	4	5	5	3.96692	3.01217	4.05206
103	3	1	3	2	5	5	4	4	5	5	3	3	3.53153	2.62209	2.28055
104	4	1	3	2	6	6	6	7	3	6	3	2	5.27483	1.12662	2.60164
105	5	1	3	2	5	4	5	3	3	5	6	2	3.48098	2.97316	2.67825
106	6	1	3	2	4	4	4	3	2	5	3	2	2.88074	0.93614	1.89392
107	7	1	3	2	3	4	3	3	3	2	3	5	2.67899	1.60906	3.63066
108	8	1	3	2	4	2	4	5	4	3	4	5	2.93724	2.29535	3.79815
109	9	1	3	2	3	3	4	3	3	5	5	5	3.10085	2.47554	4.23737
110	10	1	3	2	3	3	4	3	5	6	4	3	2.74758	3.32691	2.36773
111	11	1	3	2	6	7	7	5	6	6	5	2	4.81138	3.17561	2.38051
112	12	1	3	2	6	6	5	5	6	6	5	3	4.24738	3.69714	2.71440

ORG	DOB	LOH	HP	A	RD	CU	LD	SD	SC	VP	PH	RU	FACTOR1	FACTOR2	FACTOR3
113	13	1	3	2	4	5	4	4	5	6	5	5	3.69149	3.28631	4.03141
114	14	1	3	2	4	3	3	3	5	5	6	6	2.87580	3.81104	4.59015
115	15	1	3	2	6	7	6	6	3	6	2	3	5.32590	0.77042	2.92024
116	16	1	3	2	4	5	4	4	5	4	6	5	3.37843	3.61673	4.11853
117	17	1	3	2	3	4	4	4	7	3	5	5	2.33188	4.47739	3.15669
118	18	1	3	2	3	5	4	4	5	4	4	3	3.19378	3.02632	2.43197
119	19	1	3	2	5	6	6	4	6	6	6	2	3.90214	4.32237	2.21344
120	20	1	3	2	4	5	5	4	6	5	7	4	3.42585	4.61113	3.55065
121	1	1	1	0	5	5	5	5	3	5	5	3	4.22447	2.17372	3.33573
122	2	1	1	0	5	6	4	5	4	5	5	3	4.08813	2.67482	3.15671
123	3	1	1	0	6	6	6	6	6	5	5	3	4.48725	1.50487	2.74132
124	4	1	1	0	6	6	6	7	2	6	3	4	5.62781	0.44250	4.06456
125	5	1	1	0	7	7	7	7	7	6	6	1	5.01903	4.35755	1.72986
126	6	1	1	0	7	7	7	7	3	5	6	2	3.80604	2.17905	2.13063
127	7	1	1	0	7	6	6	6	5	6	5	3	4.96914	2.97416	3.05717
128	8	1	1	0	6	7	6	6	5	6	4	2	4.89201	2.66357	2.27755
129	9	1	1	0	5	4	5	4	3	6	4	4	3.76922	1.87358	3.47382
130	10	1	1	0	4	5	4	4	3	3	3	2	3.44352	1.61701	2.01490
131	11	1	1	0	7	6	6	6	4	6	4	2	5.04199	2.14783	2.46750
132	12	1	1	0	4	4	4	3	6	3	3	2	2.30919	3.39566	1.11795
133	13	1	1	0	6	5	6	6	5	4	4	1	4.13212	2.77366	1.41789
134	14	1	1	0	5	6	7	7	7	6	5	1	4.51060	4.08202	1.45212
135	15	1	1	0	6	7	7	7	3	7	2	1	5.67864	0.79074	1.87546
136	16	1	1	0	6	6	6	6	5	6	3	2	4.72066	2.32198	1.99271
137	17	1	1	0	6	3	5	3	7	4	3	2	2.69842	3.90223	0.86560
138	18	1	1	0	6	7	7	6	6	7	7	1	4.92330	4.42335	2.17040
139	19	1	1	0	5	6	6	5	6	7	2	1	4.22330	2.75016	0.86909
140	20	1	1	0	5	5	6	5	4	5	4	2	4.14052	2.37660	2.23553
141	1	1	1	1	6	5	6	6	4	3	3	2	4.24460	1.76087	1.97134
142	2	1	1	1	6	6	5	5	5	5	6	3	4.48013	3.38215	3.23410
143	3	1	1	1	6	6	5	5	5	6	5	5	4.60036	3.01301	4.17733
144	4	1	1	1	7	7	7	7	6	3	3	2	4.04264	2.52712	1.67933
145	5	1	1	1	7	7	7	7	7	6	6	1	5.01903	4.35755	1.72986
146	6	1	1	1	7	5	5	5	5	6	6	2	4.29322	3.64425	2.52725
147	7	1	1	1	7	7	7	7	7	7	7	1	5.16347	4.76637	2.03185
148	8	1	1	1	6	6	6	6	6	6	5	2	4.54368	3.61116	2.20547
149	9	1	1	1	4	4	5	4	3	5	6	5	3.83311	2.61796	4.61721
150	10	1	1	1	6	6	6	5	6	6	4	2	4.31928	3.37622	1.86213
151	11	1	1	1	7	7	7	7	6	7	5	2	5.43651	3.39703	2.42656
152	12	1	1	1	7	6	7	6	5	6	5	2	5.03297	3.03591	2.43546
153	13	1	1	1	6	5	5	6	5	5	5	1	4.11665	3.20087	1.73431
154	14	1	1	1	7	3	7	7	6	3	3	3	4.22106	2.61134	2.06892
155	15	1	1	1	7	7	7	7	4	7	3	2	5.77433	1.58404	2.46177
156	16	1	1	1	5	6	5	5	6	6	6	2	3.44277	3.81033	2.11044
157	17	1	1	1	6	5	5	5	7	6	6	5	4.09119	4.48441	3.85727
158	18	1	1	1	6	7	7	6	6	6	7	1	4.77080	4.39721	2.09878
159	19	1	1	1	7	7	7	7	7	7	6	1	5.17153	4.38368	1.80149
160	20	1	1	1	7	6	7	5	5	5	4	1	4.51000	2.85501	1.41302
161	1	1	1	2	4	3	4	3	5	5	6	4	2.53857	3.90070	3.21752
162	2	1	1	2	4	4	4	4	5	2	4	5	2.91015	2.84018	3.46008
163	3	1	1	2	4	5	5	5	5	5	5	4	4.00384	3.14117	3.44731
164	4	1	1	2	4	4	4	4	5	5	5	5	3.35958	3.30127	3.90532
165	5	1	1	2	6	5	6	5	5	5	6	4	4.32422	3.47243	3.65969
166	6	1	1	2	3	2	3	3	4	5	2	3	2.20772	1.84494	1.94141
167	7	1	1	2	7	7	7	7	4	7	7	2	5.25953	4.68621	2.63933
168	8	1	1	2	4	4	5	4	7	6	4	3	3.45626	2.57671	2.69354

OBS	SUB	LUM	WF	A	RD	CU	LD	SD	SC	VP	PU	RU	SAS			FACTOR1	FACTOR2	FACTOR3
													FACTOR1	FACTOR2	FACTOR3			
169	9	1	1	2	5	5	5	4	4	4	4	3	3.69172	2.43645	2.67284			
170	10	1	1	2	3	3	3	3	4	3	2	2	2.21110	2.05788	1.34705			
171	11	1	1	2	6	7	7	7	7	7	6	4	5.29119	4.17623	3.62746			
172	12	1	1	2	6	6	6	5	6	6	6	2	4.30315	4.14160	2.32286			
173	13	1	1	2	5	3	6	4	5	5	5	4	3.57244	3.35271	3.21096			
174	14	1	1	2	5	7	6	4	6	7	7	2	4.22599	4.69010	2.56990			
175	15	1	1	2	5	5	5	4	5	5	6	6	3.95544	3.51128	4.77965			
176	16	1	1	2	3	4	4	3	4	4	5	4	2.87085	3.01227	3.36477			
177	17	1	1	2	5	4	4	4	7	4	5	5	3.05393	4.28972	3.33419			
178	18	1	1	2	5	6	5	5	5	4	3	2	3.85475	2.46888	1.75447			
179	19	1	1	2	6	7	7	5	6	7	5	1	4.70696	3.80571	1.59668			
180	20	1	1	2	5	4	5	3	5	4	4	2	3.02292	3.22925	1.64994			
181	1	2	4	0	2	3	3	3	3	3	4	4	2.37941	2.17217	3.27427			
182	2	2	4	0	3	4	4	5	4	3	4	5	3.28742	2.22780	3.89621			
183	3	2	4	0	6	6	5	6	4	5	3	2	4.56911	1.79043	2.18349			
184	4	2	4	0	6	6	6	7	6	6	5	4	4.96829	3.30309	3.53340			
185	5	2	4	0	6	7	5	5	4	5	6	2	3.95362	3.16844	2.65268			
186	6	2	4	0	6	6	6	6	5	5	3	3	5.00354	2.15619	2.56860			
187	7	2	4	0	6	6	6	6	3	4	4	3	4.82536	1.52463	3.18326			
188	8	2	4	0	4	3	3	3	4	4	3	3	2.62014	2.35351	2.25297			
189	9	2	4	0	4	5	5	6	4	5	4	3	4.14061	2.20012	2.97397			
190	10	2	4	0	3	5	5	3	5	5	3	2	3.02581	2.89767	1.55277			
191	11	2	4	0	6	6	6	6	4	6	3	2	4.88151	1.79817	2.24069			
192	12	2	4	0	6	5	5	4	6	3	3	1	3.20200	3.20252	0.65639			
193	13	2	4	0	7	4	6	5	5	3	5	1	3.88071	3.31215	1.47726			
194	14	2	4	0	5	7	6	4	6	5	6	2	3.92905	4.25515	2.19628			
195	15	2	4	0	5	5	5	5	3	5	3	4	4.14953	1.48850	2.26757			
196	16	2	4	0	3	4	3	4	4	3	3	4	2.80705	2.09141	2.95982			
197	17	2	4	0	3	4	3	4	7	5	5	3	2.51731	4.56063	2.21240			
198	18	2	4	0	5	6	6	6	6	6	5	2	4.37514	3.64419	2.20901			
199	19	2	4	0	7	7	7	7	5	6	5	1	5.34879	2.92725	1.94544			
200	20	2	4	0	4	4	4	3	3	4	3	3	3.12030	1.77022	2.54098			
201	1	2	4	1	3	3	3	2	3	2	3	4	2.17104	1.87806	2.85574			
202	2	2	4	1	4	4	4	4	3	3	4	5	3.06359	2.36090	3.79411			
203	3	2	4	1	5	5	5	4	5	5	3	2	3.59536	2.60385	1.65864			
204	4	2	4	1	4	4	4	3	4	7	6	5	3.58489	3.36017	4.41393			
205	5	2	4	1	4	4	5	3	4	5	6	3	3.24766	3.44983	3.04130			
206	6	2	4	1	3	5	5	3	4	5	4	1	3.08253	2.83671	1.42364			
207	7	2	4	1	6	5	5	5	3	3	2	6	4.40541	0.69987	4.32030			
208	8	2	4	1	6	5	5	6	4	5	2	3	4.02082	2.04686	2.51054			
209	9	2	4	1	4	5	5	3	3	5	5	4	4.34946	1.97885	4.05979			
210	10	2	4	1	3	4	4	3	4	5	2	2	2.85541	2.05066	1.53014			
211	11	2	4	1	5	6	6	5	5	6	5	4	4.49565	3.10781	3.55997			
212	12	2	4	1	6	6	6	6	5	6	2	1	4.61266	2.01945	1.15487			
213	13	2	4	1	5	6	4	6	5	5	6	5	4.50467	2.74944	4.71501			
214	14	2	4	1	4	7	5	5	5	6	6	4	3.95359	3.62245	3.67719			
215	15	2	4	1	4	4	3	4	4	3	3	2	2.78346	2.21870	1.74132			
216	16	2	4	1	4	4	4	4	3	3	6	4	3.27215	2.66425	3.88092			
217	17	2	4	1	4	5	5	5	7	4	5	5	3.45717	4.11552	3.49076			
218	18	2	4	1	4	5	5	5	6	4	5	2	3.49030	3.47564	1.75757			
219	19	2	4	1	7	7	7	5	6	7	6	2	4.96351	4.07521	2.43097			
220	20	2	4	1	4	4	4	3	3	3	5	5	2.98296	2.87295	3.89707			
221	1	2	4	2	3	3	3	2	2	3	4	4	2.48439	1.38038	3.17534			
222	2	2	4	2	3	4	2	3	3	2	3	6	2.60710	1.92998	4.48294			
223	3	2	4	2	3	2	3	4	3	4	2	1	2.48143	1.53372	1.11769			
224	4	2	4	2	1	2	2	2	3	3	2	3	1.55914	1.72721	2.05659			

SAS										FACTOR1	FACTOR2	FACTOR3
CHS	SUR	THM	MP	A	DD	CU	LD	SD	SC	VP	PH	RU
225	5	2	4	2	5	4	5	3	3	5	5	3
226	6	2	4	2	1	3	2	3	2	2	2	1
227	7	2	4	2	5	3	3	3	2	2	2	6
228	8	2	4	2	4	3	4	3	4	4	3	4
229	9	2	4	2	3	5	4	5	2	5	5	5
230	10	2	4	2	2	3	2	3	3	2	7	1
231	11	2	4	2	5	6	7	5	4	2	7	5
232	12	2	4	2	4	6	6	2	7	4	2	1
233	13	2	4	2	4	3	2	2	2	4	3	6
234	14	2	4	2	3	3	3	3	3	3	3	5
235	15	2	4	2	3	4	3	3	2	3	1	4
236	16	2	4	2	2	3	3	3	3	2	5	4
237	17	2	4	2	3	4	4	3	7	4	6	6
238	18	2	4	2	2	4	4	4	7	3	3	4
239	19	2	4	2	2	4	2	1	5	3	1	1
240	20	2	4	2	2	3	2	2	7	2	1	5
241	1	2	2	0	4	4	5	4	3	5	4	3
242	2	2	2	0	4	5	3	4	4	3	4	5
243	3	2	2	0	€	€	5	5	€	6	4	2
244	4	2	2	0	7	7	7	7	4	6	4	3
245	5	2	2	0	6	5	€	5	5	6	4	1
246	6	2	2	0	7	7	7	7	6	3	6	2
247	7	2	2	0	7	7	€	7	€	6	6	2
248	8	2	2	0	5	4	5	5	4	5	4	2
249	9	2	2	0	4	5	5	4	3	5	4	4
250	10	2	2	0	3	3	4	3	3	3	3	2
251	11	2	2	0	7	7	7	7	4	4	4	2
252	12	2	2	0	4	6	4	3	6	5	4	3
253	13	2	2	0	6	6	5	5	5	5	5	2
254	14	2	2	0	€	6	5	5	€	7	7	1
255	15	2	2	0	6	5	5	7	3	7	2	1
256	16	2	2	0	5	5	4	7	4	5	4	2
257	17	2	2	0	4	5	5	5	3	3	2	2
258	18	2	2	0	4	6	7	5	3	4	5	2
259	19	2	2	0	6	6	7	5	5	7	3	1
260	20	2	2	0	4	5	4	3	4	4	4	3
261	1	2	2	1	5	5	5	5	4	4	5	3
262	2	2	2	1	4	4	4	4	4	4	5	3
263	3	2	2	1	5	5	5	4	5	4	5	4
264	4	2	2	1	7	7	7	7	5	3	3	1
265	5	2	2	1	7	7	7	7	7	7	€	1
266	6	2	2	1	6	6	6	5	5	3	3	4
267	7	2	2	1	€	7	€	€	€	€	7	1
268	8	2	2	1	4	4	4	4	4	3	4	3
269	9	2	2	1	3	4	4	4	3	5	5	4
270	10	2	2	1	3	4	4	3	5	4	4	2
271	11	2	2	1	7	7	7	7	6	€	4	1
272	12	2	2	1	5	6	4	4	6	5	4	2
273	13	2	2	1	5	€	5	5	€	7	7	2
274	14	2	2	1	6	7	7	6	7	6	6	3
275	15	2	2	1	5	€	5	€	7	5	3	2
276	16	2	2	1	5	6	6	6	6	6	5	2
277	17	2	2	1	5	5	5	€	€	5	€	5
278	18	2	2	1	4	6	5	5	€	5	5	2
279	19	2	2	1	€	7	€	€	€	€	€	2
280	20	2	2	1	6	6	6	5	5	5	5	2

QRC	SRR	LMF	MP	A	DD	CU	ID	SD	SC	VP	PU	RU	FACTOR1	FACTOR2	FACTOR3
281	1	2	2	2	3	3	4	3	5	3	6	5	2.46609	3.85357	3.82854
282	2	2	2	2	4	4	4	4	4	2	4	5	3.07100	2.31638	3.70805
283	3	2	2	2	4	4	4	4	4	5	3	5	3.53656	2.01209	3.69256
284	4	2	2	2	3	4	3	3	5	4	6	6	2.73417	3.77684	4.57654
285	5	2	2	2	3	3	3	2	3	4	6	5	2.70781	2.97984	4.28314
286	6	2	2	2	2	3	2	2	3	4	3	3	2.05153	2.06191	2.40950
287	7	2	2	2	6	6	7	6	6	6	6	5	4.98372	3.73498	4.24383
288	8	2	2	2	4	3	4	3	4	4	4	3	2.77197	2.71781	2.46890
289	9	2	2	2	4	5	5	4	2	5	5	5	4.10144	1.67037	4.68928
290	10	2	2	2	4	4	5	3	5	3	3	2	2.70994	2.85346	1.35150
291	11	2	2	2	6	7	5	5	7	7	7	5	4.91425	4.77425	4.23934
292	12	2	2	2	6	6	4	4	6	6	5	1	3.82278	4.00520	1.38647
293	13	2	2	2	3	3	2	4	4	4	5	6	2.80430	2.39940	4.41672
294	14	2	2	2	4	3	3	3	6	5	6	2	2.49058	4.63709	1.89704
295	15	2	2	2	3	3	4	2	3	3	4	5	2.41154	2.20472	3.76521
296	16	2	2	2	3	4	4	3	4	3	5	4	2.71835	2.98614	3.29314
297	17	2	2	2	5	5	5	4	7	4	4	5	3.40131	3.84754	3.14386
298	18	2	2	2	5	5	4	5	5	5	4	2	3.65987	2.93719	2.01642
299	19	2	2	2	6	6	6	3	6	6	2	2	3.87047	2.90633	1.17543
300	20	2	2	2	6	6	6	6	6	2	5	5	2.90303	2.71746	3.95286
301	1	2	0	0	6	6	6	6	3	5	4	2	4.88179	1.63092	2.64741
302	2	2	0	0	6	6	5	6	4	6	6	4	4.98955	2.80431	4.16118
303	3	2	0	0	6	6	6	6	5	6	6	4	4.88060	3.30973	3.09877
304	4	2	0	0	5	6	6	7	7	7	5	1	4.50320	4.12655	1.53818
305	5	2	0	0	7	7	7	7	7	7	6	1	5.17153	4.38368	1.80148
306	6	2	0	0	7	7	7	5	6	6	6	1	4.53553	4.17033	1.69741
307	7	2	0	0	5	6	6	5	6	5	5	2	3.99017	3.76581	2.02442
308	8	2	0	0	7	7	7	7	7	7	5	2	5.27566	3.92083	2.17859
309	9	2	0	0	5	4	6	5	4	5	5	3	4.14517	2.64007	3.62638
310	10	2	0	0	6	6	6	6	6	6	5	3	4.63975	3.53100	2.81295
311	11	2	0	0	7	7	7	7	7	6	5	2	5.12317	3.89470	2.10696
312	12	2	0	0	6	6	7	7	6	7	5	2	4.85608	3.61890	2.26266
313	13	2	0	0	7	7	7	6	6	7	5	3	5.23599	0.31470	4.33024
314	14	2	0	0	6	5	6	6	7	6	3	2	4.21955	3.41068	1.84229
315	15	2	0	0	7	7	7	7	3	7	3	1	5.83911	1.14039	2.10228
316	16	2	0	0	5	6	6	5	5	5	3	2	4.16715	2.47662	1.81166
317	17	2	0	0	6	5	5	5	7	5	5	4	3.85875	3.77305	2.71744
318	18	2	0	0	4	6	5	5	6	5	4	2	3.66173	3.81723	2.04241
319	19	2	0	0	7	7	7	5	6	7	6	2	4.96351	4.07521	2.43097
320	20	2	0	0	3	5	5	2	5	4	4	2	2.63278	3.40197	1.59851
321	1	2	0	1	5	5	5	5	4	5	5	3	4.06862	2.69752	3.08781
322	2	2	0	1	4	5	5	3	5	4	4	3	3.12986	3.14103	2.31544
323	3	2	0	1	6	5	6	6	6	6	6	4	4.54834	3.87463	3.59632
324	4	2	0	1	4	4	4	3	3	3	2	2	2.87980	1.44155	1.63151
325	5	2	0	1	7	6	7	6	6	7	6	1	4.92049	4.04872	1.88201
326	6	2	0	1	6	7	7	7	7	7	7	1	4.99493	4.79941	2.03540
327	7	2	0	1	7	7	7	7	7	7	7	1	5.16347	4.76637	2.03185
328	8	2	0	1	6	7	6	7	6	6	5	3	5.05164	3.34216	2.98040
329	9	2	0	1	5	4	5	4	5	4	4	3	3.35146	3.00135	2.37039
330	10	2	0	1	6	6	6	5	6	4	4	3	4.41535	3.29606	2.46960
331	11	2	0	1	6	7	6	6	7	7	6	1	4.77052	4.56446	1.69205
332	12	2	0	1	5	6	6	6	5	6	4	2	4.54405	2.73770	2.22663
333	13	2	0	1	6	6	6	5	5	6	6	4	4.65613	3.45747	3.78579
334	14	2	0	1	6	7	7	4	6	6	6	2	4.40949	4.23985	2.24992
335	15	2	0	1	7	6	6	6	6	6	6	4	4.89630	3.80050	3.64724
336	16	2	0	1	5	6	6	5	6	7	6	2	4.28711	4.26076	2.39804

GRS	GRN	LHN	WP	A	BD	CH	LD	SD	SC	VP	PH	RU	FACTOR1	FACTOR2	FACTOR3
337	17	2	0	1	4	5	4	2	7	4	4	7	2.00006	4.03413	4.15003
338	18	2	0	1	4	5	5	5	5	5	5	2	3.64316	3.33452	2.23591
339	19	2	0	1	4	7	5	7	5	6	5	2	5.27632	2.88012	2.60647
340	20	2	0	1	5	4	6	2	5	3	5	3	2.88585	3.63500	2.28875
341	1	2	0	2	4	5	5	4	4	5	5	5	3.70724	2.69185	4.12171
342	2	2	0	2	3	3	4	4	5	3	2	2	1.97768	2.71104	0.97166
343	3	2	0	2	4	4	5	4	5	5	4	4	3.42341	3.36304	3.28341
344	4	2	0	2	4	5	4	4	5	5	4	3	3.35492	3.03781	2.51447
345	5	2	0	2	7	4	7	6	6	6	6	1	4.94741	3.98149	1.86485
346	6	2	0	2	5	4	3	5	7	4	7	1	2.72610	5.24639	1.49245
347	7	2	0	2	6	5	6	5	5	5	4	5	4.43642	2.62689	3.82643
348	8	2	0	2	5	5	4	4	4	4	3	4	3.63595	1.99199	3.06438
349	9	2	0	2	3	4	3	3	3	4	4	3	2.78379	2.20433	2.78933
350	10	2	0	2	5	6	4	4	5	4	5	3	3.54232	3.32024	2.72414
351	11	2	0	2	6	6	5	5	5	6	6	5	4.59230	3.39570	4.40770
352	12	2	0	2	6	6	5	5	6	5	3	1	3.91880	3.06595	0.96709
353	13	2	0	2	3	4	3	4	4	5	4	5	3.20005	2.44620	3.94091
354	14	2	0	2	5	4	4	3	5	4	5	2	2.85495	3.63033	1.89474
355	15	2	0	2	5	6	4	5	7	6	7	6	4.19006	4.77887	4.75314
356	16	2	0	2	4	3	3	3	5	3	3	2	2.21073	2.93134	1.32589
357	17	2	0	2	4	3	3	4	7	3	5	4	2.29751	4.43626	2.61861
358	18	2	0	2	4	5	5	5	5	4	4	2	3.49873	2.92570	1.93392
359	19	2	0	2	3	7	4	7	7	7	1	1	4.05798	2.65754	0.73714
360	20	2	0	2	4	3	4	4	5	3	4	3	2.69110	3.06773	2.26228
361	1	3	3	0	4	5	5	4	3	4	4	3	3.68402	1.94567	2.92437
362	2	3	3	0	2	4	2	3	3	2	4	6	2.43855	1.96301	4.48649
363	3	3	3	0	4	3	4	4	5	4	2	2	2.76366	2.40865	1.26569
364	5	3	3	0	5	5	5	4	4	5	6	2	3.73202	3.30812	2.59773
365	4	3	3	0	5	5	5	4	4	4	3	4	3.79585	1.97360	3.04994
366	6	3	3	0	3	3	4	4	2	3	2	1	3.38136	0.73976	1.41819
367	7	3	3	0	6	5	5	5	3	3	3	6	4.19734	1.08256	4.55067
368	8	3	3	0	4	3	4	3	4	4	3	3	2.78004	2.33512	2.23853
369	9	3	3	0	4	6	5	6	3	6	5	5	4.81744	1.88372	4.79330
370	10	3	3	0	2	4	5	6	3	3	3	2	2.37475	1.90870	1.80342
371	11	3	3	0	5	6	5	6	3	7	6	5	5.13042	2.25951	5.09180
372	12	3	3	0	3	4	3	3	4	3	5	3	2.47045	2.70200	2.46973
373	13	3	3	0	3	4	3	4	4	4	5	5	3.03949	2.80276	4.09966
374	14	3	3	0	4	4	4	3	5	4	6	3	2.77441	3.96590	2.73614
375	15	3	3	0	2	5	3	3	3	4	2	2	2.94720	1.36331	1.89212
376	16	3	3	0	4	4	4	4	4	4	5	2	3.07973	2.99182	2.25925
377	17	3	3	0	3	2	3	3	7	4	3	2	1.69358	4.07921	0.85065
378	18	3	3	0	4	5	4	5	5	5	5	2	3.48326	3.35291	2.25015
379	19	3	3	0	5	6	6	5	6	6	3	1	4.06273	3.10672	1.02783
380	20	3	3	0	3	3	3	3	4	3	4	4	2.38710	2.66294	3.02274
381	1	3	3	1	4	3	4	3	4	4	4	4	2.86804	2.63765	3.07618
382	2	3	3	1	3	3	2	2	4	2	4	5	1.93830	2.72278	3.46004
383	3	3	3	1	4	4	5	4	4	5	4	5	3.68839	2.37639	3.90849
384	4	3	3	1	4	5	4	4	4	5	4	3	3.51577	2.51400	2.76245
385	5	3	3	1	6	7	7	7	6	7	7	1	5.15577	4.27560	2.28318
386	6	3	3	1	3	5	3	3	3	4	2	2	2.88327	1.47802	1.77559
387	7	3	3	1	2	3	3	2	3	2	3	5	2.09857	1.83093	3.46677
388	8	3	3	1	3	3	3	3	4	5	5	5	2.78010	3.01773	4.00383
389	9	3	3	1	3	4	4	3	3	5	4	5	3.28833	2.05175	4.06147
390	10	3	3	1	2	3	3	3	4	4	4	2	2.17892	2.88243	1.88297
391	11	3	3	1	6	7	7	5	6	5	5	3	4.09909	3.64539	2.81163
392	12	3	3	1	4	7	4	3	6	5	5	3	2.59472	4.17424	2.27495

SAS

OPS	SUB	LOH	WP	A	BD	CU	LD	SD	SC	VP	PU	RU	FACTOR1	FACTOR2	FACTOR3
393	13	3	3	1	3	5	3	4	6	6	6	4	3.09807	4.32439	3.42432
394	14	3	3	1	5	4	5	4	5	6	5	3	3.64839	3.43630	2.74401
395	15	3	3	1	2	3	3	3	2	3	3	4	2.54832	1.26567	3.29187
396	16	3	3	1	3	4	3	3	4	3	6	3	2.45432	3.46738	2.93047
397	17	3	3	1	3	3	3	4	7	2	5	6	2.16860	4.28284	3.76548
398	18	3	3	1	2	4	4	4	4	3	4	4	2.79034	2.48674	3.17931
399	19	3	3	1	5	6	5	5	6	6	6	3	4.07077	4.11286	2.94832
400	20	3	3	1	3	5	3	3	5	4	5	3	2.63345	3.59354	2.57822
401	1	3	3	2	2	3	2	3	5	3	6	6	2.07382	3.84323	4.46843
402	2	3	3	2	3	4	3	4	4	2	4	5	2.74255	2.36780	3.72604
403	3	3	3	2	3	4	4	4	4	4	3	3	2.86348	2.19770	2.42397
404	4	3	3	2	2	2	2	3	5	4	5	6	2.05497	3.52777	4.25522
405	5	3	3	2	3	2	2	2	2	3	4	5	2.39298	1.72401	3.95871
406	6	3	3	2	2	3	4	2	2	3	2	3	2.38774	1.09250	2.32662
407	7	3	3	2	6	6	6	6	5	6	6	4	4.88860	3.30973	3.89877
408	8	3	3	2	4	3	4	2	4	4	3	4	2.64364	2.40270	2.73303
409	9	3	3	2	3	3	5	4	4	5	6	5	3.50372	3.17480	4.37278
410	10	3	3	2	3	3	3	3	4	3	3	2	2.20303	2.44057	1.57742
411	11	3	3	2	5	7	7	4	7	7	7	5	4.51324	4.95503	4.12991
412	12	3	3	2	4	5	1	5	6	5	4	2	3.17058	3.51242	1.78643
413	13	3	3	2	3	5	3	5	5	6	5	5	3.59552	3.18999	4.16238
414	14	3	3	2	4	4	3	2	4	4	4	5	2.75115	2.68253	3.63978
415	15	3	3	2	2	3	2	3	4	3	3	5	2.16279	2.25151	3.41783
416	16	3	3	2	3	3	3	3	3	3	5	5	2.63595	2.44166	4.10856
417	17	3	3	2	3	4	3	3	7	1	5	4	2.07591	4.57595	2.56365
418	18	3	3	2	3	4	4	4	3	3	4	2	2.92760	2.09222	2.20878
419	19	3	3	2	2	3	5	1	6	5	2	2	2.34566	3.15400	0.96903
420	20	3	3	2	4	3	3	3	5	5	5	5	2.48280	3.45624	3.60906
421	1	3	1	0	5	4	5	4	4	5	5	5	3.84887	2.72604	4.13531
422	2	3	1	0	5	5	6	3	6	5	5	2	3.16641	4.14349	1.68952
423	3	3	1	0	5	5	5	5	5	5	5	4	4.00384	3.14117	3.44731
424	4	3	1	0	3	5	4	4	5	4	6	5	3.20989	3.64977	4.12209
425	5	3	1	0	7	7	7	7	6	7	6	1	5.33238	3.85988	2.04946
426	6	3	1	0	6	7	7	6	5	6	6	1	4.93971	3.49072	2.11638
427	7	3	1	0	6	6	6	5	6	6	6	2	4.30315	4.14160	2.32286
428	8	3	1	0	6	6	5	6	6	6	5	3	4.63975	3.53100	2.81295
429	9	3	1	0	3	5	5	3	4	3	4	5	3.16180	2.46380	3.71029
430	10	3	1	0	5	5	5	4	5	4	4	2	3.43480	3.04041	1.81739
431	11	3	1	0	7	7	7	7	6	7	6	1	5.33238	3.95988	2.04946
432	12	3	1	0	5	6	5	5	5	5	3	2	4.00725	2.49501	1.82609
433	13	3	1	0	5	4	5	3	4	5	5	5	3.61640	2.87379	4.02233
434	14	3	1	0	5	5	4	4	6	5	5	3	3.35456	3.91127	2.49311
435	15	3	1	0	5	6	7	6	5	6	5	4	5.05657	2.90864	3.65396
436	16	3	1	0	6	6	5	5	6	6	5	2	3.83834	3.40151	1.80849
437	17	3	1	0	5	6	5	5	7	6	6	5	4.10206	4.47634	3.91530
438	18	3	1	0	4	5	5	5	5	4	4	3	3.59480	2.84554	2.54119
439	19	3	1	0	4	7	6	6	6	6	4	5	4.72310	3.57007	2.25994
440	20	3	1	0	5	4	4	3	5	5	5	3	3.10352	3.57631	2.57384
441	1	3	1	1	5	5	4	4	3	4	4	4	3.78873	1.85087	3.54272
442	2	3	1	1	4	5	4	5	4	3	3	3	3.45131	1.93130	2.50181
443	3	3	1	1	5	5	6	5	6	6	5	5	4.25146	3.59255	3.86400
444	4	3	1	1	5	6	6	5	5	6	5	4	4.49565	3.10781	3.55897
445	5	3	1	1	6	6	6	6	6	6	6	2	4.53562	3.99385	2.43584
446	6	3	1	1	5	5	5	3	5	6	5	3	3.59533	3.54295	2.68550
447	7	3	1	1	7	6	6	6	6	6	6	2	4.70416	3.96082	2.43229
448	8	3	1	1	5	5	5	6	5	4	4	3	3.76334	2.81251	2.53794

SAS														
SUP	LIB	CP	A	PD	CU	ID	SD	SC	VP	PH	PU	FACTOR1	FACTOR2	FACTOR3
1	3	1	1	5	5	4	4	4	4	5	4	3.61982	2.75737	3.52512
10	3	1	1	6	6	5	5	6	6	4	3	4.25545	3.31445	2.48494
11	3	1	1	5	7	7	5	7	7	7	4	4.64964	4.88745	3.63542
12	3	1	1	6	5	5	5	6	5	5	2	3.81940	3.79226	1.98081
13	3	1	1	6	5	5	5	5	5	6	5	3.94058	3.44745	4.31047
14	3	1	1	5	6	6	5	6	6	7	2	4.12654	4.55732	2.55674
15	3	1	1	6	6	6	5	6	6	6	5	4.59135	3.90111	4.14524
16	3	1	1	4	4	4	3	5	4	4	2	2.69447	3.28068	1.66792
17	3	1	1	4	5	5	3	7	4	4	5	2.84440	4.04671	3.04847
18	3	1	1	4	5	5	4	4	5	5	1	3.17832	3.45353	2.74839
19	3	1	1	5	6	6	5	6	6	6	1	4.03854	4.25479	1.71894
20	3	1	1	5	6	6	3	4	4	5	2	2.85512	2.75607	1.91540
21	3	1	2	3	3	4	3	4	4	5	5	2.70750	2.97321	3.19177
22	3	1	2	5	5	6	4	6	5	6	3	3.66629	4.25718	2.69442
23	3	1	2	7	7	7	6	6	6	6	4	5.21561	3.74101	3.68728
24	3	1	2	4	4	4	3	4	3	3	2	2.71044	2.34805	1.61391
25	3	1	2	4	5	5	4	4	5	6	4	3.59476	3.70464	1.56825
26	3	1	2	6	3	6	2	7	3	7	2	2.44109	5.53621	1.54804
27	3	1	2	7	6	7	6	5	5	3	3	4.89661	2.24442	1.90310
28	3	1	2	6	5	5	5	6	4	5	5	2.79520	3.46398	3.66625
29	3	1	2	5	5	4	5	6	4	5	4	4.02083	2.57659	3.63454
30	3	1	2	5	6	5	5	6	5	5	2	3.84640	3.31882	1.57812
31	3	1	2	6	5	5	5	7	7	7	3	4.72212	4.93458	3.02439
32	3	1	2	6	5	5	4	4	5	4	5	4.20489	2.26923	1.95546
33	3	1	2	4	5	5	4	4	5	4	4	3.70791	2.55368	3.97740
34	3	1	2	4	4	4	4	5	5	7	4	3.40729	4.12842	3.74415
35	3	1	2	5	4	5	4	5	4	4	4	3.44752	2.92119	2.97787
36	3	1	2	5	5	5	4	6	5	6	4	3.43392	4.22844	3.32024
37	3	1	2	5	5	5	5	7	6	6	6	3.85882	4.45567	4.43271
38	3	1	2	5	5	5	5	6	4	3	2	3.34595	3.06681	1.45557
39	3	1	2	5	5	5	4	7	5	3	1	3.01770	3.93002	0.56965
40	3	1	2	5	4	4	4	5	3	3	4	2.54470	3.13532	2.75678
41	3	1	2	3	4	3	3	5	3	3	4	2.89533	1.69696	3.08034
42	3	2	0	3	4	4	2	4	2	3	5	2.09762	2.31634	3.20436
43	3	2	0	2	4	5	5	5	5	5	4	3.65589	3.21530	3.19639
44	3	2	0	2	4	3	2	4	2	4	6	2.18657	2.11346	4.30461
45	3	2	0	2	6	5	4	5	5	6	3	3.84665	3.71067	3.01170
46	3	2	0	3	4	4	2	3	3	3	4	1.33929	3.22181	3.22181
47	3	2	0	5	5	5	3	5	5	5	3	3.76453	2.46921	1.10383
48	3	2	0	3	3	4	3	3	3	3	4	2.87639	2.08771	3.25273
49	3	2	0	3	5	4	4	4	5	5	5	3.53130	2.76941	4.21132
50	3	2	0	3	5	7	5	6	4	6	3	2.60657	2.80167	1.56852
51	3	2	0	5	6	6	6	6	6	5	2	4.72249	4.06111	3.04555
52	3	2	0	3	6	6	6	6	6	5	2	4.04765	3.19021	2.44942
53	3	2	0	3	3	4	3	3	3	5	6	3.20498	2.01269	4.61448
54	3	2	0	4	5	5	2	3	3	5	5	2.89862	2.61611	2.87159
55	3	2	0	3	4	4	4	5	4	3	5	3.05467	2.54279	3.37651
56	3	2	0	4	4	3	3	3	3	3	2	2.55099	2.36644	1.62834
57	3	2	0	3	4	1	2	7	3	5	4	1.84344	4.72369	2.45067
58	3	2	0	3	4	4	3	4	4	3	3	2.79091	2.32705	2.29656
59	3	2	0	5	6	6	5	6	6	5	2	4.14267	3.79194	2.09605
60	3	2	0	2	3	4	2	4	3	4	3	2.04992	2.90548	2.29140
61	3	2	1	3	4	4	2	4	3	4	4	2.27270	2.68133	3.03717
62	3	2	1	4	6	6	4	6	4	6	3	3.14525	4.26408	2.62674
63	3	2	1	5	5	5	4	5	5	5	5	3.53614	2.80555	3.67140
64	3	2	1	2	2	2	2	4	3	3	3	1.55877	2.63067	2.03544

SAS	SHR	IMP	RP	A	BD	CH	LD	SD	SC	VP	PH	RU	FACTOR1	FACTOR2	FACTOR3
505															
506	5	4	2	1	5	5	5	4	5	4	5	2	3.42674	3.42310	2.04776
507	6	4	2	1	2	3	2	3	3	3	2	5	2.56417	1.19727	3.54841
508	7	4	2	1	5	5	6	5	3	5	3	5	4.59763	1.22963	4.07556
509	8	4	2	1	3	3	3	3	4	3	3	4	2.39517	2.28025	2.79237
510	9	4	2	1	3	3	3	4	3	5	3	4	3.27289	1.61987	3.35104
511	10	4	2	1	2	3	2	2	5	3	3	2	1.40127	3.16354	1.23445
512	11	4	2	1	4	7	4	7	7	7	7	6	4.51985	4.51985	5.12318
513	12	4	2	1	5	4	4	4	5	5	4	2	3.24799	3.12603	1.04898
514	13	4	2	1	3	5	3	4	4	5	5	4	3.27533	2.86796	3.61827
515	14	4	2	1	3	6	4	2	6	4	5	5	2.94012	4.01225	1.46870
516	15	4	2	1	3	5	4	5	5	5	4	5	3.61099	2.76278	3.84595
517	16	4	2	1	3	3	3	3	4	3	5	3	2.28297	3.12579	2.64563
518	17	4	2	1	3	3	3	2	7	3	3	5	1.93951	4.64353	3.05815
519	18	4	2	1	3	3	4	4	4	3	3	4	2.78754	2.11411	2.89091
520	19	4	2	1	2	3	3	2	6	5	5	2	1.76919	4.48660	1.57603
521	20	4	2	1	3	3	4	3	5	3	4	4	2.38615	1.16835	2.76333
522	1	4	2	2	2	2	3	2	6	3	5	5	1.57298	4.23495	3.20073
523	2	4	2	2	2	4	2	3	2	1	4	7	2.54297	1.33291	5.27032
524	3	4	2	2	2	7	6	3	6	6	7	4	4.20169	4.61836	3.59664
525	4	4	2	2	3	2	3	3	6	4	7	5	2.11037	4.84569	3.84252
526	5	4	2	2	3	2	4	3	4	4	5	3	2.41595	3.17462	2.64835
527	6	4	2	2	3	4	5	5	7	2	6	2	2.50795	4.76055	1.70454
528	7	4	2	2	7	6	7	6	6	5	5	1	4.62356	3.61376	1.50839
529	8	4	2	2	5	4	4	3	5	4	5	5	3.14315	3.38985	3.71716
530	9	4	2	2	5	4	3	4	4	4	5	4	3.28050	2.81686	3.40501
531	10	4	2	2	2	5	3	3	6	5	7	1	2.28862	1.18876	0.49936
532	11	4	2	2	5	7	7	4	7	7	7	3	4.32111	5.11535	2.91497
533	12	4	2	2	5	3	4	4	6	5	5	3	2.99573	3.99346	2.33417
534	13	4	2	2	2	3	3	1	1	6	5	6	2.87772	1.72082	5.20445
535	14	4	2	2	3	3	3	2	4	3	3	5	2.25876	2.34783	3.28696
536	15	4	2	2	3	2	3	2	5	2	4	4	1.66187	3.34945	2.53569
537	16	4	2	2	3	3	4	3	5	3	6	4	2.37003	3.93373	3.22107
538	17	4	2	2	3	5	4	5	7	5	7	6	3.36117	4.07829	4.64854
539	18	4	2	2	2	3	4	4	4	4	7	3	2.66736	2.63613	2.58899
540	19	4	2	2	2	2	3	3	7	4	4	7	1.99731	4.09413	4.12194
540	20	4	2	2	3	2	3	1	5	2	4	2	1.23727	3.65752	1.20776

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LIGHTING CUES TO VISUAL CLARITY

by

SHYAM N. GETTU

B.S. (Production) , University of Madras, India, 1981

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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Manhattan, Kansas

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ABSTRACT

The main objective of this study was to establish the relationship between visual clarity and certain physical lighting factors and to find an empirical formula for the predictness of visual clarity using a scale model.

A model of dimensions 24"x12"x10" was made to scale of one inch equals to one foot. Twenty seven conditions out of the seventy five conditions (five luminaire luminance levels, five workplane luminance levels and three luminaire areas; 5x5x3) were studied in this experiment. Each subject was exposed to these lighting conditions. A total of twenty subjects evaluated the lighting conditions on eight semantic scales.

The data was factor analysed and three factors, pleasantness, visual clarity and spaciousness emerged. A power relationship was fitted between visual clarity and the independent variables, ie. workplane luminance(WP), luminaire luminance(LUM) and luminaire area(A) were all subjected to logarithmic transformation before fitting a linear regression equation. Upon retransformation subsequent to regression analysis the following power relation results:

$$\text{Visual clarity} = K7(A)^{K2} \cdot (WP)^{K4} \cdot (LUM)^{K6}$$

Each of the experimental variables had a positive effect on visual clarity. Further analysis showed large individual differences among the observers with nearly equal importance in predictiveness to the physical parameters.