A STUDY OF TASK LIGHT SYSTEMS: HID KIOSKS AND FURNITURE MOUNTED FLUORESCENT LIGHTING SYSTEM

by

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INTRODUCTION

The basic function of light is providing visibility for visual task performance. Good lighting system enables the human being to perceive his visual task accurately, quickly and safely, with minimum fatigue. Morever, good illumination contributes to the pleasant and comfortable appearance of the environment.

Lighting is often taken for granted-- mostly because people can adapt to nearly any lighting situation and are not aware of what the lighting is doing for them.

Since 1973, increasing attention has been paid to the complex problem of lighting quality. Techniques such as semantic differential and multidimensional scaling have been developed by psychologists. These enable people to gain more understanding of the nature of lighting quality.

Flynn (1977) wrote: " We see the year 1973 as a prominent and significant turning point. ... In the post-1973 energy and economic environment, the value of lighting is challenged." The question: " What does lighting contribute to a building interior?" deserves people to view it from some angles other than task visibility and immediate task performance.

The energy crisis also triggered several other changes in general lighting practices in the United States. The two major changes are more extensive use of high intensity discharge lamps and the development of task/ambient light system.

Aesthetics of lighting

For a long time most people regarded the purpose of lighting to provide sufficient illumination on the work to enable people to perform their tasks, and efforts regarding the improvement of lighting conditions were dedicated to this objective.

"Objective lighting" or "engineering lighting" may be considered as the quantity, uniformity, diffusion, luminance and direction of the lighting. Steinmetz (Erhardt, 1977) wrote: " Objective illumination, as measured by the photometer is no criterion of the subjective illumination, that is the physiological effort produced by it, as regards to clearness, comfort, and satisfaction, and it is the subjective illumination by which the success of an illuminating engineering problem is judged."

Sufficient and well distributed illumination is critical to visibility, but a well illuminated space is not necessary a pleasant space. Bennett (1978) wrote: "The well-lighted uniform open plan office with rows and rows of rectangular ceiling fixture is about as pleasant as a well-lighted slaughter house." Hawkes (1979) showed that regular arrays of recessed luminaires, the common way of lighting offices, are not well liked.

Today, subjective lighting or aesthetic lighting is becoming increasing recognized as an important factor in providing a pleasant and satisfactory working environment. Flynn, Spencer, Martyniuk and Hendrick (1973) wrote: "Lighting design should be evaluated, in part for its role in adequately establishing cues that facilitate or alter the user's understanding of his environment and the activities around him." Flynn (1977) also wrote: "Human responses to spatial lighting patterns are, to some extent, shared experiences. ... The experience of vision is, in part, an experience of recognizing and assimilating communicative pattern."

Recent studies concerning aesthetic lighting have showed the effect of several major parameters of lighting of subjective impressions.

One major parameter is lighting setting. Lighting setting includes lighting distribution (uniform vs nonuniform) and lighting pattern (overhead vs peripheral). Uniform lighting produces high ratings of visual clarity and nonuniform lighting has high ratings of pleasantness, preference and relaxation. periphral or wall lighting can reinforce the impression of spaciousness.

Another major parameter is light source. One of the most important characteristics of light source related to aesthetic lighting is the color appearance of light. Previous study have suggested that warm tones of white light are perceived as somewhat more relaxing and pleasant than cool tone (Flynn, 1977).

Non-uniform lighting

Williams (1975) said: "Lighting level does not have to be reduced. By using more efficient lamps and luminaires and by putting the correct amount of light where it is needed, the designer can eliminate inefficiency and waste in energy use."

Before 1973, lighting practice was based on an assumption of plentiful and inexpensive electric energy. Uniform lighting systems were taken for granted as the most appropriate and were customary for office uses. It was found however, the uniform lighting was not always satisfactory (Hopkinson & Longmore, 1959); (Taylor, Sucov and Shaffer, 1975).

The open plan office or officescape approach to interior design has rapidly developed in the past few years. That brought many changes in the operation and appearance of the office. One change is the office furniture system and task/ambient lighting.

An office furniture system is usually a typical cubicle which may have task and ambient lighting. The cubicle consists of a desk, an "L" side table (possibly for typing), file compartments, a chair or two, and some partial partitions that do not go to the ceiling (say five or four feet high). Ambient lighting can be provided from luminaires mounted atop office furniture in the space with no physical attachment to the building structure. This ambient lighting is usually directed upward in order to bounce light off the ceiling for general illumination. Built-in task lighting is directed from some point above the task. The task light fixture may be built on the partitions either over the desk or side table or both.

There are two main advantages of office furniture systems. First is flexibility. The light fixture can move wherever the furniture moves. Second is savings. Both the ambient and task lighting systems place light at the places where it is needed and at suitable levels of illumination. This is in contrast to uniformly lighted office spaces where no distinction is made between task and ambient illumination levels.

Some figures of connected load (watts per wquare foot) at major installations of office furniture systems are given in Murphy (1977) reprot. For instance, at the Beazley Company in West Haven, Connecticut, the watts/square foot figure is 1.5; at the Norris-Cotton Federal Building in Manchester, New Hampshire, the watts/square foot figure is 1.65; at Crowley Maritime Corp. in San Francisco, it is 1.81 watts/square foot.

These figures compare favorably with an average load of four to six watts/square foot for older conventionally lighted offices.

Another approach which is gaining popularity is the kiosk. Kiosks are free-standing columns with uplight and sometimes some light directly downward. A moderately high wattage, high efficacy good color rendering source like metal halide is popular. Kiosks can be used to provide task lighting as well as ambient lighting. In addition to its flexibility and energy saving, kiosks have another distinct advantage, its quality, due to indirect illumination.

Direct lighting has the advantage of being the most efficient in terms of ultilizing luminous flux in a space. However, by directing the light straight down to the work surfaces, the system has the greatest potential for producing direct glare or veiling reflections which cause a loss of visual performance.

Lemons and Cole (1977) using scale models to investigate office system furniture showed indirect lighting systems can eliminate glare and improve task contrast. In addition, indirect light also creates a comfortable and relaxing environment.

Light source

Electric lamps may be divided into two main groups: incandescent and discharge. Discharge lamps may be further divided into two groups according to whether the gas is contained at low or high pressure. Commonly used low pressure discharge lamps include tubular fluorescent lamps and low pressure sodium lamps. Commonly used high pressure discharge lamps, also know as high intensity discharge lamps (HID lamps), include mercury, metal halide and high pressure sodium (HPS) lamps. Some principal characteristics of these light sources including average life, horizontal initial lumens, lamp lumen depreciaion, color temperature, color rendering index (CRI), and efficacy are shown in Table 1.

The simplicity, compactness and versatility of the incandescent lamp make it suitable for many applications; but for ordinary general lighting purposes, its comparatively short life and low lumen-per-watt efficacy put it at a disadvantage as compared with the other two types.

The high efficacy and long life of fluorescent lamps make them particularly suitable for general lighting purpose, and it is possible to obtain fluorescent lamps with particularly good color rendering properties when this characteristic is needed.

TABLE 1

Analysis of lamp sources made by major manufacturers

(Marquard, 1977)

Lamp	Watts	Averg. Life (hrs)	Horiz. Initial Lumens	Lamp Lumen Depre. (%)	Color Tem. (K)	CRI (%)	Efficacy (Lumen/W)
Daylight at noon					5000		
Incandescent							
General Electric Data	100	750	1750		2900	97	17.5
	300	750	6000		3000	97	20
Mercury							
Deluxe White General Electric Data	100	24000	4000	79	3900	46	40
	175	24000	8150	86	3900	46	46.6
	250	24000	11500	82	3900	46	46
	400	24000	21500	80	3900	46	53.7
Styletone Westinghouse	100	24000	3650	74	3000	52	36.5
	175	24000	7000	80	3000	52	40
	250	24000	11000	75	3000	52	44
	400	24000	19500	80	3000	52	48.7
Fluorescent							
F40CW	40	20000	3150	88	4200	66	78.7
F40CWX	40	20000	2200	83	4200	89	55
F40WW	40	20000	3150	88	3000	52	78.7
F40WWX	40	20000	2150	83	2900	73	53.7
High Intensity Discharge							
MS175/HOR	175	7500	15000	80	4500	65	85.7
MS175/C/HOR	175	7500	15000	80	3800	70	85.7
M250	250	7500	19200	80	4500	65	76.8
M250/C	250	7500	19200	80	3800	70	76.8
MS400/HOR	400	15000	40000	80	4500	65	100
MS400/C/HOR	400	15000	40000	78	3800	70	100
LU 150	150	24000	16000	90	2100	32	106
LU250/S	250	24000	30000	90	2100	32	120
LU 400	400	24000	50000	90	2100	32	125

However, with the onset of the energy crisis and rising electrical costs, building users demanded better stewardship of their money. A more efficient light source was needed, and one already existed -- the HID lamps.

Before 1973, HID lamps had been used mainly for outdoor applications such as streets, stadiums and parking lots. The benefits of HID lamps are their high efficacies. Because of poor color and high wattage which resulted in hot spots and glare, these lamps could not be accepted for indoor uses, especially low ceiling offices.

Since the energy crisis, people are no longer living in a society where electric energy is inexpensive. Because HID lighting is generally more energy efficient than fluorescent light, illuminating engineers have put in a big effort to make it more acceptable for indoor uses. The results were the improved color rendering properties and availability in low wattages that made these lamps attractive for general indoor application. Indirect HID lighting fixture also made the lamps acceptable in low ceiling offices.

Mercury lamps

High pressure mercury lamps have been produced since the 1930s. The first of these lamps radiated a bluish-green light. Color correction is added since the blue-green light distorts almost all colors. Today, the users may choose between the clear, color-corrected and white-deluxe lamps which are in ascending order of color improvement. Mercury lamps are favor-ed over incandescent or fluorescent lamps because of their exceptionally long life (24,000 hrs, av.). However, efficacy of mercury lamp is lower than the other two HID lamps, it runs between 40 to 60 lm/w. and its lumen depreciation is high. Therefore, mercury lamps should rarely be used for any application.

Metal halide lamps

The metal halide lamp is basically a mercury lamp which has been altered by the addition to the arc tube of halides of such metals as thallium, indium or sodium. The addition of those salts increases efficacies 1.5 to almost 2 times that of mercury lamps and improves the color rendering. The color produced is much warmer than the mercury light and is suitable for most indoor applications.

High pressure sodium lamps

Of all the light sources for general lighting uses, high pressure sodium (HPS) lamps are the most efficient light sources. HPS lamps have efficacies ranging from 95 to 140 lm/w. Of the three types of HID lamps, HPS also offers the best lumen maintenance characteristics. The average mean lumens for HPS lamps ranges from 90 to 91% of initial light output.

Today, however, there are still drawbacks to wide use of HPS lamps. The main reasons may be the high initial cost and reluctance to change a familiar system. Other reason may be the color is deemed less desirable than fulorescent or metal halide.

Several studies have been done on subjective impressions to HID lamps. Both positive and negative opinions have been found in these studies.

In one report (Dorsey, 1978), an actual example of relighting from fluorescent to HPS in a Milwaukee firm is described. The new lighting received favorable reaction when employees previewed it in an conference room, so overall installation proceeded. Marquard (1977) reported that as far as color is concerned, for HID lamps, the most widely accepted by the design community is the metal halide phosphor coated lamp with 3800K (color temperature) and a color rendering index (CRI) of 70. Clear metal halide is second. Other HID sources are accepted with caution. Other studies done by Fowler (1975), Stormont (1975) and Rowe & Williams (1975) showed that the high pressure sodium lamp is a usable alternative to fluorescent and represents both energy and initial cost savings.

A study conducted by Flynn and Spencer (1977) gives more detailed information about subjective impression on HID lamps. A number of light sources were installed in trans-illuminated ceiling cavity in the Architectrual Engineering Illumination Laboratory at Pennsylvania State University. The principal environment variable was the color of light in the range of 2100K to 4200K. All colored objects and displays were removed from the laboratory. This left a test room that was somewhat sterile. The experimenters were interested in the comparative responses to several typical light source colors. Light sources included HPS, cool white, warm white fluorescent, warm deluxe mercury and metal halide lamps.

Factor analysis of semantic differential rating scale data in this study indicated that there were three major and clearly identifiable factors of judgment involved:

(1) impressions of visual clarity

(2) impressions of spaciousness

(3) impressions of pleasantness and preference (evaluation).

This study showed an apparent advantage for the cool white fluorescent color in reinforcing impressions of "visual clarity" and for the warm white fluorescent color in reinforcing "evaluative"impressions (appearing pleasant). The HID source colors (particularly HPS color) were significantly poorer in these categories of judgment. However of the HID source colors, the rating of the metal halide color (with phosphor) suggests relative strengths in the "clarity" and "evaluative" categories.

A color perception results from the interaction of many highly complex factors such as: the characteristics of the object, the incident light and the sourrounding (Kaufman, 1972). Environmental color for visual pleasure was emphasis in several literatures such as: Weston (1949), Rowe & Williams (1975) and Amick (1978). Since Flynn and Spencers' study used a test room that was somewhat neutral, a question is arised: "Will the negative reaction to the HPS lamps be different if the environmental color of the test room is not neutral?"

Light source color properties

One important distinction among light sources are their color temperature and color rendering. Modern light sources provide an almost limitless selection of color appearance and spectral distribution of the light emitted. Hopkinson and Collins (1970) stated that the color rendering properties of a light source can usefully be considered under two headings. One is the "preferred" color rendering, the other is the "accuracy" of the rendering color given by the light source.

The "preferred" color rendering appears to be related to the level of illumination. Kruithof (1941) found experimentally that at low levels of illumination, most people prefer a "warm" light, whereas at high levels of illumination, a "cold" light is preferred.

The color temperature scale based on the black body chromaticity locus provides a convenient one-number color specification for any light whose chromaticity falls on the locus. When a light source has high temperature, the color of the light is more bluish, and the light is considered cold. Cool white fluorescent light and mercury light are considered cold lighting. When a light source has a low temperature, the color of the light is more reddish, and the light is considered warm. Incandescent light and high pressure sodium light are considered warm lighting.

This area was further studied by Bodmann (Hopkinson et al, 1970) and his collegues. They confirmed Kurithof's finding over a range of 600 lux (56 fc) to 3000 lux (280 fc). The results are showned in TABLE 2.

The "accuracy" of color rendering is the spectral effect of the light source on the perceived color of object appearance as compared with a familiar source such as average daylight.

The color rendering index (CRI) as specified by the Commission Internationale de l'Eclairage (CIE) is a measure of the accuracy of the rendering of colors relative to a reference illuminant at the same color temperature. The basic assumption of same color temperature, however, limits the application of CRI as a tool for comparing light source colors having different color temperature. Thorington (1975) wrote: "Its (CRI) detractors point to the failure of low value of the one-number index to convey anything but very limited information about color rendering and to the fact that the index is biased in favor of the daylight and Planckian spectral series."

Another measure for hue discrimination performance of the light source is the gamut area (Boyce and Simons, 1977) of the eight CIE test colors, that is the area enclosed on the 1960 CIE-uniform chromaticity scale diagram by the eight colors used in the calculation of CRI. It should generally be expected that the greater the discrimination provided by a source, the further apart the test colors will lie on the diagram. So provided that the shape is not too distorted, a larger gamut area should be associated with better color discrimination.

Delaney, Hughes, McNelis, Sarver and Soules (1978) and Boyce et al (1977) both used the Farnsworth-Munsell 100 hue test

TABLE 2

Subjective evaluation of satisfactory luminance levels in a conference room illuminated by different fluorescent lamps (Hopkinson & Collins, 1970)

Average Level Illumination (lux)	Average Level Luminance (cd/m^2)	Color of Light: Warm white	Color of Light: White	Color of Light: Daylight
Less than 700	Less than 90	Not unpleasant	Dim	Cool
700 - 3000	90 - 380	Pleasant	Pleasant	Neutral
More than 3000	More than 380	Excessive, artificial	Pleasant lively	Pleasant

to investigate the effect of color rendering of light sources on color discrimination performance. The results showed color temperatures make no significant difference in performance. Both gamut area and CRI are good predicators for hue discrimination.

However, in general office lighting application, the color perceptions are not usually so critical. In most situations, where only two or three colors need to be distinguished, some color distortion could even enhance discrimination. This is based on the idea that the color of light can be used to increase contrast either by intensifying or by subduing certain colors inherent in the task. For example, in viewing yellow on black, a light source rich in yellow will increase the contrast by intensifying the yellow; in viewing yellow on white, a light source rich in blue will increase contrast by graying the yellow.

One objective of the present study was to investigate how the light source color affected performance on a hue discrimination task where there were only few colors involved.

Semantic differential scaling and factor analysis

Subjective impressions to light and satisfaction of the user have drawn the attention and interest of the lighting designers and engineers. Techniques such as the semantic differential and multidimensional scaling have been adopted for measuring subjective impressions in lighting (Flynn, Hendrick, Spencer, Martyniuk, 1979). These techniques involve subjects in making appraisals of lighting situations, which the experimenter then processes through a statistical analysis.

The semantic differential technique was originated by Osgood (Snider & Osgood, 1969) and his associates. This technique attempts to measure what meaning a concept might have for people in terms of dimensions which have been empirically defined and factor-analyzed. Since the measure has a high degree of face validity, and the reliability of the technique is high, it is widely used in the behavioral sciences and in many applied areas.

The semantic differential technique involves judgments of a concept against a series of descriptive polar-adjectival scales. An example would be:

pleasant __ : __ : __ : __ : __ : __ : __ unpleasant

Progressing from left to right on the scale, the positions are described to the subjects participating in the study as representing: "extremely pleasant," "very pleasant," "slightly pleasant," "neutral," "slightly unpleasant," "very unpleasant," and "extremely unpleasant."

The semantic differential scaling can differentiate the meaning of the lighted environment by dimensions which reflect the subjects' shared experience, feeling toward the environment. This is based on the idea that lighting systems might be communicative in the sense that this systems suggest or reinforce ideas that are shared (in some degree) by people who share the same culture background (Flynn, 1977). But it is desirable and practicable to minimize the number of dimensions to describe the meaning of the environment.

However, when the ratings on the various differential scales are compared, it usually turned out that the scales show a fair degree of correlation with each other. For environments which are rated "high" on the pleasant/unpleasant scales are often also "high" on the following scales: like/dislike, satisfactory/ frustrating, beautiful/ugly, etc.. Thus, many scales are actually repetitious and redundant.

To analyze the complex correlations among all scales with all others, a statistical procedure called factor analysis is applied. This procedure assumes that there are certain "factors" as common causes of the variance of the environment on the scales. These determine the placement of the environment on several scales. So by reducing these dimensions of meaning having a maximal differentiating power to a minimal set, factor analysis can bring some order out of scale complexity.

Flynn (1973) and his associates did initial work to test the usefulness of the semantic differential for lighting research. The results suggested that lighting variables do induce some consistent and shared impressions for the users.

Some of the recent studies using the semantic differential technique for subjective lighting were done by Flynn and Spencer (1977), Flynn (1977), Bennett, Ali, Percherla and Rubison (1978), Delandy, Hughes, McMelis, Sarver and Soules (1978) and Hawkes, Leo and Rowlands (1979) and Santamaria (1979). These mainly used light sources and lighting patterns and distributions as the variables. Their results verified the validity and feasibility of the semantic differential techniques in investigating effects of lighting on impression and satisfaction of the users. Illuminating Engineering Research Institute Project No.92 was a project attempted to develop a standardized research procedure for studying the subjective effect of environment lighting. As the result of this work, several broad categories of impression can be cued or modified by lighting systems (Flynn et al, 1979). Those catefories of impression that are of particular interest are:

Perceptual Categories

impressions of Visual Clarity

impressions of Spaciousness

impressions of Color Tone

impressions of Glare

Behavior Setting

impressions of Public vs Private Space

impressions of Relaxing vs Tense Space

Overall Preference

impressions of Preference (like/dislike)

impressions of Pleasantness

Visual performance

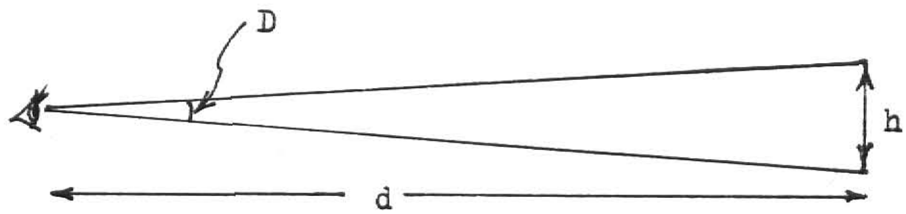
Lighting affects people very directly. It determines how well people will be able to see and perform their work.

The standard method of describing the capacity of the eyes under various conditions is to measure the sharpness of vision or visual acuity. Visual acuity is a measure of the ability to distinguish fine details. Quantitatively, it is the reciprocal of the angular size in minutes of the critical detail that is just large enough to be seen.

The visual size of any detail that needs to be seen is a function of its physical size and distance from the point of observation. By combining these two dimensions, one can express the size as a visual angle which usually is measured in minutes of arc. Figure 1 shows the size of arc object being measured in minutes of arc.

Landolt rings, one type of test objects, have been used for evaluating the size discrimination ability of the eye. This is a circle with a gap which can occur at any point. The task requires the observer to detect where this gap occurs.

A visual task of this type has been used by Lythgoe (Hopkinson et al, 1970). He investigated the effect of the surround to a visual task on the minimum size of detail in the task which can be resolved. Weston (1949) developed a series of visual tasks which consisted of a large number of Landolt rings printed in a pattern arranged so that the positions of the gaps in the rings fall in a random distribution in the pattern. The task of the observer was to cancel, with a pencil, every ring with the gap in a particular specified direction. In order to do this, he had to search through the whole array of rings in a systematic way, the method being determined by himself.



$$D = \frac{3400 \times h}{d}$$

Figure 1. The size of arc object is measured in minute of arc.

Performance therefore depended on both accuracy and speed.

It has been understood that important factors in visual performance are task size, task contrast, task luminance (related to illumination through task reflectance), individual differences in seeing (including those correlated with age), required speed of performance and required accuracy of performance (Bennett, Chitlangia, and Pangrekar, 1978). Very little attention has been paid to another environmental factor -- the light source. Lion (1964) showed that the performance of manipulative and inspection tasks were significantly different under different light sources (incandescent and fluorescent) giving the same level of illumination. Subjects worked significantly more quickly under warm white fluorescent lighting than tungsten lighting. But the type of lighting had no effect on performance of the clerical task. Floyd (Lion, 1964) made a study of Post Office workers and found that for clerical tasks the type of illumination (filament and fluorescent lighting) does not affect performance.

PROBLEM

The prupose of this study is to find out the acceptability of HID sources in indoor use for task lighting. The HID souce will be compared with cool white fluorescent, the most common fluorescent source in use in North America.

Past researches on subjective lighting involved only evaluation on the lighting conditions, this research will use practical visual tasks: hue discrimination and inspection tasks. This will give subjects the chance to work under the specified lighting source before evaluation.

Performance will be objectively measured by the time to perform and the accuracy. The lighting sources will be evaluated using the semantic differential technique.

Flynn et al (1973, 1977, 1979) and other investigators used mostly overhead or peripheral wall lighting on subjective lighting. In this study, a kiosk and a furniture mounted luminaires will be used. Another major distinction between the present study and Flynn's study (1977) is that a colorful test room will be used.

To summarize, the objectives of the studies were

(1) to determine the performance of subject on a hue discrimination task and a inspection task when the tasks are seen under different light sources;

(2) to find whether the environmental color and the type of luminaire may attenuate or correct the negative tendencies associated with color of light;

(3) to compare the HID kiosk with the furniture mounted fluorescent fixture on subjective impressions.

METHOD

Room and lighting

Four light sources were chosen in this study, namely, high pressure sodium lamp, metal halide lamp, combination of metal halide and high pressure sodium lamps and cool white fluorescent lamp. Two different fixtures, were used to contain these lamps. One was a furniture mounted fixture 48" x 24" x 5" (see Figure 2) 20 inches above the desk. The fixture contained four 48 inch 40W cool white fluorescent tubes. The luminaire was equipped with a plastic lens for diffusing purposes. The other fixture was a kiosk 16" x 16" x 74" (see Figure 3), which contained one 400W clear high pressure sodium lamp (Westinghouse Ceramalux lamp, C400S51), one 400W clear metal halide lamp (Sylvania Metalarc lamp, M400/BD) and their ballasts. The kiosk was made of half inch plywood and 2" x 4"s. The inside of the kiosk was painted white and the outside was covered by white self-adhesive plastic sheeting.

The experiment was done in a room which had the size of 114" x 90" x 108". The room was so arranged to make it look like a pleasant office or study room. There were two chairs, a table and a piece of carpet (dark green) in the room. Two paintings were hanged on the wall: one faced to the subject and the other one on the right hand side of the subject. One clock and one note pad were put on the table. The ceiling of the room was white sparkling ceiling. The tile had the color of ecru

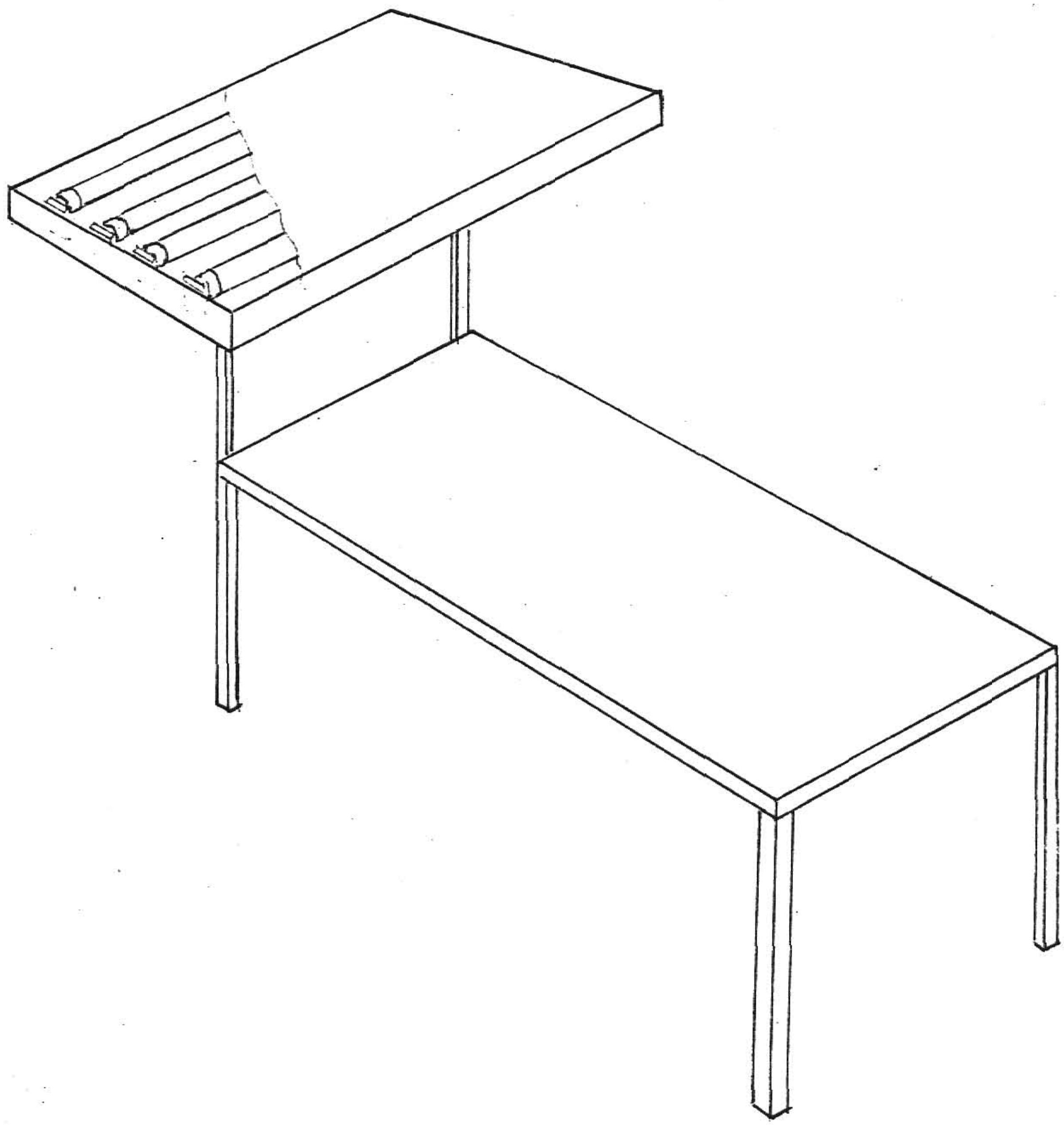


Figure 2. Furniture-mounted fluorescent lighting fixture.

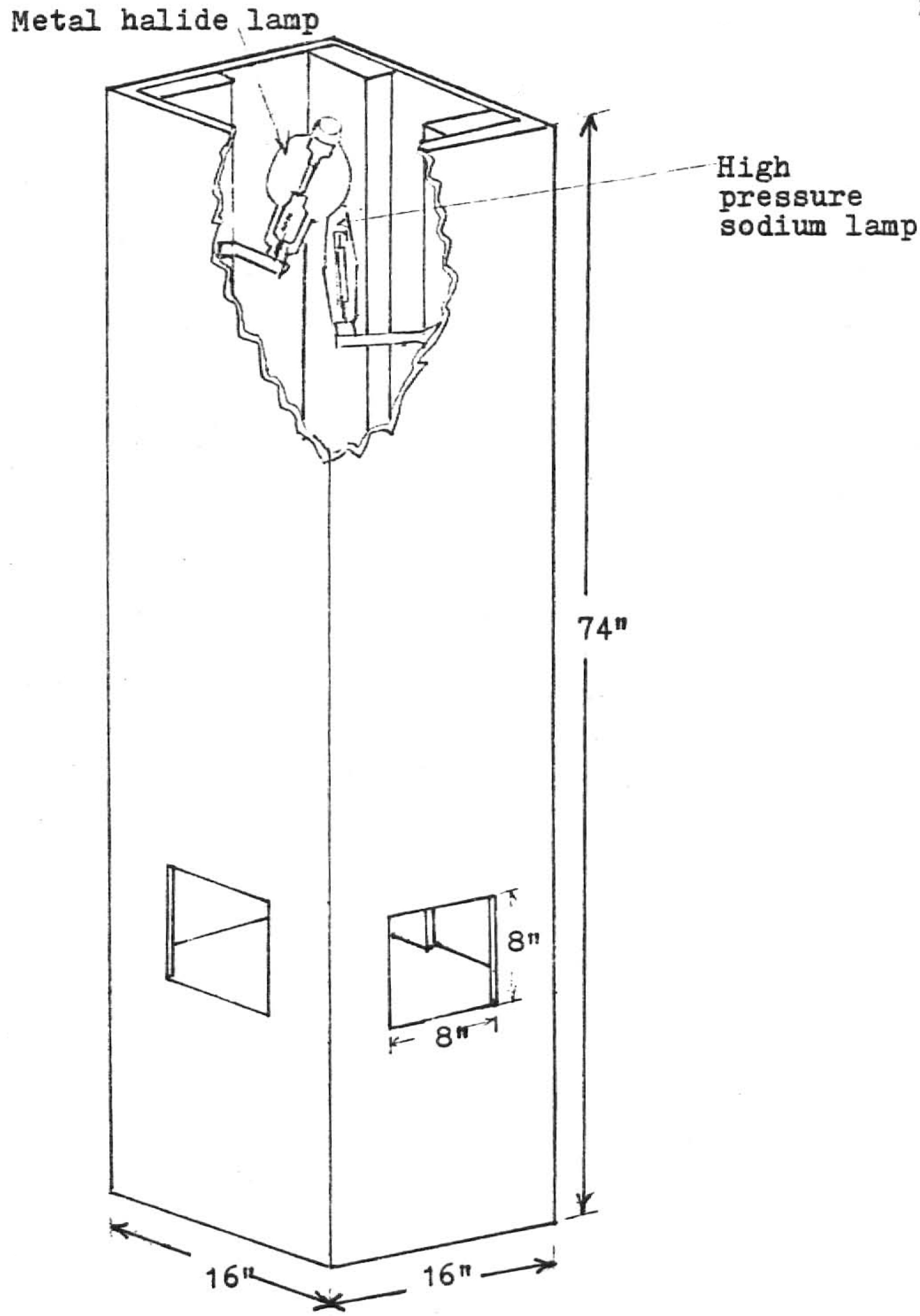


Figure 3. Kiosk with high pressure sodium lamp and metal halide lamp.

with tan spots. The color of the wall was yellow. The Munsell designations that describe the room finishes during the tests are listed in Table 3. The room had ceiling reflectance of 0.56, wall reflectance of 0.68, and floor reflectance of 0.46. The room could be lighted by either the fluorescent, the high pressure sodium, the metal halide, the combination of metal halide and high pressure sodium. There was only one luminaire kept in the room at a time (see Figure 4 and 5). The floor plans of the room with its lighting arrangements are shown in Figure 6 and 7.

Due to the difficulties of setting up the luminaires to provide a particular light source, the subjects were divided into eight groups. There were 48 subjects, thus each group had six subjects. Every subject was performing the tasks under only one lighting condition. The light sources were arbitrarily assigned to each group. Table 4 shows the order of light sources assigned to each group.

Tasks

There were two tasks to be performed by the subjects. The first one was a color discrimination task. Fourteen color plates (Dvorine, 1944) were used. The order of these plates was randomly arranged for each subject. Each plate had either a one or two digit number on it. The color of the number and the color of the background had different hues, values and chromas. The number and the background were formed by dots in four sizes. The sizes of the dots, the number and the colors of each plate are shown in Table 5. Each subject saw one plate at one time, he

TABLE 3

Munsell designations

Walls	5Y	8/2	Yellow
Ceiling	N		White sparkling ceiling
Floor	7.5YR 10YR	7/2 9/1	tile color is ecru with tan spots
Table	N		White
Chair	2.5Y 7.5YR	5/6 3/4	Colors of chair cusion are yellow, brown and black stripe
Carpet	2.5GY	5/8	dark green

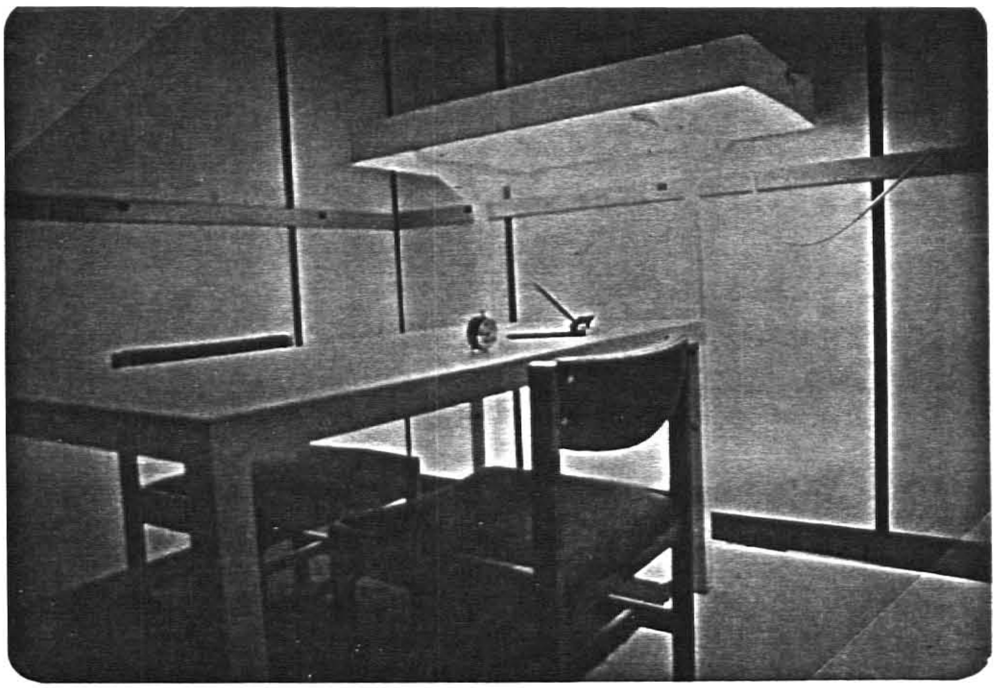


Figure 4. Experiment room with furniture-mounted fixture.

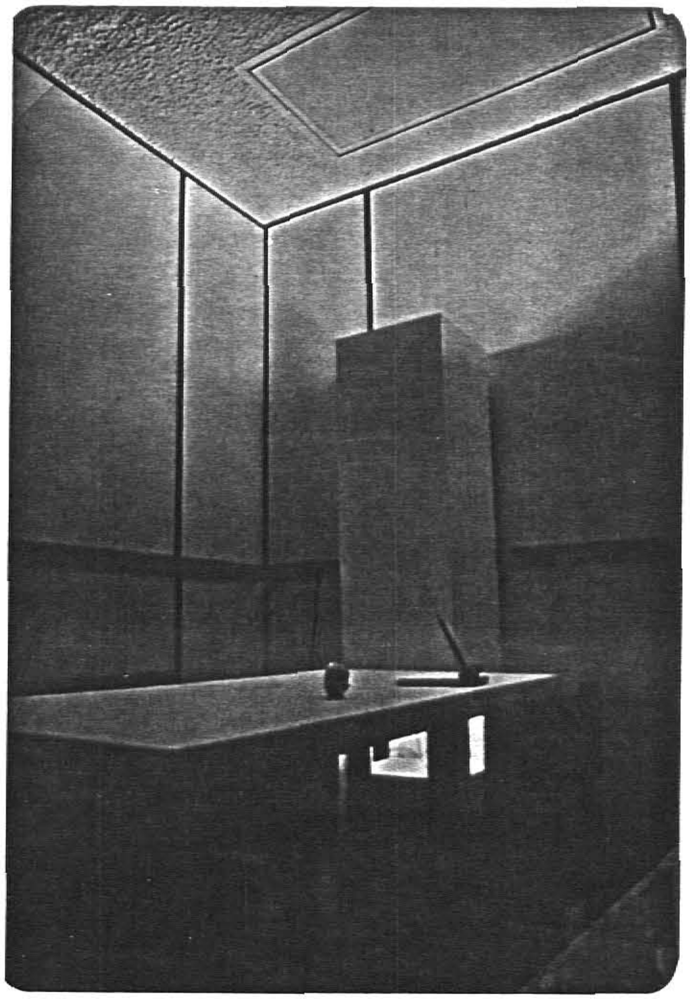


Figure 5. Experiment room with kiosk.

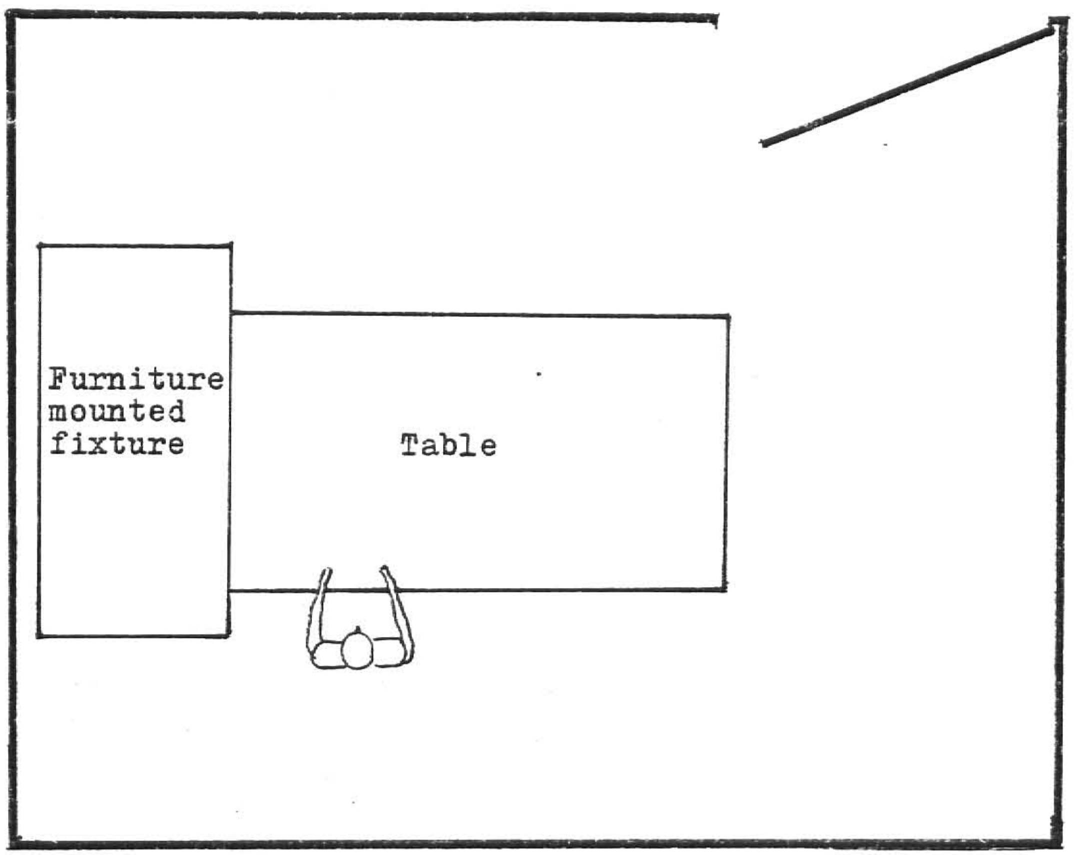


Figure 6. Floor plan of the experimental room with its fluorescent lighting fixture

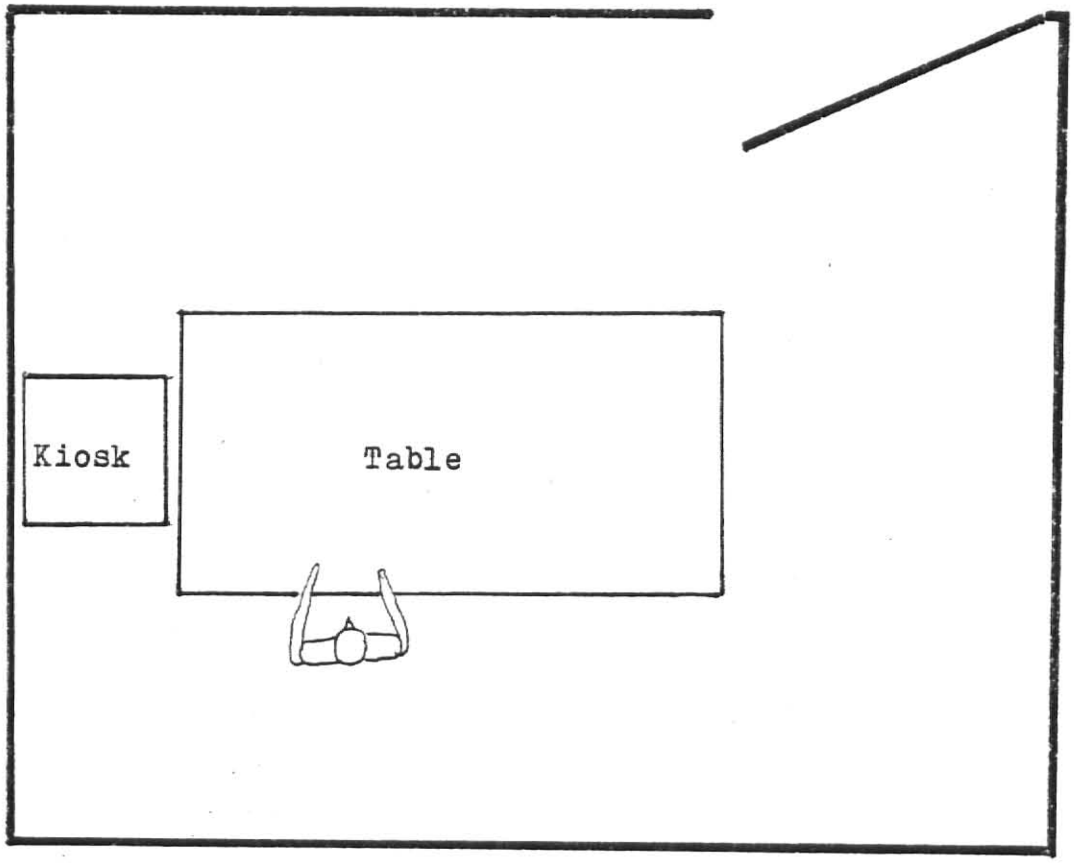


Figure 7. Floor plan of the experimental room with its HID kiosk.

TABLE 4

The order of light sources assigned to each group

Group No.	Subject No.	Light Sources
1	1 - 6	Cool white fluorescent
2	7 - 12	Metal halide
3	13 - 18	High pressure sodium
4	19 - 24	Metal halide + High pressure sodium
5	25 - 30	Metal halide + High pressure sodium
6	31 - 36	Cool white fluorescent
7	37 - 42	Metal halide
8	43 - 48	High pressure sodium

TABLE 5

Number and colors, size of the dots of fourteen color plates

Plate No.	Number on the plate	Color of the number Hue	Value / Chroma	Color of the background Hue	Value / Chroma
1	49	5R	5 / 10	5Y	6 / 6
		5R	7 / 6	5Y	8 / 6
2	35	5GY	6 / 6	5R	6 / 4
		5GY	7 / 4	5R	7 / 6
3	29	5R	5 / 14	5P	5 / 6
		7.5R	8 / 4	5P	7 / 2
4	59	5Y	5 / 1	5R	6 / 10
		5Y	7 / 1	5R	7 / 6
5	99	5GY	8 / 4	5Y	8 / 6
		5GY	6 / 6	5Y	6 / 6
6	7	10PB	6 / 8	5Y	6 / 6
		10PB	8 / 1	5Y	8 / 6
7	46	7.5B	6 / 6	5YR	6 / 10
		5BG	7 / 2	7.5YR	8 / 8
8	39	5P	5 / 6	7.5B	5 / 6
		5P	7 / 2	10BG	7 / 2
9	36	7.5B	5 / 8	10YR	5 / 1
		7.5BG	7 / 2	10YR	7 / 1
10	28	2.5Y	6 / 10	2.5GY	5 / 6
		5YR	7 / 8	5GY	8 / 4
11	47	5YR	5 / 12	2.5Y	5 / 4
		5YR	7 / 8	7.5YR	7 / 2

TABLE 4 (cont.)

Number and colors, size of the dots of fourteen color plates

Plate No.	Number on the plate	Color of the number Hue	Value	Chroma	Color of the background Hue	Value	Chroma
12	93	5P	6 /	6	5GY	6 /	6
		5P	8 /	4	2.5GY	7 /	4
13	57	10YR	5 /	1	5GY	6 /	6
		10YR	6 /	1	5GY	7 /	4
14	88	2.5Y	4 /	6	5YR	5 /	1
		10YR	7 /	4	5YR	6 /	1

Dot size

3/16"

1/8"

3/32"

1/16"

identified the number and read the number into a type recorder. After he finished one plate he put the plate aside and looked at the next plate till he finished all fouteen plates. Time was measured by stopwatch.

The second task was an inspection task. A chart (see Figure 8) with 256 Landolt rings was provided in front of the subjects under transparent sheet. The gap subtended the desired angle (3.4 minute of arc) at a viewing distance of 12 inches, and this gap was in any one of eight positions. One of the gap directions was randomly selected as defect to a subject. The task of the subject was to cancel, with a marker pen, on the transparent sheet every ring with the gap in the specified direction. The chart could be displayed in four ways, with either A, B, C, D side on the top. In this experiment only A side on the top was used.

Subjective evaluation

When the subject finished these two tasks, he was asked to evaluate the lighting system on semantic differential scales. The scales reflected the subjects' subjective impression of the lighting system. The subject was also asked questions concerning the lighting system. The form is shown in Figure 9.

There were 13 rating scales selected from the literature (Flynn, 1977). Nine scales represented three factors: clarity, evaluation and spaciousness. The other four scales were included to detect what have been called "modifying influences". These scales and the factors which they represented are shown in

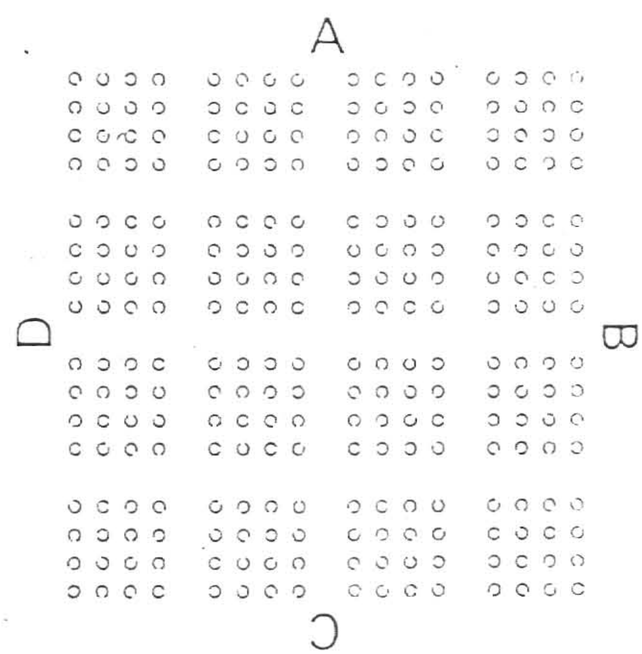


Figure 8. Landolt ring performance chart for inspection task.

Subject No.: ______

Evaluation Sheet

unpleasant	:___	:___	:___	:___	:___	:___	:___	pleasant
clear	:___	:___	:___	:___	:___	:___	:___	hazy
public	:___	:___	:___	:___	:___	:___	:___	private
colorful	:___	:___	:___	:___	:___	:___	:___	colorless
confined	:___	:___	:___	:___	:___	:___	:___	spacious
dislike	:___	:___	:___	:___	:___	:___	:___	like
warm	:___	:___	:___	:___	:___	:___	:___	cool
tense	:___	:___	:___	:___	:___	:___	:___	relaxing
large	:___	:___	:___	:___	:___	:___	:___	small
beautiful	:___	:___	:___	:___	:___	:___	:___	ugly
distinct	:___	:___	:___	:___	:___	:___	:___	vague
glare	:___	:___	:___	:___	:___	:___	:___	non-glare
dim	:___	:___	:___	:___	:___	:___	:___	bright

Question 1: Would you like to have this light replace the one you mostly use?

Question 2: Please give reason(s) that make you "particularly like" or "particularly dislike" this lighting system.

Figure 9. Form of the subjective evaluation sheet

Table 6.

<u>Experimental design</u>

The appropriate lighting was switched on before the subject entered the room. The illumination level on the desk was checked by the light meter to provide exact illumination (70 fc). A particular spot on the desk was chosen as a reference point. The illumination level of the fluorescent lighting was adjusted by a dimmer until the reading of the light meter at the reference point was 70 fc. The illumination levels of the high pressure sodium and metal halide lighting were adjusted by changing the mounting height of the lamps in the kiosk fixture. The illumination level of the combination sources of metal halide and high pressure sodium was adjusted to 35 fc individually to create 70 fc at the reference point when both lamps were turned on.

When the subject entered the room, he was given the "Instructions and Informed Consent" (see Figure 10). After he consented to participate the study, he signed the "Informed Consent Statement" form (see Figure 11). The subject was given the acuity and color vision test with the Titimus Vision Tester. All subjects had normal vision or corrected normal vision (20/20) and passed the color vision test. The subject, then, read the instructions of the color discrimination task (see Figure 12) and started that task. After he finished the task a one minute break was given while the experimentor prepared the material for the next task. Instruction for the inspection task (see Figure

TABLE 6

Listing of rating scales (Flynn, 1977)

Evluative scales

unpleasant/pleasant

dislike/like

tense/relaxing

beautiful/ugly

Clarity scales

distinct/vague

clear/hazy

dim/bright

Spaciousness scales

confined/spacious

large/small

Miscellanious scales

glare/non-glare

warm/cool

colorful/colorless

public/private

INSTRUCTIONS and INFORMED CONSENT

Please Read Carefully

This experiment is designed to measure the effect of illumination on work performance. You will be asked to do two different tasks: color discriminating and inspection. Specific instruction will be provided explaining the procedures for performing each task.

After finishing these two tasks, you will be asked a subjective evaluation of the quality of illumination. Some bipolar scales will be provided, with the characteristics to analyze listed. There are also some questions to be answered.

You will get paid $2.00 for participating in this experiment. The approximate time to complete the experiment will be 30 minutes. There is no risk or discomfort involved. However, you are free to stop your participation at any time. If you have any questions, feel free to ask any time.

Figure 10. Instructions and informed consent form

INFORMED CONSENT STATEMENT

Having read the instructions and informed consent, I hereby agree to be a subject in the research entitled: "A study of task lighting systems".

Sub. No.	Age	Sex (M/F)	Color of eyes	Signature	Date

Figure 11. Informed consent statement given to the subjects

INSTRUCTION FOR COLOR DISCRIMINATION TASK

Fourteen color plates, each of which has a number either one digit or two digits, will be placed in front of you. The number and its background are in different colors. Please read out the number to the tape recorder. If you can not identify the number, just say "can not identify". Be as accurate as possible and try to perform this task with the maximum speed you can. When you finish one plate, put the plate aside and proceed to the next plate. Please move the plate using method and speed as uniform as possible throughout the whole task. You will have a one minute break before the next task. Now turn this page and start!

Figure 12. Instructions for the color discrimination task

13) was given to the subject. The subject proceeded to do the second task. After the task, the subject took the second one-minute break and the experimenter prepared the materials for the lighting evaluation. The subject read the instruction for the evaluation (see Figure 14) and rated the lighting system. The total time for the experiment was about 20 minutes.

In this study lighting sources and luminaires were the independent variables, the other conditions in the room were kept unchanged. However, there are several factors can not be controlled in this test. One is the temperature of the test room. The ventilation system of the room was very poor, so for different sources, different time, different room temperature might be gained (from 73 to 76 Fahrenheit degrees). Another factor was noise level from the ballast, the range of the noise level was from 42 dbA (fluorescent and metal halide) to 56 dbA (HPS and combination of metal halide and HPS).

<u>Subjects</u>

Subject for this study were 48 Kansas state university students (30 male, 18 female). The age range of the students were from 19 to 30. The subjects were paid $2.00 for participating the experiment. The experimenter recruited the subjects by two different ways. One was the experimenter asked any student at random passing by whether they were interested in earning $2.00 by being a subject on a study of lighting for 30 minutes. Another way of recruiting subjects was by passing a sign-up paper having the same question on it in a class. People who

INSTRUCTION FOR INSPECTION TASK

A chart with 256 Landolt rings under a transparent sheet and a marker pen will be placed in front of you. There are eight directions of the gap of the rings:

Your task is to try to find out the defective rings which gap is pointed like this . Once you find out the defective rings, please cancel them with marker pen like this . Be careful not to mark over to the good rings which gap directions are different from the defective ones. The accuracy will be the measure of performance. Try to perform this task with the maximum speed you can. You will have a one minute break before your evaluation of the lighting.

Figure 13. Instructions for the inspection task.

INSTRUCTION FOR THE EVALUATION

You are now going to rate the quality of the lighting system used. After your rating, you will be asked two questions concerning the lighting. You will rate the lighting system on 13 rating scales. Each scale has two adjectives opposite in meaning to each other. The scale is divided into seven segments.

The ratings are done in the following manner. If you would describe the room as extremely pleasant, place an X on the scale as shown below:

pleasant :_X_ :___ :___ :___ :___ :___ :___ unpleasant

The degrees between the two anchor words conveyed by the segments in order from left to right are: extremely pleasant, very pleasant, slightly pleasant, neutral, slightly unpleasant, very unpleasant and extremely unpleasant. Please place the X in the position in the scale that most accurately describes your impression.

Each rating should be made in similar fashion. Be sure to read both words at each end of the scale before you decide where to place the X. We want your subjective judgment concerning how the lighting system appears to you.

Figure 14. Instruction for the evaluation of lighting system

were interested in participating in the experiment signed the paper and left their telephone numbers. The experimenter then called them up and made appointments.

RESULTS

Color discrimination and inspection tasks

Each subject performed the color discrimination task and the inspection task under one light source. Time and errors were the criteria of performance of these tasks. Time to perform each task was measured and recorded. Errors for the color discrimination task was the number of color plate which the subject could not identify or mistakenly identified the number on the plate. Errors for the inspection task was the ratio of the number of missed defects to the number of total defects on the chart. There were no false positives found. Tables 7 and 8 show the time to perform and errors of each task.

The Statistical Analysis System (Barr, Goodnight, Sall, Blair and Chiko, 1979) program was used to analyze the data. The results of the analysis of variance run on the performance of two tasks for four light sources are shown on Tables 9, 10, 11, and 12.

Subjective evaluation of the light sources

After performing the two tasks, the subject evaluated the light source he used on 13 scales and answered two questions. The subjective reactions of the subjects for each light source on each scale are given in the Table 13. The last scale "prefer' is the answer which subject answered to the first question. A value of one was assigned to answer "yes" and two to answer

TABLE 7

Color discrimination task performance: time to perform (hundredths of a minute) and errors (No. of plates)

Light source	Subject No.	Time to perform	Errors
Fluorescent	1	28.5	0
	2	47.5	1
	3	38.5	0
	4	36.5	0
	5	47.0	0
	6	45.5	2
	31	62.0	0
	32	45.0	0
	33	39.0	0
	34	43.0	0
	35	37.0	0
	36	51.0	2
		Mean = 43.4	Mean = 0.42
Metal halide	7	40.0	0
	8	46.0	0
	9	57.5	0
	10	50.0	0
	11	61.0	1
	12	42.0	0
	37	30.0	0
	38	41.0	0
	39	38.5	0
	40	38.0	1
	41	38.0	1
	42	60.0	1
		Mean = 45.2	Mean = 0.33

TABLE 7 (cont.)

Color discrimination task performance: time to perform (hundredths of a minute) and errors (No. of plates)

Light source	Subject No.	Time to perform	Errors
High pressure sodium	13	63.0	1
	14	50.0	0
	15	50.0	1
	16	35.5	0
	17	49.0	1
	18	37.0	0
	43	49.0	0
	44	46.0	1
	45	45.0	0
	46	55.0	0
	47	41.0	0
	48	44.0	0
		Mean = 47.0	Mean = 0.33
Comb. of metal halide + high pressure sodium	19	49.0	0
	20	40.5	0
	21	41.0	0
	22	39.0	0
	23	40.0	0
	24	47.0	0
	25	43.0	1
	26	42.0	2
	27	53.0	0
	28	37.0	0
	29	56.0	0
	30	40.0	0
		Mean = 44.0	Mean = 0.25

TABLE 8

Inspection task performance: time to perform (hundredths of a minute) and error

Light source	Subject No.	Time to perform	Errors
Fluorescent	1	162.5	0.07
	2	204.0	0.02
	3	260.0	0.16
	4	137.5	0.05
	5	192.5	0.16
	6	156.0	0.25
	31	210.0	0.08
	32	122.0	0.10
	33	242.0	0.13
	34	193.5	0.28
	35	172.0	0.06
	36	195.0	0.35
		Mean = 187.2	Mean = 0.142
Metal halide	7	143.0	0.06
	8	169.0	0.20
	9	270.0	0.03
	10	173.0	0.24
	11	164.0	0.10
	12	160.0	0.44
	37	163.0	0.21
	38	183.0	0.06
	39	184.0	0.16
	40	206.0	0.03
	41	154.0	0.00
	42	165.0	0.13
		Mean = 177.8	Mean = o.138

TABLE 8 (cont.)

Inspection task performance: time to perform (hundredths of a minute) and error

Light source	Subject No.	Time to perform	Errors
High pressure sodium	13	193.0	0.26
	14	190.0	0.30
	15	189.0	0.26
	16	105.5	0.44
	17	160.0	0.18
	18	153.0	0.12
	43	192.0	0.13
	44	168.0	0.33
	45	138.0	0.31
	46	177.0	0.03
	47	153.0	0.00
	48	250.0	0.05
		Mean = 172.4	Mean = 0.201
Comb. of metal halide + high pressure sodium	19	184.0	0.20
	20	149.0	0.27
	21	144.0	0.10
	22	159.0	0.03
	23	164.5	0.23
	24	122.0	0.19
	25	180.0	0.22
	26	153.0	0.08
	27	220.0	0.47
	28	227.0	0.03
	29	190.0	0.22
	30	120.0	0.43
		Mean = 167.7	Mean = 0.204

TABLE 9

Inspection task: analysis of variance for light sources as time is the criterion

Source of variance	df	Mean square	F	Significance level
Between light sources	3	845.60	0.66	0.58
Error	44	1237.81		
Total	47			

TABLE 10

Inspection task: analysis of variance for light sources as error is the criterion

Source of variance	df	Mean square	F	Significance level
Between light source	3	0.0154	0.96	0.42
Error	44	0.0161		
Total	47			

TABLE 11

Color discrimination task: analysis of variance for light sources as time is the criterion

Source of variance	df	Mean square	F	Significance level
Between light source	3	31.19	0.47	0.70
Error	44	65.83		
Total	47			

TABLE 12

Color discrimination task: analysis of variance for light source as error is the criterion

Source of variance	df	Mean square	F	Significance level
Between light source	3	0.055	0.15	0.93
Error	44	0.375		
Total	47			

TABLE 13

Subjective judgment for each scale for the four sources

Light source	OBS	SUBJECT	PLEASANT	CLEAR	PRIVATE	COLORFUL	SPACIOUS	LIKE	COOL	RELAXING	LARGE	BEAUTIFUL	DISTINCT	NONGLARE	BRIGHT	PREFER
Fluorescent	1	1	6	2	6	5	3	6	4	5	3	3	2	4	5	1
	2	2	6	4	6	6	2	6	5	5	5	2	3	6	2	2
	3	3	5	3	6	2	1	5	2	3	6	2	3	6	3	2
	4	4	6	2	5	5	2	5	2	6	7	4	4	7	3	1
	5	5	2	5	4	5	2	1	2	2	6	6	6	1	3	2
	6	6	6	5	7	4	2	7	1	6	5	4	5	7	5	1
	7	31	5	5	6	4	3	5	4	4	6	3	3	6	4	1
	8	32	5	2	6	5	2	5	2	6	6	3	6	5	2	2
	9	33	4	4	7	7	3	3	4	5	7	6	4	7	5	1
	10	34	6	2	3	6	6	6	3	7	3	4	2	6	5	1
	11	35	5	3	5	6	3	5	6	3	4	4	5	4	3	2
	12	36	5	2	5	3	4	4	3	6	2	4	2	2	6	1
Metal halide	13	7	7	1	1	2	2	4	4	7	7	4	2	7	5	1
	14	8	3	1	5	6	2	4	5	2	4	4	2	7	5	1
	15	9	6	2	2	3	3	5	3	4	5	4	2	6	4	1
	16	10	6	2	6	7	2	7	1	6	3	4	6	6	3	2
	17	11	5	3	3	5	6	3	5	3	4	3	3	6	3	2
	18	12	2	1	6	1	6	6	6	7	5	2	2	7	7	1
	19	37	3	2	5	5	5	5	3	6	5	2	3	7	3	1
	20	38	7	2	7	3	5	6	4	4	5	4	3	5	5	1
	21	39	5	6	5	7	2	3	4	3	5	6	6	3	3	2
	22	40	3	4	2	3	5	5	3	4	4	3	3	5	5	1
	23	41	6	7	7	6	5	6	5	6	6	3	3	6	5	1
	24	42	2	1	2	1	7	3	2	5	1	3	1	1	7	2
HPS	25	13	5	2	3	2	4	3	2	4	4	5	2	7	3	1
	26	14	3	3	5	5	2	2	3	3	6	5	6	7	1	2
	27	15	2	5	7	2	2	1	2	2	6	4	5	5	3	2
	28	16	4	5	3	6	2	3	5	2	6	4	5	6	3	2
	29	17	4	3	6	5	2	1	6	6	3	4	1	3	2	2
	30	18	2	2	6	2	6	6	2	6	2	2	2	1	4	1
	31	43	3	5	5	3	4	2	3	5	4	5	5	2	4	2
	32	44	5	2	6	4	3	6	2	7	4	5	3	7	3	1
	33	45	5	3	5	3	3	5	6	6	5	4	3	3	3	1
	34	46	7	6	5	7	2	1	2	7	6	3	6	7	1	2

TABLE 13 (cont.)

Subjective judgment for each scale for the four sources

Light source	OBS	SBJECT	PLEASANT	CLEAR	PRIVATE	COLORFUL	SPACIOUS	LIKE	COOL	RELAXING	LARGE	BEAUTIFUL	DISTINCT	NONGLARE	BRIGHT	PREFER
HPS	35	47	5	6	4	6	4	2	6	3	4	3	3	6	3	1
	36	48	3	5	2	4	6	3	2	2	2	4	3	2	6	2
Comb.	37	19	2	1	2	2	4	3	1	4	6	3	1	7	7	1
of metal	38	20	5	2	1	2	6	5	2	2	4	5	2	3	7	2
halide	39	21	2	6	2	6	3	2	1	1	5	6	5	2	3	2
+ HPS	40	22	6	2	7	3	3	7	2	6	3	2	2	7	4	1
	41	23	3	3	5	4	2	4	3	4	3	3	3	5	2	1
	42	24	6	2	4	7	2	7	3	3	5	4	3	6	6	1
	43	25	3	6	5	4	2	1	3	2	5	5	6	3	4	2
	44	26	6	2	1	7	2	2	4	4	4	6	2	2	7	1
	45	27	3	3	6	5	5	1	1	2	3	4	4	6	6	2
	46	28	5	4	7	3	4	6	1	4	4	3	1	2	4	2
	47	29	3	1	4	6	4	6	3	4	4	5	2	4	5	1
	48	30	4	1	7	3	5	3	1	2	4	4	2	6	6	1

"no". For the second question, the subject was asked to write down the reason(s) which made the subject particularly like or dislike the lighting system he used. Table 14 lists the favorable and negative terms which subjects used to answer the questions. Table 15 shows the correlation matrix for the 14 scales. Factor analysis of the 14 scales was carried out with the correlation matrix using the Statistical Analysis System (Barr, et al., 1979). Five factors were extracted and rotated. Table 16 shows the five factors found for the 14 scales with respective loadings. High loadings on factor 1 occurred with scales 3 and 10, which are "public/private" and "beautiful/ugly"; factor 1 is named "social prominence"factor. High loadings on factor 2 occurred with the scales 1, 6 and 8, which are "unpleasant/pleasant", "dislike/like" and "tense/relasing"; factor 2 is named "evaluation". High loadings on factor 3 are scales 2, 4, 11, 13, and 14, which are the "clear/hazy", "colorful/colorless", "distinct/vague", "dim/bright" and "prefer/non-prefer"; factor 3 is named "clarith"factor. High loadings on factor 4 are scales 5, 9, and 12, which are "confined/spacious", "large/small" and "glare/non-glare"; factor 4 is named "spaciousness"factor. High loading on factor 5 occurred with the scale 7, which is "warm/cool"; and factor 5 is named "warmth" factor. The seven steps of each bipolar rating scale were assigned a numberical value, beginning with a 1 for the left-most step and proceeding sequentially -- with a 7 assigned to the right-most step. The

TABLE 14

List of favorable and negative terms subjects used to answer question two.

Light source	Favorable term	Freq.	Negative term	Freq.
Fluorescent	soft	1	dim	3
	no glare	5	glare	2
	bright	3	strain	1
	not blinding	1	little shadows	1
	comfortable	2	prefer more yellow	1
	relaxing	2		
	diffused	1		
Metal halide	soft	2	dim	2
	no glare	4	penetrating	1
	bright	3		
	comfortable	2		
	cheerful	1		
	clear	1		
	no shadow	1		
	even	1		
	pleasant	1		
	relaxing	1		
High pressure sodium	can get used to it	1	not flattering to the face	1
	pleasant	3		
	easy on eyes	1	too yellow	1
	relaxing	2	strain	2
	uniform	1	hazy	1

TABLE 14 (cont.)

List of favorable and negative terms subjects used to answer question two.

Light source	Favorable term	Freq.	Negative term	Freq.
	no glare	2	drab	1
	warm	1	dim	2
	comfortable	1	sleepy	2
	soft	1	glare	1
	diffuse	1	too bright	1
			fatigue	1
Comb. of Metal halide + HPS	clear	1	too bright	1
	colorful	4	glare	1
	distinct	1	hard to focus	1
	no glare	4	dim	3
	no distraction	1	tense	1
			hazy	1
			too warm	1
			uncomfortable	1

TABLE 15

Correlation matrix

	PLEASANT	CLEAR	PRIVATE	COLORFUL	SPACIOUS	LIKE	COOL
PLEASANT	1.000	0.016	0.046	-0.258	-0.252	0.372	0.127
CLEAR	0.016	1.000	-0.110	0.358	0.184	0.332	-0.066
PRIVATE	0.046	-0.110	1.000	-0.027	-0.134	0.255	-0.010
COLORFUL	-0.258	0.358	-0.027	1.000	0.363	0.124	-0.282
SPACIOUS	-0.252	0.184	-0.134	0.363	1.000	0.132	-0.093
LIKE	0.372	0.332	0.255	0.124	0.132	1.000	-0.025
COOL	0.127	-0.066	-0.010	-0.282	-0.093	-0.025	1.000
RELAXING	0.356	0.348	0.198	0.107	0.075	0.473	-0.043
LARGE	-0.119	0.283	-0.043	0.136	0.507	0.179	-0.072
BEAUTIFUL	0.028	0.178	0.284	0.339	0.229	0.405	0.029
DISTINCT	0.073	0.552	-0.145	0.441	0.449	0.319	0.195
NON-GLARE	0.308	0.168	0.218	-0.125	-0.242	0.205	-0.003
BRIGHT	-0.131	0.287	-0.246	0.363	0.562	0.083	-0.010
PREFER	0.196	0.369	0.048	0.129	0.124	0.429	0.157

	RELAXING	LARGE	BEAUTIFUL	DISTINCT	NON-GLARE	BRIGHT	PREFER
PLEASANT	0.356	-0.119	0.028	0.073	0.308	-0.131	0.196
CLEAR	0.348	0.283	0.178	0.552	0.168	0.287	0.369
PRIVATE	0.198	-0.043	0.284	-0.145	0.218	-0.246	0.048
COLORFUL	0.107	0.136	0.339	0.441	-0.125	0.363	0.129
SPACIOUS	0.075	0.507	0.229	0.449	-0.242	0.562	0.124
LIKE	0.473	0.179	0.405	0.319	0.205	0.083	0.429
COOL	-0.043	-0.072	0.029	0.195	-0.003	-0.010	0.157
RELAXING	1.000	0.101	0.324	0.310	0.192	0.049	0.429
LARGE	0.101	1.000	0.188	0.396	-0.459	0.302	-0.005
BEAUTIFUL	0.324	0.188	1.000	0.386	0.247	-0.051	0.131
DISTINCT	0.310	0.396	0.386	1.000	-0.022	0.492	0.509
NON-GLARE	0.192	-0.459	0.247	-0.022	1.000	-0.182	0.355
BRIGHT	0.049	0.302	-0.051	0.492	-0.182	1.000	0.334
PREFER	0.429	-0.005	0.131	0.509	0.355	0.334	1.000

TABLE 16

Rotated factor pattern for the scales

	Factor 1 Social prominence	Factor 2 Evaluation	Factor 3 Clarity	Factor 4 Spaciousness	Factor 5 Warmth
Pleasant	0.109	0.772	0.128	0.181	0.205
clear	-0.036	0.331	-0.623	-0.034	-0.254
private	-0.701	0.123	0.313	0.121	0.004
colorful	-0.304	-0.228	-0.556	-0.116	-0.506
spacious	-0.141	-0.117	-0.478	-0.600	-0.123
like	-0.395	0.688	-0.185	-0.084	-0.065
cool	-0.063	-0.043	-0.138	0.017	0.938
relaxing	-0.267	0.708	-0.195	-0.005	-0.121
large	-0.102	0.161	-0.130	-0.863	-0.058
beautiful	-0.838	0.100	-0.207	-0.069	-0.019
distinct	-0.196	0.209	-0.789	-0.286	0.135
non-glare	-0.249	0.257	-0.156	0.773	0.004
bright	0.217	-0.049	-0.702	-0.336	-0.057
prefer	-0.078	0.429	-0.649	0.236	0.163

mean comparative ratings are listed in Table 17.

These five factors were analyzed seperately using one way analysis of variance for light source differences. These analyses were to test whether there would be any significant differences among the four light sources. The level of significance chosen for all analyses was 0.05. The results of the analyses are shown in Tables 18, 19, 20, 21 and 22. The results indicate that there are no significant differences among the four light sources for all factors.

Other analysis of variance was carried out to compare the kiosk with the furniture-mounted fixture and to compare the HID sources with each other on all factors. The results are shown in Tables 23, 24, 25, 26 and 27. The results indicate that there are no significant differences between kiosk and furniture-mounted fixture for all factors. For HID sources, metal halide light is significantly stronger than HPS light for "clarity" factor.

TABLE 17

Mean comparitive ratings

	Cool white Fluorescent	Metal Halide	HPS	Metal halide + HPS
Social prominence				
public/private	5.500	4.250	4.750	4.250
ugly/beautiful	4.250	4.500	4.000	3.833
Evaluation				
unpleasant/pleasant	5.083	4.583	4.000	4.000
dislike/like	4.833	4.750	2.917	3.917
tense/relaxing	4.833	4.750	4.417	3.167
Clarity				
hazy/clear	4.750	5.333	4.803	5.250
colorless/colorful	3.167	3.197	3.197	4.667
vague/distinct	4.250	5.000	4.333	5.250
dim/bright	3.833	4.583	3.000	5.083
non-prefer/prefer	1.583	1.667	1.417	1.583
Spaciousness				
confined/spacious	2.750	4.167	3.333	3.500
small/large	3.000	3.500	3.667	3.833
glare/non-glare	5.083	5.500	4.667	4.417
Warmth				
warm/cool	3.167	3.750	3.417	2.083

TABLE 18

Social prominence factor: analysis of variance for light sources

Source of variance	*df*	Mean square	*F*	Significance level
Between light sources	3	1.076	1.09	0.37
Error	44	0.988		
Total	47			

TABLE 19

Evaluation factor: analysis of variance for light sources

Source of variance	df	Mean square	F	Significance level
Between light sources	3	1.614	1.71	0.18
Error	44	0.942		
Total	47			

TABLE 20

Clarity factor: analysis of variance for light sources

Sources of variance	df	Mean square	F	Significance level
Between light sources	3	2.120	2.20	0.10
Error	44	0.962		
Total	47			

TABLE 21

Spaciousness factor: analysis of variance for light sources

Source of variance	df	Mean square	F	Significance level
Between light sources	3	1.207	0.40	0.75
Error	44	1.004		
Total	47			

TABLE 22

Warmth factor: analysis of variance for light sources

Source of variance	df	Mean square	F	Significance level
Between light sources	3	1.029	1.12	0.35
Error	44	0.923		
Total	47			

TABLE 23

Social prominence factor: analysis of variance for comparing kiosk with furniture-mounted fixture and for HID sources

Source of variance	df	Mean square	F	Significance level
Kiosk vs furniture-mounted fixture	1	0.439	0.44	0.50
Metal halide vs HPS	1	0.000	0.00	.99
Metal halide vs Combination	1	2.100	2.13	0.15
HPS vs Combination	1	2.082	2.11	0.15
Error	44	0.988		

TABLE 24

Evaluation factor: analysis of variance for comparing kiosk with furniture-mounted fixture and for HID sources

Source of variance	df	Mean square	F	Significance level
Kiosk vs furniture-mounted fixture	1	3.225	3.42	0.07
Metal halide vs HPS	1	1.555	1.65	0.20
Metal halide vs combination	1	0.708	0.75	0.39
HPS vs Combination	1	0.164	0.17	0.68
Error	44	0.942		

TABLE 25

Clarity factor: analysis of variance for comparing kiosk with furniture-mounted fixture and for HID sources

Source of variance	df	Mean square	F	Significance level
Kiosk vs furniture-mounted fixture	1	1.950	2.03	0.16
Metal halide vs HPS	1	3.934	4.09	0.05*
HPS vs Combination	1	2.527	2.63	0.11
Metal halide vs Combination	1	0.155	0.16	0.69
Error	44	0.962		

* Significant at 0.05 level

TABLE 26

Spaciousness factor: analysis of variance for comparing kiosk with furniture-mounted fixture and for HID sources

Source of variance	df	Mean square	F	Significance level
Kiosk vs furniture-mounted fixture	1	0.981	0.98	0.33
Metal halide vs HPS	1	0.016	0.02	0.89
Metal halide vs Combination	1	0.212	0.21	0.64
HPS vs Combination	1	0.110	0.11	0.74
Error	44	1.004		

TABLE 27

Warmth factor: analysis of variance for comparing kiosk with furniture-mounted fixture and for HID sources

Source of variance	df	Mean square	F	Significance level
Kiosk vs furniture-mounted fixture	1	0.062	0.07	0.79
Metal halide vs HPS	1	0.092	0.10	0.75
Metal halide vs Combination	1	2.674	2.91	0.09
HPS vs Combination	1	1.775	1.92	0.17
Error	44	0.923		

DISCUSSION

Performance under four light sources

The performance of the two tasks: color discrimination and inspection, were measured by the time to perform and error. The analysis of variance shows that there is no significant difference among the four light sourecs for both tasks.

Color discrimination. The results suggest that color of light source does not affect the performance of color discrimination. Although the 14 color plates chosen did not include all color combinations, the results should be considered acceptable. Because colors involved in office work usually are few and they may have either very different hue or value.

Inspection. The inspection task used in this study included reading and marking, and was considered similiar to clerical work. The results of present study show agreement with the results of the Lion study (1964) and Floyd study (Lion, 1964): the light sources appeared to have no effect on performance of the clerical task.

Factor analysis

The 13 scales used in this study were chosen from Flynn's (1977) study. In Flynn's study, these scales were listed under four factors: "Spaciousness", "evaluation", "clarity" and "miscellaneious". The results of factor analysis of present study show slight difference from Flynn's. Five factors are extracted from the present study, they are "social prominence", "evaluation", "clarity", " spaciousness" and "warmth". Figure 15 shows the comparison of factor structure of the present study with Flynn's study (1977).

Social prominence. The high loading scales on "social prominence" with their factor loading are

public/private	-0.838
ugly/beautiful	-0.701

The subjects tend to use these two scales in a similiar ways, when the light sources were considered private they were also considered beautiful. One exception is the combination of metal halide and HPS light. The combination of metal halide and HPS light was judged private but not beautiful.

Evaluation. The high loading scales on "evaluation" factor with their factor loading are:

unpleasant/pleasant	0.772
dislike/like	0.688
tense/relaxing	0.708

The subjects used these three scales in a similiar way. When light sources were judged pleasant, it were also judged to be liked and relaxing. However, HPS light and the combination of metal halide and HPS light both were judged neither pleasant nor unpleasant. HPS light was judged toward dislike but relaxing. The combination of metal and HPS light was judged dislike and tense.

Flynn's Study (1977)	Present Study
Evaluation Factor	Evaluation Factor
unpleasant/pleasant	unpleasant/pleasant
dislike/like	dislike/like
tense/relaxing	tense/relaxing
beautiful/ugly	- - -
Spaciousness Factor	Spaciousness Factor
confined/spacious	confined/spacious
large/small	large/small
- - -	glare/non-glare
Clarity Factor	Clarity Factor
clear/hazy	clear/hazy
distinct/vague	distinct/vague
dim/bright	dim/bright
- - -	Coloful/colorless
- - -	prefer/non-prefer
Miscellaneous	Social prominence
colorful/colorless	public/private
- - -	beautiful/ugly
public/private	- - -
glare/non-glare	- - -
	Warmth Factor
visually warm/visually cool	warm/cool

Figure 15. Comparison of factor structure of the present study with Flynn's study (1977)

Clarity. The high loading scales on "clarity" factor with their factor leadings are:

hazy/clear	-0.623
colorless/colorful	-0.556
vague/distinct	-0.789
dim/bright	-0.702
non-prefer/prefer	-0.649

The subjects used these scales in a similar way. When light sources were judged toward clear, they were also judged toward the distinct or bright or perferred. The factor loading of "colorless/colorful" scale is relative low, this indicates this scale has weaker correlation with other scales in the "clarity" factor.

There are some exceptions. Cool white fluorescent and HPS light were judged toward coear and distinct but not judged bright. For fluorescent light, this could be due to the fact that the fluorescent task lighting does not give as much illumination to the surrounding as common overhead uniform fluorescent lighting does. For the HPS light, this could be due to the unfamiliar yellow color of the light.

Spaciousness. The high loading scales on "spaciousness" factor with their factor loadings are:

confined/spacious	-0.600
small/large	-0.863
glare/non-glare	0.773

The subjects tend to use these three scales in a similiar way, when the light sources were considered confined or small they were also considered having low glare. One exception is metal halide light. Metal halide light was judged toward small and non-glare, but not confined.

Warmth. This factor has only one scale:

warm/cool 0.938

All light sources were rated toward warm despite the fact that CW fluorescent and metal halide both have higher temperatures and are considered cool light. One explaination may be that people are familiar with cool white fluorescent color and metal halide light has very close color temperature (4500K) to the CW fluorescent color temperature (4200K), so subjects judged both lights warm. Another explaination is that the experiment was run during winter time (Feburary), the temperature in the room had range from 73 to 76 Fahrenheit degrees. Compared to outdoor temperatures the test room was relatively warm. This may lead subjects to judge the light warm.

Effect of light source

The analysis of variance shows that there is no significant difference among four light sources for all factors. In Flynn's study (1977), HPS had a poorer impression on "evaluation". In present study, no significant difference was found. The major difference between Flynn's study and present study is that the environmental color was neutral in Flynn's study and was not in present study; and task ambient lighting was used in the present study instead of an overhead uniform system. The results suggest that the environmental color or type of luminaire or both together can improve the impression of light source colors (especially HPS light color). Analysis on HID light sources for "clarity" factor shows metal halide light is significantly stronger than HPS on this factor.

HID kiosk vs furniture-mounted fluorescent

The analysis of variance comparing HID kiosk with furniture mounted fluorescent fixture on five factors shows there is no significant difference between these two fixtures for all factors. This results suggest that the efficient HID kiosk is a usable alternative to fluorescent task lighting for office use.

Implications

The present study finds no differences on performance of color discrimination and inspection tasks among four light sources. For the "clarity" factor, HPS light shows a poorer impression than the HPS light.

The major difference between the present study and Flynn's study is the environmental color and luminaire. Although it is difficult to conclude whether the environmental color or the luminaire or both improve the impression on HPS light color, it is suggested that the impression of color of light source can be corrected, so the HPS light should be an usable alternative light source for office use.

More research should be done with carefully selected environmental color (ceiling, wall, furniture, etc.) with strictly controlled room temperature, noise level and using longer exposure time for the subject to find more evidence of the accpetability of HID sources.

CONCLUSIONS

1. There is no significant difference found among light sources for the performance of color discrimination and inspection tasks.
2. Five factors were extracted from the factor analysis, they are social prominence, clarity, evaluation, spaciousness and warmth.
3. For the effect of light source, HPS light is poorer than metal halide light on clarity factor. No other differences were found on other factors among four light sources.
4. HID kiosk lighting is a usable alternative for office task lighting system.
5. Further research can be done as a continuation of the present study, with carefully selected environmental color and type of luminaire, strictly controlled environment. A greater number of subjects and longer exposure time to the light source should also be used to obtain completely independent subjective responses.

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A STUDY OF TASK LIGHT SYSTEMS: HID KIOSKS AND FURNITURE MOUNTED FLUORESCENT LIGHTING SYSTEM

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ABSTRACT

This report describes the effect of light on visual performance and user impressions. The basic purpose of this research was to find the acceptability of high intensity discharge (HID) light sources for office uses.

The light sources used in this study were cool white fluorescent and HID sources including metal halide, high pressure sodium (HPS) and combination of metal halide and HPS lights. Two types of luminaire were used. One was furniture-mounted fixture for cool white fluorescent, the other one was kiosk for HID light sources.

The experimental room was so arranged to make it look like a pleasant office or study room. Colorful furnitures and decorations were used. Each subject performed color discrimination and inspection tasks under only one light source. After performing the tasks, the subject evaluated the lighting system on semantic scales and answered two questions.

There were no significant differences in the performance of both tasks among the four light sources. Factor analysis of the semantic scales was carried out. Five factors were extracted.

There were no significant differences in the subjective judgments among the four light sources except metal halide was stronger than HPS on clarity factor.

The results were compared with the results of Flynn's (1977) study. Flynn used an experimental room which was neutral in characteristic and measured the color effect of light sources on user impression. Flynn found HPS light was poorer than other light sources for "evaluation". The results of present study suggest that the negative tendencies associated with color of light might be attenuated or corrected by environmental color or luminaire. Thus, HPS light should be an usable alternative light source for office use.

More research should be done with carefully controlled experimental environment and using longer exposure time for the subject to find more evidence of the acceptability of HID sources.