A STUDY OF THE ADEQUACY AND ECONOMICS OF LIGHTING IN RETAIL STORES

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ABSTRACT

A STUDY OF THE ADEQUACY AND ECONOMICS OF
LIGHTING IN RETAIL STORES

By

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The present lighting levels in retail stores is adequate for the merchandising functions being performed. Any increase in light level will cause a proportionally higher operational cost with little, if any, tangible return on the increased lighting investment.

Secondary information was procured from such sources as the General Electric Lighting Institute at Nela Park, Cleveland, Ohio. The Illuminating Engineering Handbook (fourth edition) proved invaluable in supplying technical information. Additional information came from personal interviews with store managers and maintenance personnel, actual inspection of the merchandising areas and questionnaires sent to stores in other sections of the country. Because of the possible scope of this topic the study was limited to men and women's ready-to-wear departments of middle to high margin retail department stores. The adequacy and economics of lighting in retail

stores was determined through the investigation of: what elements are required to see objects; the characteristics of various light sources; the derivation of the recommended light levels; the present retail lighting environment and an economic cost analysis of the various lighting alternatives.

Elements of seeing were arrived at by reading books on the subject of visibility. These books concluded that there are four visibility factors which produce sight. These factors are: Object Size, Contrast, Brightness and Time. Of these four factors, Brightness and Contrast have proved to be the most important. Emperical studies have shown that Object Size and Time, required to see an object, are a function of the objects Brightness and Contrast. These statements indicate that the manipulation of object Brightness and Contrast should be the major areas of study in making an object more visible.

Characteristics of the three major light sources are varied. The incandescent lamp produces light via a wire or filament, which is heated to incandence by its resistance to a flow of electric current through it. Their advantages are: their circuitry is simple; they can operate at low temperatures and their life is not a function of burning hours per start. Their disadvantages consists of: low luminous efficiency; they produce a large amount of infrared, which can put a practical limit on the footcandles level for general lighting because of the heat

produced and they are extremely sensitive to voltage variations.

Mercury lamps produce light by a current passing through a gas or vapor under pressure. These lamps require correct voltage with very little variation. A 10 per cent drop in the required voltage can result in as much as a 20 per cent decrease in lamp output. A voltage increase will raise operation temperatures and result in reduced electrode life and shorter lamp life. Electrical power interruptions lasting more than a few cycles will cause the lamps to go out but they will start automatically when the voltage is reapplied. However, the starting time for a warm lamp is longer. The luminous efficiency is about two to three times that of the common incandescent lamp. They have good life, approximately 1,200 hours at five or more hours per start, provided there is a stable current, and the light color produced can be altered by applying phosphors coatings to the inside surface of the outer bulb.

The fluorescent lamp is a long tube containing a drop of mercury and some argon. Light is produced by the electrodes, at one end of the fluorescent tube, emitting electrons. They travel through the tube at very high speeds until they collide with an electron from a mercury atom. The collision diverts the electron, from the mercury atom, out of its orbit. When this mercury atom snaps back

to its proper location ultraviolet radiations are produced. When these ultraviolet radiations reach the phosphors coatings, located on the inside surface of the fluorescent tube, there is a collision, similar to the electron collision previously described and visible light is produced. Lamp life is a direct function of the number of starts, because electron material is emitted from the electrodes everytime the lamp is started. This lamp life is approximately 7,500 hours at six hours per start. These lamps can be made to produce different colors by changing the type of phosphor used on the inside surface of the tube. Fluorescent lamps operate most efficiently at temperatures between 70-90°F. Lower temperature produce less light, higher temperatures shifts the ultraviolet radiations to longer wavelengths, which have less effect upon the phosphorus lining, thereby producing less visible light. There luminous efficiency is about two to three times that of a high-wattage incandescent lamp and their initial cost is higher than incandescent but they are much cheaper to operate.

The present recommended lighting levels were derived by the Illuminating Engineering Society (I.E.S.). They have based their recommendations on a standard of being able to see the most difficult visual task at the rate of five assimulations per second (A.P.S.) with 99 per cent accuracy. For the merchandising field the I.E.S. has decided that the most difficult visual task is reaching the price tag, which is assumed to be a white card printed with light blue ink. This procedure for setting recommended light levels may not identify the optimum level.

Analysis of the present lighting environment indicates that fluorescent lamps are by far the most popular form of lighting. The average light level provided by the stores used in this study was sixty-one footcandles for both men and women's departments. The ceilings and walls were generally white or at least light pastel colors, while, the floors were darker. Lamp maintenance consists of replacing lamps upon burnout and lamp cleaning is generally left until the department is redecorated or a major department cleaning program is instituted. This indicates that the present lighting environment consists of fluorescent lamps on white ceilings, with light walls and dark floors. This combination results in sixty-one footcandles of light over the entire merchandising area.

An economic cost analysis of the various lighting alternatives indicate that the most economical lamp is the warm white fluorescent tube. However, this lamp is deficient of a red element, which results in poor color rendition capabilities. Mercury vapor lamps are more expensive than fluorescent because of their high initial cost. The most expensive lighting alternative is the incandescent lamp, due to its operational inefficiency.

An analysis of the various maintenance schedules indicates that cleaning the lamps every four months produces the most light for the least operational costs.

Despite the Illuminating Engineering Societys' recommended light levels, present lighting in retail stores is adequate. The I.E.S. requires that the visual task be seen at the rate of five A.P.S. with 99 per cent accuracy. The five A.P.S. requirement is unrepresentative of the merchandising environment and results in raising the recommended level to a figure (100 FC) that is higher than is actually needed. This results in unnecessary additional operating costs. From an economic stand point the standard warm white fluorescent lamp is the cheapest to operate, but its lack of a red element must be compensated for with incandescent lamps. This dual lighting system design has some inherent advantages. It provides more flexibility to the system by being able to emphasis merchandise, via spot lights, and with two independently wired lighting systems one serves as a backup for the other. This type of system is more costly than a 100 per cent fluorescent system but it is felt that merchandising functions should be given a higher priority than operational costs. The maintenance schedule used by a retail store must be determined by the "opportunity costs" of their maintenance men, since the optimum lamp cleaning schedule is approximately every four months.

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CHAPTER I

INTRODUCTION

The genesis of this study starts in 1968 when Gerald J. Zboch conducted a study on the lighting conditions in the Lansing area. His conclusions were that "no department or drug store met the minimum requirements of good lighting." In August of 1969 another lighting study was done by the author. In this study, the Lansing stores were rechecked and department stores in the Detroit area were investigated. The results of this study were basically the same as the initial study done by Mr. Zboch. One of the recommendations made in this second study was that a third study should be undertaken to investigate the recommended illumination levels provided by organizations interested in lighting. This is the main purpose of this study--to investigate the derivation of the present recommended illumination levels and to evaluate these levels from a cost and pragmatic viewpoint.

In order to perform such a function the scope of the study had to be limited to a manageable size. For this reason, the study is limited to men and women's ready-to-wear departments of middle to high margin retail department stores. The ready-to-wear department was chosen because it was felt that it would be the most common department among the store population sampled. Every store should have a ready-to-wear department. Middle to high priced retailers were chosen because they would have the working capital to provide an optimum lighting system rather than being forced to utilize a least cost system only.

The significance of this study lies in its apparent uniqueness. Most companies interviewed expressed interest in the study and stated that they really had not given much serious thought to designing a lighting system that met their individual needs. In some of the later chapters information will be presented that will tend to substantiate the claim that there is not enough thought devoted to lighting system design. Therefore, this study is important in that it presents the principal elements and factors of lighting and investigates methods by which they may be advantageously manipulated. This type of information appears to be limited, based on comments made by people being interviewed in the course of this study.

The data sources for this study came from many areas. A trip was made to the General Electric Lighting Institute in Nela Park, Cleveland, Ohio. There, much information was gathered on the properties of lighting and their possible uses. Also, an interview was arranged with Mr. Fredrick Dickie who is a member of the Illuminating Engineering Society's merchandising committee. He spent several hours discussing the derivation of the Society's recommended illumination levels and presented his ideas on the development of this paper. A more thorough presentation of this society will be presented in a later chapter of this paper.

In addition to traveling to Cleveland, several stores were visited in Detroit, Grand Rapids, Lansing, and Troy, Michigan. At these various locations empirical data was recorded on the lighting system and they were discussed with management and maintenance personnel. Information from stores not visited was gathered via a questionnaire that was sent to specific stores.

Much information was gained from the Illuminating Engineering Handbook, the Illuminating Engineering Societie's fundamental lighting course, and their periodical, Illuminating Engineering. Other books were read on the history of light and the various components that make visibility possible.

There are limitations to this study. The conclusions are based upon the responses of twelve different stores. This may appear to be a rather small sample size but an analysis, presented later, will show that these twelve stores deviated little in lighting design. This fact tends to support the conclusions and recommendations made in this paper.

Another limitation of this paper is the absence of information on customer lighting preference. There has been very little done in this area. General Electric is presently conducting a study in which they are trying to develop a Visual Comfort Probability Table. This table will indicate the footcandle level that is needed to theoretically please a given percentage of the users of the lighting systems. General Electric said that they have been working on these tables for a couple of years and they estimated that it would be another year before the tables were completed. This gives some indication of how difficult it is to gather reliable consumer preference information. Because of the difficulty and time that would be involved in gathering this type of information it was placed beyond the scope of this study.

In the next chapter, a history of light will be presented. The earliest lighting facilities and their following modifications will be discussed. Chapter III is a discussion of the Science of Seeing, where the various elements and factors that make visibility possible are discussed. Chapter IV presents a history of the Illuminating Engineering Society and the role it plays in past and present lighting design. Chapter V presents Light Sources and their characteristics and adds comments on possible lighting combinations. Chapter VI presents Illuminationg Calculations and Nomenclature. This data will be used as a base upon which the rest of the paper will be built. Chapter VII furnishes information on the Present Lighting Environment in Retail Stores. It indicates what type of lighting is the most popular, what illumination levels are provided and the lamp maintenance schedule followed. Chapter VIII provides an economic Cost Analysis of Various Lighting Alternatives. Here, light sources, maintenance schedules and illumination levels are evaluated on a purely economic basis. Chapter IX goes through Designing a Lighting System for a Ready-to-Wear Department. In this chapter, the various lighting alternatives are evaluated from an economic and functional viewpoint and a best alternative is chosen. Chapter X concludes the paper and reemphasize some of the findings and presents some recommendations for present and future lighting systems.

CHAPTER II

THE HISTORY OF LIGHT

When night fell the earliest pre-historic men had their activities almost completely curtailed because of darkness. Without artificial light, man was inactive approximately half of his life. Since he did not require that much sleep, in proportion to the number of hours of darkness frustration must have developed. This frustration (perhaps) was the initial stimulus for the discovery of artificial light sources. Mr. Matthew Luckiesh, in his book Artificial Light Its Influence Upon Civilization, mentions a primitive attempt to provide artificial light by imprisoning glowing insects inside perforated gourds. This practice was prevalent in the West Indies where these fireflies emit an almost continuous luminous glow. This probably was the first practical solution to the development of artificial light, since it was a simple adaptation of readily available resources and not the result of some interacting process. The light provided must have been extremely limited. Nevertheless, this primitive light source must have exposed man to the possible advantages of an artificial light source.

The wood fire, in all likelihood, should be considered the first real source of artificial light. Undoubtedly, it was discovered by accident and was not the result of man's ingenuity. Whatever the circumstance though, the discovery that fire produced light must be considered one of the greatest strides ever made in the advancement of civilization. With this new knowledge, man started making devices which would make light more portable, thereby originating lamps. These primitive lamps were nothing more than flat, and/or concave, stones upon which burning organic material was placed. A later refinement was the glowing splinter which was suspended from the ground and placed at an angle (off vertical) with the glowing end closest to the ground.

As man progressed in the development of artificial light, he noticed that resinous or fatty material increased both the flame size and the illumination. This observation caused him to attempt to reproduce this substance. Such experiments led to the development of oil and grease lamps. This occurred near the close of the Bronze Age, or approximately 10,000 B.C. The fuel for these lamps came from such things as whale, nut, animal and vegetable oil.

These compounds eventually lead to the development of the candle, which is still in use today and will probably continue for many future years. Early candles were made from beeswax and tallow and used the pith of rushes for wicks.

Most advancements in lighting, have been the result of accidents and experience rather than research. However, in the late Eighteenth Century, the laws of physics were being applied to light sources and soon thereafter great advancements in lighting began.

Scientists learned that the brightness of a flame is due to the incomplete combustion of hydrocarbous. Incoming cool air prohibits the flame from completely burning the fuel. As these unburned particles are heated, they rise by conviction into the air, glowing with heat and thereby producing a brighter light. With this discovery, efforts were made to get more heat resistant solids into hotter flames, inorder to produce a still brighter light. One such solid material was lime, which was widely used and coined the phrase "lime-light." Because very high temperatures were required to produce a brilliant light it was clear that some other method should be developed to make bright light a more practical possibility.

In 1800, Count Alesandro Volta announced the discovery of what is now called a battery. Soon afterwards, scientists were making light from electric arcs. In 1870, the Gramme dynamo provided a practical source of electrical current. Arc lamps became a welcome replacement to the lard oil lamps which were then in use. However they required frequent electrode replacement.

This electrode problem was solved in 1878 when Thomas A. Edison developed the filament lamp. The filament lamp creates light by heating a wire electrically, rather than having the electricity arc between electrodes. Early filaments were made of platinum, however due to high volatility and low melting-point, they had only limited success. Today, filaments are made of tungsten, and have excellent life and light characteristics.

CHAPTER III

THE SCIENCE OF SEEING

The most important part of any merchandising function is the visibility of the product. Therefore, some time must be spent analyzing the elements of seeing. Basically, there are three: the eye, the light and the object (task). There is very little that can be done with the eye, except to sharpen vision through the use of glasses. Consequently, to make a significant change in seeing the quantity of light or the object and its surroundings must be modified. The above three elements combine four visibility factors to produce sight. These factors are: Object Size, Contrast, Brightness and Time. The first factor Object Size is important, it must be large enough to be seen. The smallest object or detail which can just be recognized under a given set of seeing conditions is called the threshold size. Generally, this size is measured, at the point of eye, in minutes of visual angle subtended by the size of the object, when the line of sight is perpendicular to the plane of the test object (see Figure 3-1).

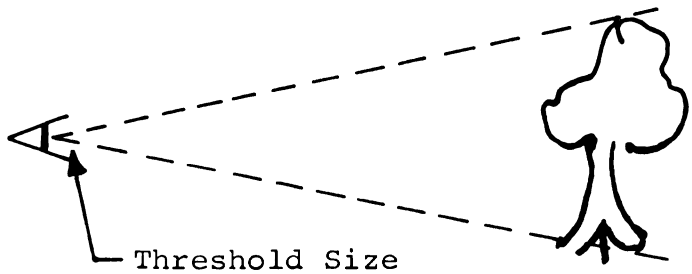

Fig. 3-1.--Location of threshold measurement

The second visibility factor is Contrast. This is defined as "the difference in brightness between the background and the critical detail."[1] In other words, contrast would be greater for black type on white paper than black type on dark gray paper.

The third factor is Brightness. This is defined as "the amount of light reflected from a surface or the amount of light emitted by a surface."[2] The measurement unit for brightness is the footlambert, which is defined as "the brightness of a perfectly diffusing and reflecting surface illuminated by one footcandle."[3] It can be calculated by

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[1]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (New York: Illuminating Engineering Society, 1961), p. 5.

[2]Ibid.

[3]Matthew Luckiesh, Light, Vision and Seeing (New York: D. Van Nostrand Company, Inc., 1944), p. 73.

multiplying the diffusely reflection-factor by the foot-candles of illumination.

$$DRF \times FC = FL$$

Therefore, if a light source provides twenty footcandles of illumination on a surface that has an 80 per cent reflection-factor the brightness equals:

$$.80\ DRF \times 20\ FC = 16\ FL$$

Some thought should be given to this equation because the DRF can have an important effect on the required foot-candles if a constant brightness level is desired. This point is illustrated in Table 3-1. Table 3-1 shows the footcandles required to make all of the various DRF surfaces equal to a brightness of 10 FL. The importance of the DRF factor is obvious. As the DRF is lowered, more light must be emitted in order to maintain a constant illumination level and this results in increased operational costs.

Brightness and contrast are closely related and are by far the most important visibility factors. They are so important that scientists have developed mathematical equations to determine the relationship between the two. There are optimum brightness-contrast relationships for good visibility. Generally, these ratios are expressed in percentages and are calculated as follows:

TABLE 1-1.--Number of footcandles required to make various DRF surfaces equal to a brightness of 10 FL.

Surface (DRF)	Required fc	Surface (DRF)	Required fc
100	10.0	10	100
90	11.1	9	111
80	12.5	8	125
70	14.3	7	143
60	16.7	6	167
50	20.0	5	200
40	25.0	4	250
30	33.0	3	333
20	50.0	2	500
10	100.0	1	1000

[a]Matthew Luckiesh, Light, Vision and Seeing (New York: D. Van Nostrand Company, inc., 1944), p. 76.

$$BC = 100 \times \frac{\text{Brightness of Background} - \text{Brightness of Object}}{\text{Brightness of Background}}$$

If the object is brighter than its background, for example white chalk on a blackboard, one simply interchanges the object and the background in the above formula. If diffused reflectance data is available brightness-contrast ratios can be calculated by using the formula:

$$BC = 100 \times \frac{\text{DRF of Background} - \text{DRF of Object}}{\text{DRF of Background}}$$

Again, if the reflection-factor of the object is greater than the background just interchange the numerator of the above equation.

Using the knowledge presented in the above equations, it is interesting to look at a graphical analysis of the footcandles required to see various threshold sizes (see Figure 3-2).

From Figure 3-2 it is obvious that the threshold size decreases very slowly in proportion to the footcandle increase beyond the thirty footcandle level. This relationship will be important in later parts of the study.

The fourth factor in seeing is Time, it takes some increment of time to see an object. This time increment is a function of the other three factors. If the object is small or has little brightness or contrast more time is going to be required to see the object. This time element is important when split-second seeing is necessary such as, production assembly, cafeterias or supermarkets. However, in ready-to-wear merchandising the time factor is of little significance.

There have been many tests devised to measure the speed of seeing under various light levels. The results of one of these tests, The Luckiesh-Moss Demonstration Visual Test is presented in Figure 3-3.

Most comparable tests have simular curves which demonstrates that the speed of seeing is little affected by increased footcandle levels beyond the first 10-20 fc. For example, one could read these printed lines nearly as fast under 10 fc as under 100 fc. This is true because few people read at their maximum rate, therefore, there is a built in safety factor. The same rate can be maintained,

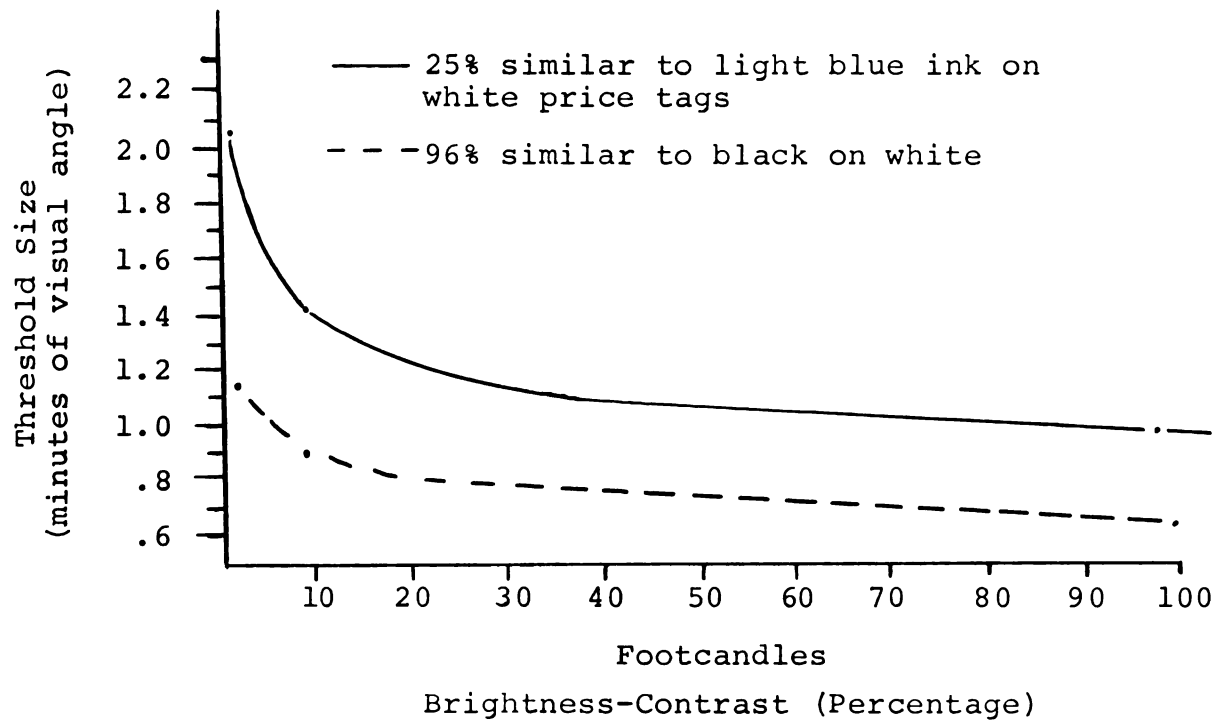


Fig. 3.2.--Footcandles required to see various threshold sizes[a]

[a]Matthew Luckiesh, Light, Vision and Seeing (New York: D. Van Nostrand Company, Inc., 1944), p. 115.

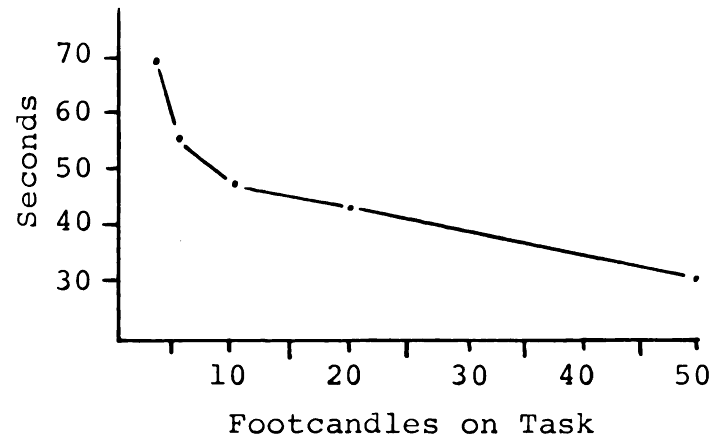


Fig. 3-3.--Time required to perform a specific visual task at given footcandle levels[a]

[a]Matthew Luckiesh, Light, Vision and Seeing (New York: D. Van Nostrand Company, Inc., 1944), p. 136.

under lower light levels, with increased reading effort. This concept can be utilized if the reader does not become fatigued and/or uncomfortable as a result of this increased reading effort.

CHAPTER IV

HISTORY OF THE ILLUMINATING ENGINEERING SOCIETY

The preceding two chapters have presented the history and science of light. They have attempted to explain light development and its relationship to seeing. The following chapter introduces a group of individuals who involved themselves in some manner with light and/or seeing. These men felt that it was most important that some sort of association should be formed to systematize, and record, all of the knowledge that has accumulated through the ages.

The first action taken toward the formation of a group to be involved with lighting was taken on December 13, 1905. On that date, a letter signed by Messrs. R. B. Marks, E. Leavenworth Elliott and Van Rensselaer Lansingh was sent to a number of people who were known to be interested in the subject of illumination. The letter suggested that a meeting should be held in New York City on December 21, to discuss the formation of a society to represent the science and art of illumination.

The meeting was held even though only twenty-five people were in attendance. The discussion that took place at the meeting centered around the lack of cooperation between various groups that were concerned with illumination. It was concluded that these various groups should be brought into closer contact through the formation of a separate society specifically for those people who dealt in the art and science of illumination. They also formed a committee to draw up a constitution and by-laws for the proposed society. Finally, they agreed to set a date of January 10, 1906 in New York City for the next meeting.

On January 10, the meeting was held and officers were elected. The first president of the Illuminating Engineering Society (I.E.S.) was Mr. L. B. Marks. Mr. Marks discussed the present state of illuminating engineering in his inaugural address. He felt that engineers, previous to the societies formation were primarily concerned with only improving the efficiency of the generating apparatus and in reducing power transmission losses. Once this power had reached its destination and was ready to be turned into light, the engineers interest had disappeared. Bare lamps of excessive brightness were so common that studies had been made showing that these lamps were causing permanent eye injury.

In addition to discussing the present state of illuminating engineering, Mr. Marks proposed some goals for the newly formed society. It was his opinion that the society should assist in remedying poor lighting practices that were existing at that time. He felt that they should assume a leadership role in the illuminating field and should point the way to obtain the best illumination from any given light source. He also felt they should investigate the theoretical, practical and esthetic side of lighting along with the economics.

He thought that the best method for achievement of these goals was to formulate the society in such a manner as to obtain the maximum cooperation of all groups.

Ever since the formation of this society a basic question they have tried to answer is: "How much light is required for seeing?" Over the years, various committees have recommended illumination levels for their own specific fields. These levels have not always been accepted without question, but they are based on the committee's available knowledge. Through the years, different standards and evaluating techniques have been used. In the early days, they simply recommended whatever light level was attainable. As lamps became brighter and more economical the recommended illumination levels became more difficult to derive.

Today's light levels were derived from a testing procedure developed by Dr. H. Richard Blackwell, then Director of the Vision Research Laboratories at the University of Michigan in 1958. What he did was to establish a target-contrast factor. This can be calculated as follows:

$$\text{Target-Contrast} = \frac{\text{Lumenance of Background} - \text{Lumenance of Object}}{\text{Lumenance of Background}}$$

This formula should seem quite familiar since it is similar to the brightness-contrast equation presented in Chapter III. What it indicates is the minimum contrast that can be detected. This is done by presenting a visual task, to an observer, at some specific fraction of the possible presentations, usually 50 per cent. When this contrast information is plotted against the required brightness, in footlamberts, and ideal curve can be established, if seeing conditions are standardized.

The Illuminating Engineering Society has performed extensive testing to determine standard seeing conditions. The results indicate that the unhurried eye requires approximately one-fifth of a second to see an ordinary task. Since this figure has been reached by many researchers, it is used as one of the standard conditions--the object must be able to be seen in one-fifth of a second or five assimulations per second (A.P.S.). Another standard condition is the per cent accuracy in viewing the visual task. It was established at 99 per cent accuracy, which is considered to be the maximum practical accuracy.

Using these standard conditions, five A.P.S. with 99 per cent accuracy, Blackwell performed extensive tests. He varied the field luminances from 0.001 to 800 footlamberts, threshold size through visual angles from 0.8 to

64 minutes and exposure times from 0.001 to 1 second. From these tests he established an ideal curve, which indicates the footlambert level required to meet the pre-established standards under varied contrast conditions.

With the establishment of Blackwell's ideal curve, the required footlambert level for any given condition can be established. The DRF, presented in Chapter III, can be established for any visual task through actual measurement. With these two knowns the footcandle level can be determined by solving the following equation:

$$DRF \times FC = FL$$

This is basically the proceedure used by the I.E.S. to establish todays recommended illumination levels for specific visual tasks.

The I.E.S. makes their lighting recommendations based upon the level of light required for the optimum performance of a given visual task. Therefore, to obtain this type of visual performance the light must be adequate for the most difficult visual task related to the function being accomplished. For retail merchandising the I.E.S. decided that the most difficult visual task is reading the price tag, which is assumed to be a white card printed with light blue ink (see Figure 3-2). Consequently, all of their recommended light levels, for merchandising areas, are based upon the amount of light required to read a price tag with 99 per cent accuracy at the rate of 5 A.P.S.

CHAPTER V

LIGHT SOURCES AND THEIR CHARACTERISTICS

The most common methods of producing light are incandescence and gaseous discharge. The mechanics of operation of each of these light sources deserves a brief explanation, in order to better understand their advantages and disadvantages.

The incandescent lamp produces light by a wire or filament, which is heated to incandence by its resistance to a flow of electric current through it. Modern incandescent lamps use tungsten as filament material. Tungsten is used because of these combined characteristics: high melting point, low evaporation, strength, ductility and favorable radiation characteristics.

The essential parts of an incandescent lamp are illustrated in Figure 5-1.

Electricity flows from the lamp base through the fuse into the lead-in wires and across the filament. The whole internal structure of the lamp operates in either a vacuum or an inert gas. If the lamp produces forty-watts or above, it is gas filled, generally with argon or

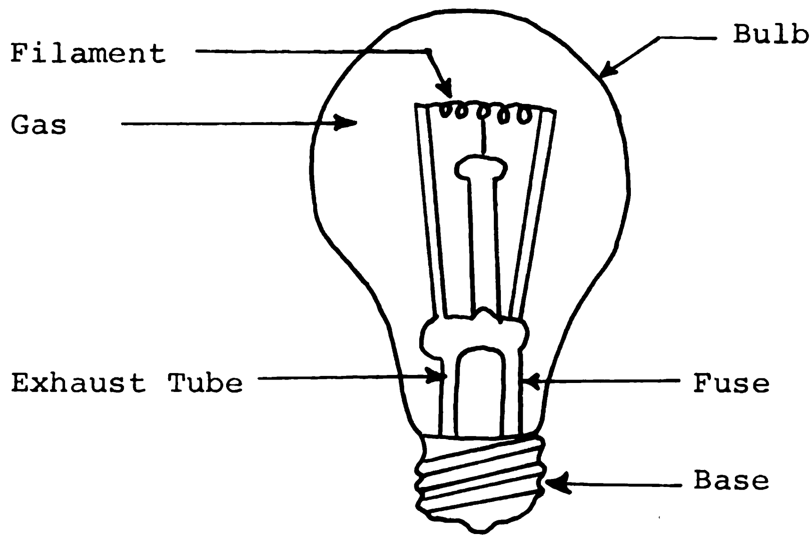


Fig. 5-1.--Essential parts of an incandescent lamp[a]

[a]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (New York: Illuminating Engineering Society, 1961), p. 17.

nitrogen. The reason for filling a lamp with these inert gasses is that the gas retards evaporation of the filament, therefore, the filament may operate at a more efficient (higher) temperature. Twenty-five watt lamps and below are vacuum, because any gain in efficiency is lost when trying to conduct low wattage current through an inert gas. Finally, all of these internal components are protected from the atmosphere by a glass bulb.

Incandescent lamps use many different style bases and bulbs depending upon their function. They do have some specialized functions such as bake-oven lamps and spotlights but normally they are used for general lighting. Advantages of the incandescent lamp are: one, their circuitry is simple; two, they can operate at low temperatures and three, their life is not a function of burning hours per start. Their disadvantages consists of: one, low luminous efficiency (most lamps radiate 10 to 12 per cent of their input energy as light); two, they produce a large amount of infrared, which can put a practical limit on the footcandle level for general lighting because of the heat produced, and three, they are extremely sensitive to voltage variations.

Gaseous discharge lamps are of two types; mercury vapor and fluorescent. The mercury lamp produces light by a current passing through a gas or vapor under a pressure of 1.7 to 10 atmospheres. Once the arc is established, the current passing through the gas increases because there is a negative resistance established. In order to control this increased current a "ballast" device must be used.

The essential parts of a mercury lamp are illustrated in Figure 5-2.

As with the incandescent lamp the base serves as the electrical connecting and holding device and they are available in several designs. The bulb, encloses the arc tube, which helps to stabilize the lamp's operating temperature and prevents oxidation of the arc tube. An inert gas is introduced between the arc tube and the outer bulb to aid in the performance of these two functions.

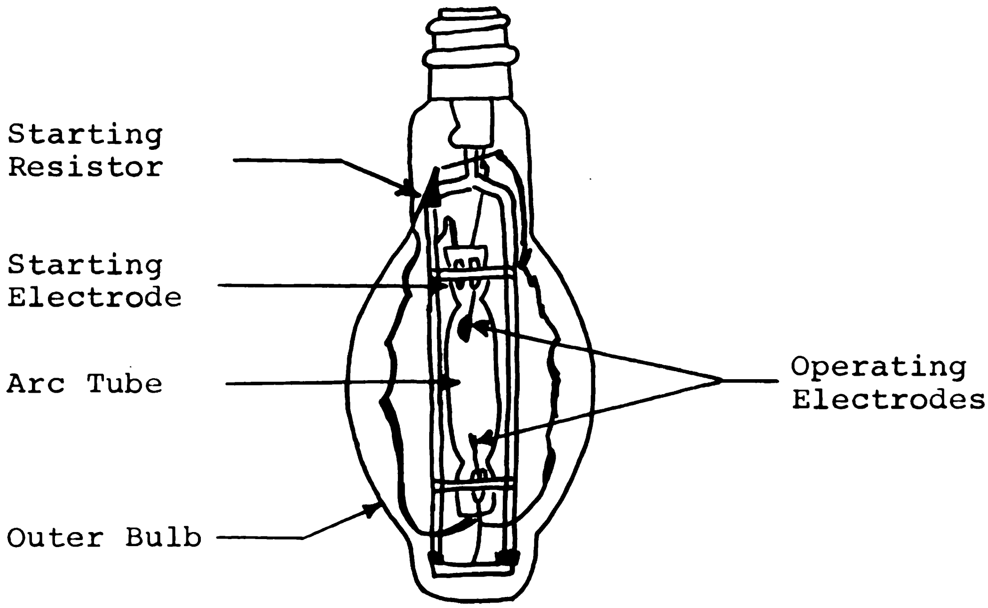


Fig. 5-2.--Essential parts of a mercury lamp[a]

[a]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (New York: Illuminating Engineering Society, 1961), p. 23.

Mercury lamps are available in several different types. There are clear mercury lamps, which produce light energy in the yellow-green and blue-violet portions of the visible spectrum. These lamps lack red light energy and consequently should not be used where color identification is a function of the visual task. In order to correct this lack of red light energy, phosphors coatings have been applied to the inside surface of the outer bulb to provide better color rendition. However, this is accomplished at the expense of an approximate 5 per cent decrease in lighting efficiency. They are available in several different tints in order to perform specific functions such as photography, sunlamps and black lighting.

The operating characteristics of the mercury lamp require correct voltage with very little variation. A 10 per cent drop in the required voltage can result in as much as a 20 per cent decrease in lamp output. The lower voltages cause lower electrode temperatures and reduced electron emission efficiency. As a result, the light output is decreased and the electrodes erode, producing shorter lamp life. Higher voltages will cause higher electrode temperatures which will increase light output, but the increased temperature reduces electrode life, which means a shorter lamp life. It can be seen that currents which are too high or too low will result in reduced lamp life and increased maintenance costs.

To start a mercury lamp a small arc is initiated between the starting electrode and the nearest operating electrode. This ionizes a small quantity of the starting argon and the lamp produces a bluish glow. A few electrical current cycles later an arc strikes between the two operating electrodes and the lamp lights. It takes about four to seven minutes for all the mercury in the tube to warm up and vaporize. When it is completely vaporized the lamp is producing its full light output.

Electrical power interruptions lasting more than a few cycles will cause the lamps to go out. The lamps will start automatically when the voltage is reapplied but the starting time for a warm lamp is longer. The longer starting time is caused by increased temperatures within the tube which raise the vapor pressure to the point where the designed voltage will not strike an arc. Therefore, the temperature must be lowered before the lamp will relight.

The starting characteristics of mercury lamps are also affected by their age. As the lamp is used, emissive material from the electrodes gradually darkens the arc tube. The gas in the arc tube is contaminated by this material and as a result higher voltages are required to initiate an arc. At this point it must be decided whether to increase the voltage or replace the lamp.

The lighting characteristics of the mercury lamp are generally good. Their luminous efficiency is about two to three times that of the common incandescent lamp. They have good life, approximately 12,000 hours at five or more hours per start, provided there is a stable current. Because mercury lamps have such a high efficiency and lumen output for their size, they are economical to use in medium to high ceiling areas.

The other type of gas discharge lamp is the fluorescent lamp. Essentially this lamp is a long tube containing a drop of mercury and some argon, which aid in starting. Light is produced by the electrodes, at one end of the fluorescent tube, emitting electrons. They travel through the tube at very high speeds until they collide with an electron from a mercury atom. The collision diverts the electron, from the mercury atom, out of its orbit. When this mercury atom snaps back to its proper location ultraviolet radiations are produced. When these ultraviolet radiations reach the phosphors coating, located on the inside surface of the fluorescent tube, there is a collision, similar to the electron collision previously described, and visible light is produced.

The essential parts of a fluorescent tube are illustrated in Figure 5-3.

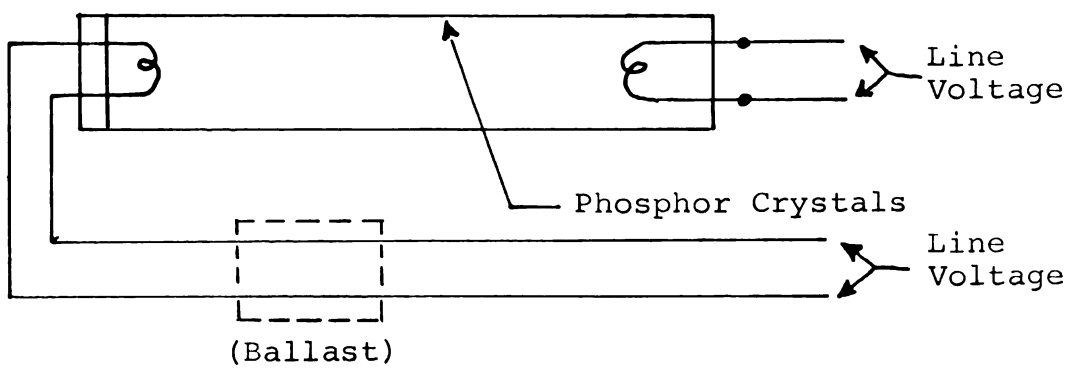


Fig. 5-3.--Essential parts of a fluorescent tube[a]

[a]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (New York: Illuminating Engineering Society, 1961), p. 29.

The ballast regulates current so it will not rise to a value that would destroy the lamp.

These lamps can be purchased in many diameters and shapes depending upon installational requirements. Their lighting and performance characteristics are good. Lamp life is a direct function of the number of starts, because electron material is emitted from the electrodes everytime the lamp is started. The most commonly used lamps have lamp lives rated at 7,500 hours, based on three hours of operation per start. This is approximately seven to ten times longer than the general service incandescent lamp. These figures can be increased even further by increasing the operational time per start. For example, at six hours per start the 7,500 hours must be multiplied by 1.25. Twelve hours operational times use a multiplier of 1.6 and continuous burning uses a multiplying factor of 2.5.

In addition to long life, the fluorescent can be made to produce different colors simply by changing the type of phosphor used on the inside surface of the tube. Some of the more commonly used colors are: Standard Cool White, which creates a psychologically cool working atmosphere and gives a natural outdoor lighting effect; Deluxe Cool White, which contains more red light energy than standard and is therefore more flattering to people and merchandise; Standard Warm White, which is used when a warm social atmosphere is desirable, because its beige tint gives a bright warm appearance to reds and yellows, brings out the yellow in green, and adds a warm tone to blue; Deluxe Warm White, which has a red element in it to make people and merchandise more flattering than standard warm white; White, which emphasizes yellows, yellow-greens and oranges; and Daylight, where the blue color associated with the "north light" of actual daylight is perferred, for example industrial operations.

Performance wise, the fluorescent lamp operates most efficiently at temperatures between 70-90°F. Lower temperatures reduce the mercury pressure, which causes less ultraviolet radiation to collide with the phosphors coating and consequently less light is produced. For temperatures above 90°F, the ultraviolet radiations shift to longer wavelengths, which have less effect upon the phosphorus lining, thereby producing less visible light. Fluorescent lamps are not as sensitive to voltage variations as incandescent lamps, but they must be operated within the voltage range of the ballast for proper performance and life.

The luminous efficiency of the fluorescent lamp is about two to three times that of a high-wattage incandescent lamp. From an economic standpoint, the initial cost of fluorescent equipment is higher than incandescent, for a constant illumination level, but power consumption is less. Therefore, if the burning hours are over 1,000, fluorescent lighting generally yields a lower operational cost. Whether or not this lower electric demand is of any significance depends upon the rate paid for electricity.

CHAPTER VI

ILLUMINATION NONMENCLATURE AND CALCULATIONS

The study of lighting is very old, hence the science has a well established vocabulary and mathematical background. Before any valuable discussion of lighting environment or design can be undertaken, a common vocabulary must be established. In addition to this, lighting relationships between interacting components must be expressed. Generally, the best way to perform this latter task is through mathematical expression. In the following few paragraphs, the basic vocabulary and interrelationships of lighting will be presented so that later chapters can use this knowledge as a basis for other decisions.

Light is considered a radiant flow of energy from a source, commonly described as <u>luminous flux</u> (F). The measurement unit for this flow is the <u>lumen</u> (lm). This unit flow has an intensity called luminous intensity (I) (generally it is called candlepower) and is defined as the luminous flux density for a given direction. The measurement unit for this density is the candela (cd). It is significant because it is a good indicator of a lamp's ability to produce illumination in a specific direction.

Illumination (E) is luminous flux density affecting an object. When the luminous flux is in lumens and the affected area is in square feet, illumination is measured in footcandles (fc). However, illumination can be calculated from the following formula:

$$E = F/A$$

Where A equals surface area.

Brightness (B), is basically the intensity of a sensation, which is the result of viewing some surface from which light reaches the eye. When the unit of luminous flux is the lumen and the area is in square feet, brightness is measured in footlamberts (FL). A footlambert is a unit of luminance provided by a perfectly diffusing (reflecting) light at a rate of one lumen per square foot.

Reflectance (R) is a ratio of the total light reflected from a surface, to the light initially emitted from a source. This can be expressed mathematically as:

$$P = \frac{B \text{ (brightness)}}{E \text{ (illumination)}}$$

Reflectance data is very important in designating any lighting system. Usually, the data is presented in a sketch similar to the one presented in Figure 6-1.

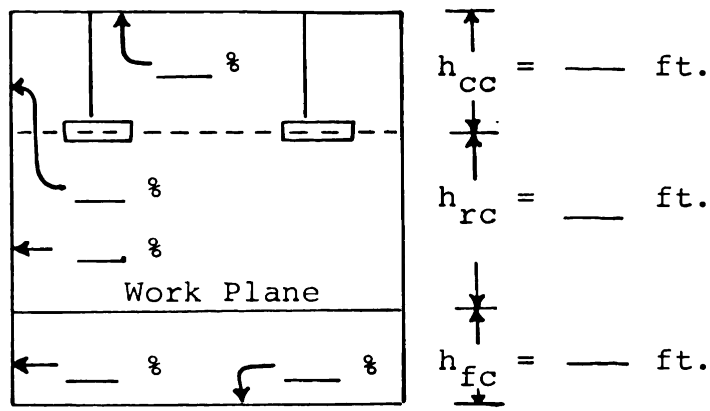


Fig. 6-1.--Sketch of important lighting information[a]

[a]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (Supplement to Lesson 6, 1964; New York: Illuminating Engineering Society, 1961), p. 3.

When the sketch is compiled, the data is used to calculate the coefficient of utilization (CU). This coefficient is the ratio of luninous flux (lumens) received on the work plane to the rated lumens emitted by the lamps. The work plane is defined as the height of the plane at which most work is done. The reason that the coefficient of utilization must be calculated is that it is one of the components of more sophisticated equations used to calculate the footcandles provided by a lighting system and the area illuminated by each luminaire.

To calculate the coefficient of utilization, first convert the reflectance data from the sketch into the various cavity ratios (Room Cavity ratio--R.C.R., Ceiling Cavity Ratio--C.C.R., Floor Cavity Ratio--F.C.R.). This is done by using the following formulas:

$$\text{R.C.R.} = \frac{5hRC\ (L + W)}{LW}$$

$$\text{F.C.R.} = \frac{5hFC\ (L + W)}{LW}$$

$$\text{C.C.R.} = \frac{5hCC\ (L + W)}{LW}$$

These cavity ratios are then converted into effective ceiling cavity reflectance (pCC) and effective floor cavity reflectance (pFC). This is done through the use of a table. The column containing the ceiling reflectance and the wall reflectance above the luminaire level is located and the effective reflectance is read opposite the ceiling cavity ratio. The same procedure is used to determine the effective floor cavity ratio except the floor cavity ratio is used instead of the ceiling cavity ratio. Once these figures are obtained, the C.U. can be easily read from the same reflectance table used to determine the effective cavity reflectance. The only change is that the table is entered at the effective ceiling cavity reflectance (pCC) and wall reflectance column and the coefficient of utilization is read opposite the room cavity ratio.

Two other factors that affect lamp output must be determined. First is the lamp lumen depreciation factor (L.L.D.). This factor takes into consideration rate of drop in lumen output of specific lamps as a function of time. The drop is caused by filament and electrode deterioration along with bulb coatings and other lamp characteristics previously mentioned in Chapter V. The Illumination Engineering Society publishes L.L.D. labels and it is very easy to find the L.L.D. factor once the lamp is identified.

The second component is the luminaire dirt depreciation factor (L.D.D.). This factor combines the maintenance schedule and the cleanliness of the working environment. Here again, the Illuminating Engineering Society publishes tables for the determination of this factor. All that is required is the maintenance schedule and general lamp category.

With this information it is possible to calculate the light level (in footcandles) present for a given work plane. This can be calculated from the following equation:

$$fc = \frac{(\text{Total Lamp Lumens/Luminaire})\ (CU)\ (LLD)\ (LDD)}{\text{Area/Luminaire}}$$

Also, the area illuminated per luminaire can be calculated from the following equation:

$$\text{Area/Luminaire} = \frac{\begin{array}{c}(\text{Total Lamp Lumens/Luminaire})\\ (CU)\ (LLD)\ (LDD)\end{array}}{fc}$$

From this data it is possible to calculate the number of luminaires required to provide a given light level. The equation is:

$$\text{Number of Luminaires} = \frac{(\text{Floor Area})\ (\text{Footcandles})}{(\text{Total Lamp Lumens/Luminaire})\ (\text{CU})\ (\text{LLD})\ (\text{LDD})}$$

An alternate form of the above equation makes it possible to calculate the required lumens for a specified light level:

$$\text{Required Lumens} = \frac{(\text{Illumination Level})\ (\text{Area})}{(\text{CU})\ (\text{LLD})\ (\text{LDD})}$$

Another form of the number of luminaires equation will indicate the number of lamps required to maintain a specified illumination level:

$$\text{Number of Lamps} = \frac{\text{Required Lamp Lumens}}{\text{Rated Initial Lamp Lumens}}$$

The spacing of luminaires for acceptable illumination uniformity is usually provided by the lamp manufacturer. The mounting height is measured from the work plane and is therefore equal to hRC. Near walls, the illumination level usually drops off rather rapidly. Therefore the spacing of the first row away from the wall should be calculated in the following manner:

$$\text{Wall to Luminaire} = \frac{\text{Manufacturers Suggested Luminaire Spacing}}{3}$$

The minimum number of rows of luminaires can be calculated from the following equation:

$$\text{Minimum Number of Rows} = \frac{\text{Room Width}}{\text{Maximum Spacing Allowed}}$$

The maximum number of lamps per row is equal to:

$$\text{Maximum Number of Units/Row} = \frac{\text{Room Length - Total End Spacing}}{\text{Luminaire Length}}$$

All of these equations were used to make the quantitative decisions presented in Chapter VIII and IX. The tables referred to can be found in any I.E.S. lighting handbook or from lamp manufacturers.

CHAPTER VII

PRESENT LIGHTING ENVIRONMENT IN RETAIL STORES

With the information presented in Chapter III the "Science on Seeing," on what factors are actually required for visibility an evaluation of the present-day lighting environment becomes more relevant. As has been previously mentioned, this study only deals with the ready-to-wear departments of middle to high margin retail stores. The lighting environment, presented below, was derived from averaging data generated from actual measurement and survey sheets sent to other department stores. Table 7-1 presents the raw data from which a typical environment will be derived.

Analysis of this data indicates that fluorescent lamps are by far the most popular type of lighting. The light level provided is approximately sixty-one footcandles for both men and women's departments. The ceilings and walls are generally white or at least light pastel colors. This helps light reflectance (or the DRF). The floors are generally darker. Here, the trade-off between reflected

TABLE 7-1.--Raw data accumulated from retail stores.

Store	Lamp Type*	Footcandles		Color			Ceiling Height	Floor Space**		Lamps/ Luminaire	Burning Hrs/Month	Maintenance**	
		Men	Women	Ceiling	Walls	Floor		Men				Cleaning Sched.	Lamp Replace.
A	INC	20	20	White	Light Gray	Dark Brown	18 ft	NA	NA	1	252	N.S.P.	Burn Out
B	INC	55	55	White	White	White	22 ft	NA	NA	1	252	N.S.P.	Burn Out
C	INC FLU	55	55	White	Tan	Light Gray	16 ft	4,700	5,200	8	304	N.S.P.	Burn Out
D	INC FLU	60	60	White	White Brown	Green Red	16 ft	7,200	16,500	8	324	Once/ Year	Burn Out
E	FLU	75	75	White	Lt. Blue Dk. Red	Dk. Blue White	16 ft	2,700	10,500	8	288	N.S.P.	Burn Out
F	FLU	100	100	White	Tan	Red Green	16 ft	4,000	8,800	4	324	N.S.P.	Burn Out
G	FLU	23	15	Lt. Beige White	Lt. Beige Lt. Green	Lt. Green Lt. Gray	12 ft 8 ft	5,000	10,500	3	292	N.S.P.	Burn Out
H	FLU	100	100	White	Lt. Green	Lt. Blue Red	16 ft	13,800	13,800	8	288	N.S.P.	Burn Out
I	INC FLU	100	100	White	White Lt. Green	Orange Dk. Green	14 ft	2,300	5,400	8	304	N.S.P.	Burn Out
J	INC FLU	75	75	White	Lt. Blue Lt. Green	Orange Red	16 ft	3,900	6,200	8	288	N.S.P.	Burn Out
K	INC FLU	20	23	Black White	Light Gray	Light Gray	11 ft	2,000	5,400	1	264	N.S.P.	Burn Out
L	FLU	40	40	White	Light Green	Light Gray	13 ft	NA	NA	1	276	Once/ Year	Burn Out
Avg.	FLU	61.0	60.6	White	Light Color	Medium Color	14.92 ft	5,067	9,144	5	288	N.S.P.	Burn Out

*Women's Departments are on top when two entries are presented.
**Floor space in sq. ft.
***N.S.P. = No Standard Proceedure.

light and floor cleaning maintenance dictates that the darker colors be used. The ceiling height averaged 14.9 feet with the most frequent height being 16 feet. This table (Table 7-1) will have significance in later chapters dealing with lighting system design and their economics.

All of the departments investigated had sales clerks to help customers. Therefore, the recommended light level provided by the Illuminating Engineering Society, for areas using sales clerks, is one hundred footcandles. The raw data in Table 7-1 shows that only three stores provided this recommended level, the others were less.

The lights are used approximately 288 hours per month or about twelve hours per day. Lamp maintenance is quite limited with all stores replacing lamps upon burnout and lamp cleaning is generally left until the department is redecorated or a major department cleaning program is instituted. Some of the stores interviewed stated that some member stores, within their chain, did follow regular cleaning and lamp replacement schedules, but the interviewee felt that the most representative maintenance schedule was only to replace lamps upon burnout, and to clean them only when a major cleaning process was undertaken. This lamp maintenance topic will be more thoroughly discussed in a later chapter dealing with illumination calculations.

The lighting pattern followed by the different department stores was of the same general type in that they did not appear to follow traffic patterns or attempt to provide more light over the displayed merchandise.

A majority of the stores utilized lighting patterns involving the use of both fluorescent and incandescent lamps, with the fluorescent lamps assuming the larger percentage. Usually, the luminaires would be spaced eight or nine feet apart for the two principal vector directions. For those stores using incandescents alone, the lamps were spaced on six foot centers and covered the ceiling uniformly.

Most of the luminaires were recessed in the ceiling. However, one of the stores, that used all incandescent lamps, had its lamps and shades projecting below the ceiling as illustrated in Figure 7-1.

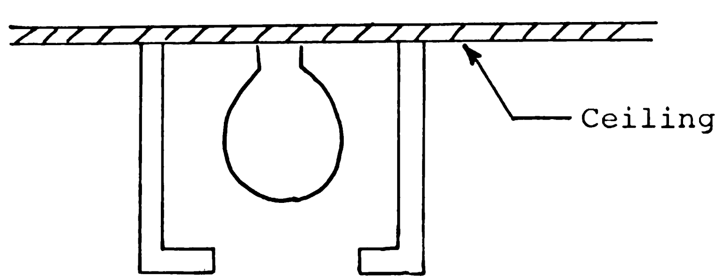


Fig. 7-1.--Illustration of store's luminaire design

A few retailers had their lamps hanging from the ceiling with the average distance being approximately three feet.

There were numerous types of lamps used. It has already been mentioned that the most popular lamp was the fluorescent tube (used in 83 per cent of all departments). Sixty per cent of all stores using fluorescent lamps used the warm white color. Deluxe cool white placed second with a 40 per cent representation. The incandescent lamps were 300-500 watt blubs, when they were used in conjunction with fluorescent lamps. However, in the two stores, where incandescents were used exclusively, Verde-A-Ray lamps were used because of their longer life. These stores had used incandescent lamps with a rated life of 1,000 hours but because of the shade design (Figure 7-1) heat is trapped in the shade and lamp life was reduced to 400 hours. In an attempt to reduce the lamp replacement cost a more expensive bulb (Verdi-A-Ray) has been installed because of its longer rated life (2,500 hours). At the time of the interview it was too early to evaluate the lamp change.

From the data presented in this chapter it can generally be concluded that the present lighting environment consists of fluorescent lamps on white ceilings, with light walls and dark floors. This combination appears to provide approximately sixty-one footcandles of light over the entire merchandising area when the general lighting pattern is used.

CHAPTER VIII

ECONOMIC COST ANALYSIS OF LIGHTING ALTERNATIVES

It can be seen from Chapter V, "Light Sources and Their Characteristics," that there are several alternatives availble in designing a lighting system. Chapter VI provides the mathematical equations required to calculate the various required elements to provide a specific illumination level given any design or light source. In Chapter VII the actual illumination level provided at the various stores surveyed was presented and a typical lighting environment was presented. This chapter shall investigate the economic factors involved in using various light sources, illumination levels and maintenance schedules.

One of the most important variables in any economic evaluation of a lighting system is the cost of electricity. The rates used in this study are the present rates now utilized by the Lansing Board of Water and Light. The rationale for using their rates is that public utilities do not have to pay Federal or State taxes and as a result their rates should be lower than privately owned utilities. Since the stores represented in this study consume large amounts of electricity, even a small price differential could result in a very significant cost savings. Consequently, this study assumes that a store is using city utility rates.

The general rate structure used by the Board of Water and Light is a step function in that the cost of electricity decreases with increased demand (see Figure 8-1 below).

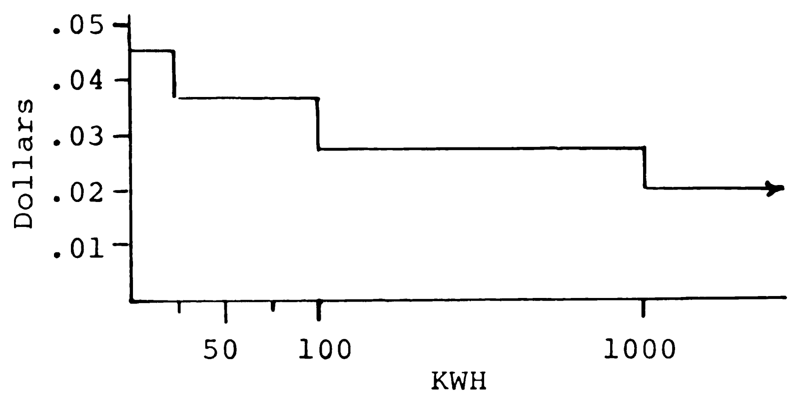


Fig. 8-1.--Rate structure used by the Board of Water and Light (dollars/KWH)[a]

[a]Board of Water and Light, Lansing, Michigan, Rate No. 3 (Lansing, Mich.: Board of Water and Light, 1967).

The lowest cost step is at the 1,000 KW demand. At this point the rate becomes constant at $.02 per KWH. This rate structure will not compute the actual cost for any given store because it is modified somewhat, given the specific volume demands of each individual store. However, the rate used in this study is strictly for comparison purposes and therefore will not alter the results, as long as the rate is held constant for all alternatives.

The total electrical consumption rate for all the department stores surveyed is far above the 1,000 KWH figure so electrical costs are assumed to be $.02/KWH and will remain constant throughout this study.

In addition to assuming a constant electrical rate, the following assumptions are made in an attempt to make the comparisons of the various lighting alternatives equitable:

1. Equal illumination levels
2. Equal burning hours
3. Equal maintenance and labor rates--for a given lamp

With the foregoing assumptions it is now possible to evaluate the various lighting alternatives on an economic basis.

In the last chapter it was determined that the average men's department had approximately 5,100 square feet (100 x 51). The average women's department had approximately 9,100 square feet (130 x 70). The average height was 14.9 feet but ceiling heights are generally standardized in two foot increments, consequently, the fifteen foot ceiling was abandoned in favor of the most frequently occuring ceiling height--sixteen feet. Generally, the ceilings were white, the walls were pastel colors and the floors were usually darker than the walls. From this information, approximate reflectance figures can be assigned to the various room components. The Illuminating Engineering Society has determined that white ceilings usually have a reflectance value of 75-90 per cent. For purposes of this study, ceiling reflectance is assumed to be 80 per cent. The walls are assumed to have a reflectance of 50 per cent, while the darker floors (carpeted) are assumed to have a reflectance value of 20 per cent. These figures will form the parameters of the typical ready-to-wear department.

Given these parameters, it is now possible to calculate theoretical operational costs for various alternatives by using the appropriate equations presented in Chapter VI. The first step in constructing a cost analysis of the various lighting alternatives is to determine exactly what alternatives are available. Chapter V presented the various light sources, incandescent filament, mercury vapor and fluorescent, so each of these must be evaluated. Table 8-1 presents a cost analysis of the most probably lighting alternatives given a ready-to-wear department. Inspection of Table 8-1 shows that the most economical incandescent-filament lamp is the 750 watt bulb. The most economical mercury vapor lamp is the 400 watt variety and the warm white lamp is the most economical fluorescent tube. It should be mentioned that this chart

TABLE 8-1.--Cost analysis of various lighting alternatives (100 FC).

Luminaire Description		300 WATT INC	500 WATT INC	750 WATT INC	250 WATT M.V.	400 WATT M.V.	700 WATT M.V.	75 WATT FLU CW	75 WATT FLU CWX	75 WATT FLU WW	75 WATT FLU WWX
1. Initial Lamp Lumens/ Luminaire		5,050	8,610	13,900	11,700	21,500	40,800	43,520	34,240	51,200	50,160
2. Lamp Life (Hours)		2,500	2,500	2,500	24,000	24,000	24,000	20,000	20,000	20,000	20,000
3. Avg. Watts/Lamp		300	500	750	250	400	700	75	75	75	75
4. Watts/Luminaire		300	500	750	250	400	700	600	600	600	600
5. Coefficient of Utilization	M W	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62
6. L.L.D.		.90	.90	.86	.73	.83	.68	.86	.80	.86	.80
7. L.D.D.		.88	.88	.88	.88	.88	.88	.88	.88	.88	.88
8. Avg. Lumens/Luminaire (1x5x6x7)	M W	2,273 2,475	3,875 4,219	5,991 6,591	4,282 4,657	8,944 9,740	13,913 15,137	18,757 20,411	13,730 14,963	22,067 24,013	20,114 21,920
9. Luminaires Required to Maintain 100 FC	M W	225 368	132 216	86 139	120 196	58 94	37 61	28 45	37 61	24 38	26 42
10. Burning Hours/Year		3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
11. Energy Costs $\frac{4x10x24}{100,000}$		$ 20.74	$ 34.54	$ 51.84	$ 17.28	$ 27.65	$ 48.38	$ 41.47	$ 41.47	$ 41.47	$ 41.47
12. Lamps Replaced/Year (10xLamps/Unit)÷#2		1.38	1.38	1.38	.144	.144	.144	1.38	1.38	1.38	1.38
13. Lamp Cost (12xNet Price)		$ 3.49	$ 5.34	$ 12.61	$ 3.16	$ 3.59	$ 3.83	$ 8.21	$ 5.37	$ 7.60	$ 5.37
14. Labor Cost For Lamp Replacement		$ 3.93	$ 3.93	$ 3.93	$ .98	$ .98	$ .98	$ 2.68	$ 2.68	$ 2.68	$ 2.68
15. Cost of Cleaning Once/Year		$ .65	$ .65	$ .65	$ .65	$ .65	$ .65	$ 2.35	$ 2.35	$ 2.35	$ 2.35
16. Total Annual Operating Cost/Lum (11+13+14+15)		$ 28.81	$ 44.88	$ 69.03	$ 26.74	$ 32.87	$ 53.84	$ 54.71	$ 51.87	$ 54.10	$ 51.87
17. Relative Annual Operating Cost for 100 FC (16x9)	M W	$ 6,482.75 $10,602.08	$5,924.16 $9,694.08	$5,936.58 $9,595.17	$3,208.80 $4,241.14	$1,906.46 $3,089.78	$1,992.08 $3,284.24	$1,531.88 $2,461.95	$1,919.19 $3,164.07	$1,298.40 $2,055.80	$1,348.62 $2,178.54

was calculated using all Verd-A-Ray lamp specifications and prices so there may be some variance if different brands are used but the relationships should remain the same.

One look at the relative annual operating costs for the various alternatives will explain why ten out of the twelve stores surveyed used fluorescent lamps and of these ten, six used warm white tubes (see Table 8-1). It is quite clear that incandescent lighting can be very expensive. Mercury vapor lamps may be able to be competitive if their initial high fixed cost could be lowered. They have a very long life span and recent developments have greatly improved their color rendition capabilities. This color problem is something that has plagued mercury lamps for a long time and as a result, most people do not think that mercury lamps can be used in merchandising areas, where true color is important. Today this is generally untrue.

Another alternative in lighting design is to intermix various light sources. Table 8-2 shows the operating costs associated with various percentages of incandescent and fluorescent lamps. Obviously, the lower the percentage of incandescent lighting the lower the operating costs. Therefore, in order to design a least cost system warm white fluorescent lamps would be used exclusively. However, the color produced by warm white lamps does not provide the best environment for merchandising functions,

TABLE 8-2.--Operating costs of various percentages of incandescent and fluorescent lamps.

			30%I-70%F		40%I-60%F		50%I-50%F		60%I-40%F		70%I-30%F
1.	Initial Lamp Lumens/ Luminaire	I[a]		13,900		13,900		13,900		13,900		13,900
		F[b]		51,200		51,200		51,200		51,200		51,200
2.	Lamp Life (Hours)	I		2,500		2,500		2,500		2,500		2,500
		F		20,000		20,000		20,000		20,000		20,000
3.	Average Watts/Lamp	I		750		750		750		750		750
		F		75		75		75		75		75
4.	Average Watts/ Luminaire	I		750		750		750		750		750
		F		600		600		600		600		600
5.	Coefficient of Utilization	I		.57		.57		.57		.57		.57
		F		.62		.62		.62		.62		.62
6.	L.L.D.	I		.86		.86		.86		.86		.86
		F		.86		.86		.86		.86		.86
7.	L.D.D.	I		.88		.88		.88		.88		.88
		F		.88		.88		.88		.88		.88
8.	Ave. Lumens/Luminaire (1x5x6x7)	M[c]		5,977I 22,016F		5,977I 22,016F		5,977I 22,016F		5,977I 22,016F		5,977I 22,016F
		W[d]		6,533I 24,064F		6,533I 24,064F		6,533I 24,064F		6,533I 24,064F		6,533I 24,064F
9.	Luminaires Required to Maintain 100 FC	M		26I-17F		35I-14F		43I-12F		52I-10F		60I-7F
		W		42I-27F		56I-23F		70I-19F		84I-16F		98I-12F
10.	Burning Hours/Year	I		3,456		3,456		3,456		3,456		3,456
		F		3,456		3,456		3,456		3,456		3,456
11.	Energy Cost $\frac{4x9x24}{100,000}$	I	$	51.84	$	51.84	$	51.84	$	51.84	$	51.84
		F	$	41.47	$	41.47	$	41.47	$	41.47	$	41.47
12.	Lamps Replaced/ Year (10xLamps/Unit)÷2	I		1.38		1.38		1.38		1.38		1.38
		F		1.38		1.38		1.38		1.38		1.38
13.	Lamp Cost (11xNet Price)	I	$	12.61	$	12.61	$	12.61	$	12.61	$	12.61
		F	$	7.60	$	7.60	$	7.60	$	7.60	$	7.60
14.	Labor Cost For Replacement	I	$	3.93	$	3.93	$	3.93	$	3.93	$	3.93
		F	$	2.68	$	2.68	$	2.68	$	2.68	$	2.68
15.	Cost of Cleaning Once/Year	I	$	.65	$	.65	$	.65	$	.65	$	.65
		F	$	2.35	$	2.35	$	2.35	$	2.35	$	2.35
16.	Total Annual Operating Costs (11+13+14+15)	I	$	69.03	$	69.03	$	69.03	$	69.03	$	69.03
		F	$	54.10	$	54.10	$	54.10	$	54.10	$	54.10
17.	Relative Annual Operating Costs (15x9)	M		$2,714.48		$3,173.45		$3,617.49		$4,130.56		$4,520.50
		W		$4,359.96		$5,109.98		$5,860.00		$6,664.12		$7,414.14

[a]I = Incandescent

[b]F = Fluorescent

[c]M = Men's Department

[d]W = Women's Department

so other alternatives should be evaluated, such as deluxe warm white or warm white-incandescent. From an economic standpoint the deluxe warm white is cheaper than the warm white incandescent alternative.

Still another lighting alternative involves varying the footcandle level within the area. Table 8-3 is a cost analysis of the same lighting alternatives present in Table 8-1 except the footcandle level has been dropped from 100 fc to 50 fc. A comparison of the operating costs for any alternative will show that the 50 fc illumination level is one half the cost of providing 100 fc. Therefore any change in the illumination level will have a proportional change on the operation costs.

Information provided in Chapter III, "The Science of Seeing," indicates that man can see accurately at very low light levels if he has enough time and brightness-contrast (see Figure 3-2). Consequently, the actual illumination level needed is that level which will allow the customer to perform the various visual tasks at the speed associated with the function being performed. The actual level recommended by this paper will be discussed in Chapter IX, "Designing a Ready-To-Wear Lighting System."

One final economic alternative in designing a lighting system involves lamp maintenance. Should the lamps be cleaned periodically or not at all? Should they be replaced in groups or at burnout? Using the lighting equations, it is possible to calculate the operational

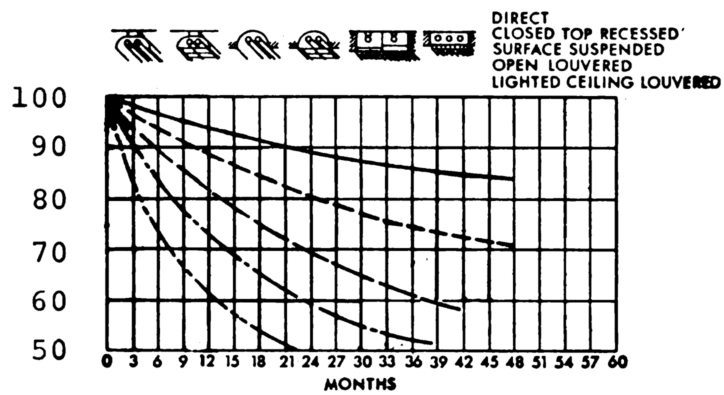
TABLE 8-3.--Cost analysis of various lighting alternatives (50FC).

Luminaire Description		300 WATT INC	500 WATT INC	750 WATT INC	250 WATT M.V.	400 WATT M.V.	700 WATT M.V.	75 WATT FLU CW	75 WATT FLU CWX	75 WATT FLU WW	75 WATT FLU WWX
1. Initial Lamp Lumens/ Luminaire		5,050	8,610	13,900	11,700	21,500	40,800	43,520	34,240	51,200	50,160
2. Lamp Life (Hours)		2,500	2,500	2,500	24,000	24,000	24,000	20,000	20,000	20,000	20,000
3. Avg. Watts/Lamp		300	500	750	250	400	700	75	75	75	75
4. Watts/Luminaire		300	500	750	250	400	700	600	600	600	600
5. Coefficient of	M	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
Utilization	W	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62
6. L.L.D.		.90	.90	.86	.73	.83	.68	.85	.80	.86	.80
7. L.D.D.		.88	.88	.88	.88	.88	.88	.88	.88	.88	.88
8. Avg. Lumens/Lumi-	M	2,273	3,875	5,977	4,329	9,300	13,872	18,714	17,408	19,814	20,064
naire (1x5x6x7)	W	2,475	4,219	6,394	4,680	9,675	15,096	20,019	19,149	24,013	22,070
9. Luminaires Required	M	113	66	41	60	29	19	14	19	12	13
to Maintain 50 FC	W	84	108	67	98	47	31	23	31	19	21
10. Burning Hours/Year		3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
11. Energy Costs $\frac{4x10x24}{100,000}$		$ 20.74	$ 34.56	$ 51.84	$ 17.28	$ 27.65	$ 48.38	$ 41.47	$ 41.47	$ 41.47	$ 41.47
12. Lamps Replaced/Year (10xLamps/Unit)÷#2		1.38	1.38	1.38	.144	.144	1.38	1.38	1.38	1.38	1.38
13. Lamp Cost (12xNet Price)		$ 3.49	$ 5.34	$ 12.61	$ 3.16	$ 3.59	$ 3.83	$ 8.21	$ 5.37	$ 7.60	$ 5.37
14. Labor Cost For Lamp Replacement		$ 3.93	$ 3.93	$ 3.93	$ .98	$ .98	$ .98	$ 2.68	$ 2.68	$ 2.68	$ 2.68
15. Cost of Cleaning Once/Year		$ .65	$ .65	$ .65	$ .65	$ .65	$ .65	$ 2.35	$ 2.35	$ 2.35	$ 2.35
16. Total Annual Operating Cost/Lum (11+13+14+15)		$ 28.81	$ 44.88	$ 69.03	$ 26.74	$ 32.87	$ 53.84	$ 54.71	$ 51.87	$ 54.10	$ 51.87
17. Relative Annual Operating Cost for	M	$3,241.38	$2,962.08	$2,968.29	$1,604.40	$ 953.23	$1,022.96	$ 765.94	$ 959.60	$ 649.20	$ 674.31
50 FC (16x9)	W	$5,301.04	$4,897.04	$4,797.59	$2,620.52	$1,544.89	$1,669.04	$1,230.98	$1,582.04	$1,027.90	$1,089.27

costs of various maintenance schedules and then determine the optimum schedule. The two most important elements are, first, the LLD (lamp lumen depreciation) which takes into account the rate at which the lumen output of the lamp drops off as a function of time. The second important element is the LDD (luminaire dirt appreciation), which combines maintenance and the dirtiness of the environment. These elements have been very thoroughly studied in the past and the results tabulated for the various light sources and environments.

The LLD factor can be obtained from the lamp manufacturers or their literature. The LDD can be determined from a chart which is available in any lighting handbook. This study assumes that most of the lighting would be recessed because this style is generally felt to have a greater esthetic appeal than is possible with fluorescent lamps hanging from the ceiling. This recessed lighting assumption means that the LDD factor will come from a "Category 4" and this chart is presented on the following page. From this chart LDD figures can be determined for any maintenance schedule, once the dirt condition of the atmosphere is determined. For a ready-to-wear department the atmosphere is assumed to be clean, when evaluated on the "Degree of Dirt Conditions" table presented in Figure 8-3.

CATEGORY IV



———	Very Clean
----	Clean
— —	Medium
—·—·—	Dirty
—··—··	Very Dirty

Fig. 8-2.--Luminaire Dirt Depreciation Factors (LDD) and five degrees of dirtiness as determined from Figure 8-3[a]

[a]Committee on Lighting Education of the Illuminating Engineering Society, IES Lighting Fundamentals Course-ED-2 (Supplement to Lesson 6, 1964; New York: Illuminating Engineering Society, 1961), p. 3.

With these two elements and the lamp characteristics provided by the manufacturer, different maintenance schedules were evaluated for the most economical lighting alternative of the three possible light sources. These are the 750 watt incandescent, 400 watt mercury vapor, and the W. W. fluorescent. Tables 8-4, 8-5, 8-6, and Figures 8-4, 8-5, 8-6 present this data. An analysis clearly indicates that cleaning the lamps approximately every four months provides the most light for the least operational cost. This policy should probably be followed

	Very Clean	Clean	Medium	Dirty	Very Dirty
Generated Dirt	None	Very little	Noticeable but not heavy	Accumulates rapidly	Constant accumulation
Ambient Dirt	None (or enters (area)	Some (almost none enters)	Some enters area	Large amount enters area	Almost none excluded
Removal or Filtration	Excellent	Better than average	Poorer than average	Only fans or blowers if any	None
Adhesion	None	Slight	Enough to be visible after some months	High--probably due to oil, humidity, or static	High
Examples	High grade offices, not near production; laboratories; clean rooms	Offices in older buildings or near production; light assembly; inspection	Mill offices; paper processing; light machining	Heat treating; high speed printing; rubber processing	Similar to Dirty but luminaires within immediate area of contamination

Fig. 8-3.--Five degrees of conditions[a]

[a]Board of Water and Light, Lansing, Michigan, Rate No. 3 (Lansing, Michigan: Board of Water and Light, 1967).

TABLE 8-4.--Cost analysis of various cleaning schedules for a 750 watt incandescent lamp.

Lamp Cleaning Schedule (Months)		1	2	3	4	5	6	12	18	24	30	36
1. Initial Lamp Lumens/Luminaire		13,900	13,900	13,900	13,900	13,900	13,900	13,900	13,900	13,900	13,900	13,900
2. Lamp Life (Hours)		2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500
3. Avg. Watts/Lamp		750	750	750	750	750	750	750	750	750	750	750
4. Watts/Luminaire		750	750	750	750	750	750	750	750	750	750	750
5. Coefficient of Utilization	M W	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62	.57 .62
6. L.L.D.		.86	.86	.86	.86	.86	.86	.86	.86	.86	.86	.86
7. L.D.D.		.99	.98	.97	.96	.95	.94	.88	.85	.80	.77	.74
8. Avg. Lumens/Luminaire (1x5x6x7)	M W	6,743 7,355	6,675 7,261	6,607 7,187	6,539 7,113	6,471 7,039	6,402 6,965	5,991 6,591	5,789 6,298	5,449 5,927	5,245 5,705	5,040 5,483
9. Luminaires Required to Maintain 100 FC	M W	76 125	76 126	78 127	78 128	79 130	80 131	86 139	89 145	94 154	98 160	102 167
10. Burning Hours/Year		3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
11. Energy Costs (4x10x24) / 100,000		$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84	$ 51.84
12. Lamps Replaced/Year (10xLamps/Unit)÷#2		1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
13. Lamp Cost (12xNet Price)		$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61	$ 12.61
14. Labor Cost For Lamp Replacement		$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93	$ 3.93
15. Cost of Cleaning Once/Year		$ 7.80	$ 3.90	$ 2.60	$ 1.95	$ 1.56	$ 1.30	$ .65	$ .43	$ .33	$ .26	$ .22
16. Total Annual Operating Cost/Lum (11+13+14+15)		$ 86.28	$ 82.38	$ 81.08	$ 80.43	$ 80.04	$ 79.78	$ 79.13	$ 78.91	$ 78.81	$ 78.74	$ 78.70
17. Relative Annual Operating Cost for 100 FC (16x9)	M W	$ 6,557.28 $10,785.00	$ 6,260.88 $10,379.88	$ 6,324.24 $10,297.16	$ 6,273.54 $10,295.04	$ 6,323.16 $10,405.20	$ 6,382.40 $10,451.18	$ 6,805.18 $10,999.07	$ 7,022.99 $11,441.95	$ 7,408.14 $12,136.74	$ 7,716.52 $12,598.40	$ 8,027.40 $13,142.90

TABLE 8-5.--Cost analysis of various cleaning schedules for a 400 watt mercury vapor lamp.

Lamp Cleaning Schedule (Months)		1	2	3	4	5	6	12	18	24	30	36
1. Initial Lamp Lumens/ Luminaire		21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500
2. Lamp Life (Hours)		24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000
3. Avg. Watts/Lamp		400	400	400	400	400	400	400	400	400	400	400
4. Watts/Luminaire		400	400	400	400	400	400	400	400	400	400	400
5. Coefficient of Utilization	M	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
	W	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62
6. L.L.D.		.83	.83	.83	.83	.83	.83	.83	.83	.83	.83	.83
7. L.D.D.		.99	.98	.97	.96	.95	.94	.88	.85	.80	.77	.74
8. Avg. Lumens/Luminaire (1x5x6x7)	M	10,070	9,969	9,867	9,765	9,663	9,562	8,944	8,646	8,138	7,832	7,527
	W	10,953	10,843	10,732	10,621	10,511	10,400	9,740	9,404	8,851	8,519	8,187
9. Luminaires Required to Maintain 100 FC	M	51	52	52	53	53	55	58	59	63	66	68
	W	83	84	85	86	87	88	94	97	103	107	112
10. Burning Hours/Year		3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
11. Energy Costs $\frac{4x10x24}{100,000}$		$ 27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	27.65	$ 27.65	$ 27.65
12. Lamps Replaced/Year (10xLamps/Unit)÷#2		.144	.144	.144	.144	.144	.144	.144	.144	.144	.144	.144
13. Lamp Cost (12xNet Price)		$ 3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	$ 3.59	$ 3.59
14. Labor Cost For Lamp Replacement		$ .98	.98	.98	.98	.98	.98	.98	.98	.98	$ .98	$ .98
15. Cost of Cleaning Once/Year		$ 7.80	3.90	2.60	1.95	1.56	1.30	.65	.43	.33	$ .26	$ .22
16. Total Annual Operating Cost/Lum (11+13+14+15)		$ 40.02	36.12	34.82	34.17	33.78	33.52	32.87	32.65	32.55	$ 32.48	$ 32.44
17. Relative Annual Operating Cost for 100 FC (16x9)	M	$2,041.02	$1,878.24	$1,810.64	$1,811.01	$1,790.34	$1,843.60	$1,906.46	$1,926.35	$2,050.65	$ 2,143.68	$ 2,205.92
	W	$3,321.66	$3,034.08	$2,959.70	$2,858.62	$2,938.86	$2,949.76	$3,089.78	$3,167.05	$3,352.65	$ 3,475.36	$ 3,633.28

TABLE 8-6.--Cost analysis of various cleaning schedules for a 75 watt warm white fluorescent lamp.

Lamp Cleaning Schedule (Months)		1	2	3	4	5	6	12	18	24	30	36
1. Initial Lamp Lumens/ Luminaire		51,200	51,200	51,200	51,200	51,200	51,200	51,200	51,200	51,200	51,200	51,200
2. Lamp Life (Hours)		20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
3. Avg. Watts/Lamp		75	75	75	75	75	75	75	75	75	75	75
4. Watts/Luminaire		600	600	600	600	600	600	600	600	600	600	600
5. Coefficient of Utilization	M	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
	W	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62	.62
6. L.L.D.		.86	.86	.86	.86	.86	.86	.86	.86	.86	.86	.86
7. L.D.D.		.99	.98	.97	.96	.95	.94	.88	.85	.80	.77	.74
8. Avg. Lumens/Luminaire (1x5x6x7)	M	24,832	24,576	24,371	24,166	23,859	23,603	22,067	21,350	20,070	19,354	18,586
	W	27,034	26,778	26,470	26,214	25,958	25,651	24,013	23,194	21,862	21,043	20,224
9. Luminaires Required to Maintain 100 FC	M	21	21	21	21	22	23	24	24	26	26	27
	W	34	34	34	35	35	36	38	39	42	44	45
10. Burning Hours/Year		3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456	3,456
11. Energy Costs $\frac{4x10x24}{100,000}$		$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47	$ 41.47
12. Lamps Replaced/Year (10xLamps/Unit)÷#2		1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
13. Lamp Cost (12xNet Price)		$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60	$ 7.60
14. Labor Cost For Lamp Replacement		$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68	$ 2.68
15. Cost of Cleaning Once/Year		$ 28.20	$ 14.10	$ 9.40	$ 7.05	$ 5.64	$ 4.70	$ 2.35	$ 1.55	$ 1.18	$ .94	$ .78
16. Total Annual Operating Cost/Lum (11+13+14+15)		$ 79.95	$ 65.85	$ 61.15	$ 58.70	$ 57.39	$ 56.45	$ 54.10	$ 53.30	$ 52.93	$ 52.69	$ 52.53
17. Relative Annual Operating Cost for 100 FC (16x9)	M	$ 1,678.95	$ 1,382.57	$ 1,284.15	$ 1,232.70	$ 1,262.58	$ 1,298.35	$ 1,298.40	$ 1,279.20	$ 1,376.18	$ 1,369.94	$ 1,418.31
	W	$ 2,718.30	$ 2,238.90	$ 2,079.10	$ 2,054.50	$ 2,008.65	$ 2,032.20	$ 2,055.80	$ 2,078.70	$ 2,223.06	$ 2,318.36	$ 2,363.85

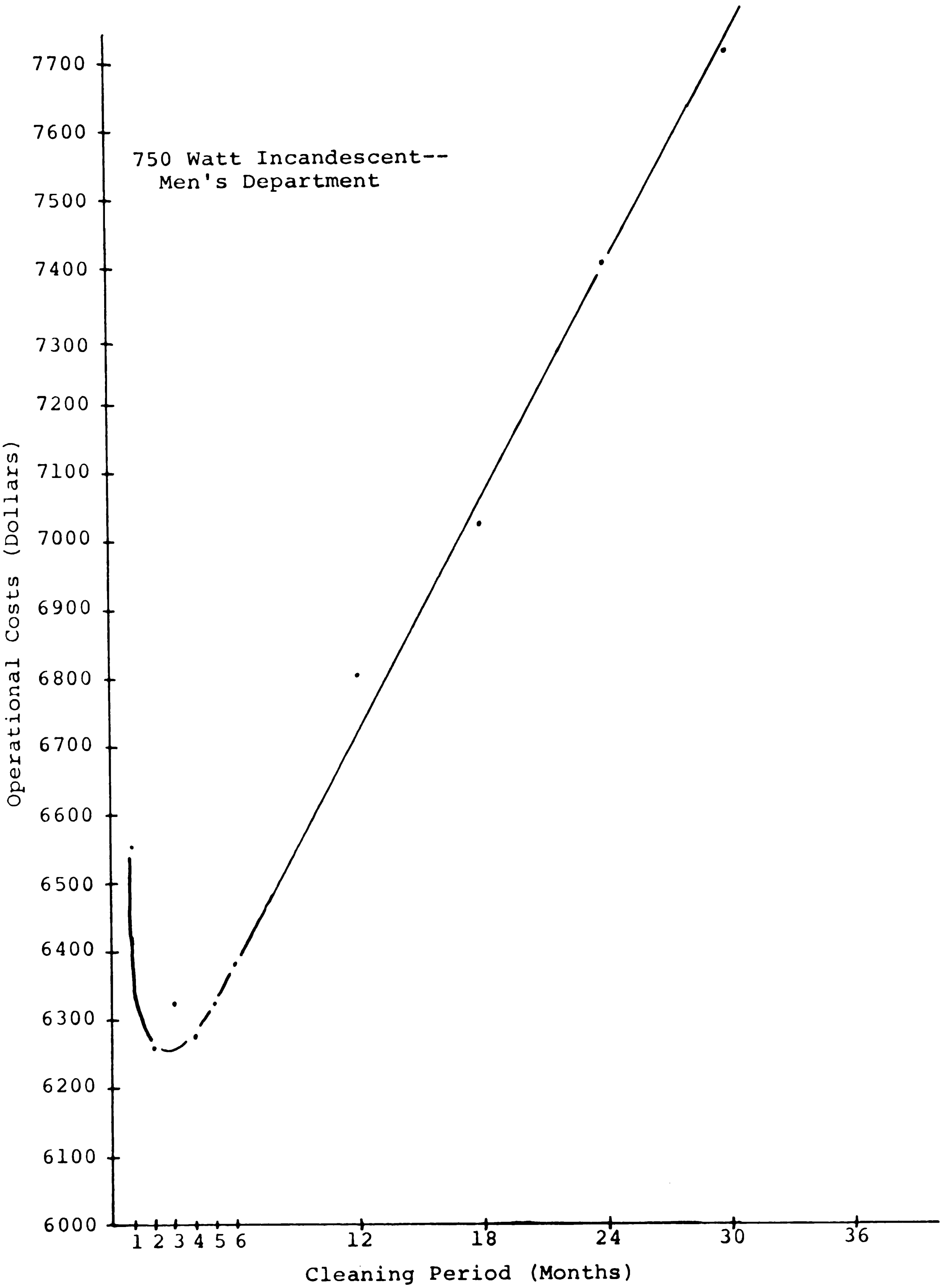


Fig. 8-4.--A graphical analysis of the operational costs of a 750 watt incandescent lamp, given specific time periods between cleaning.

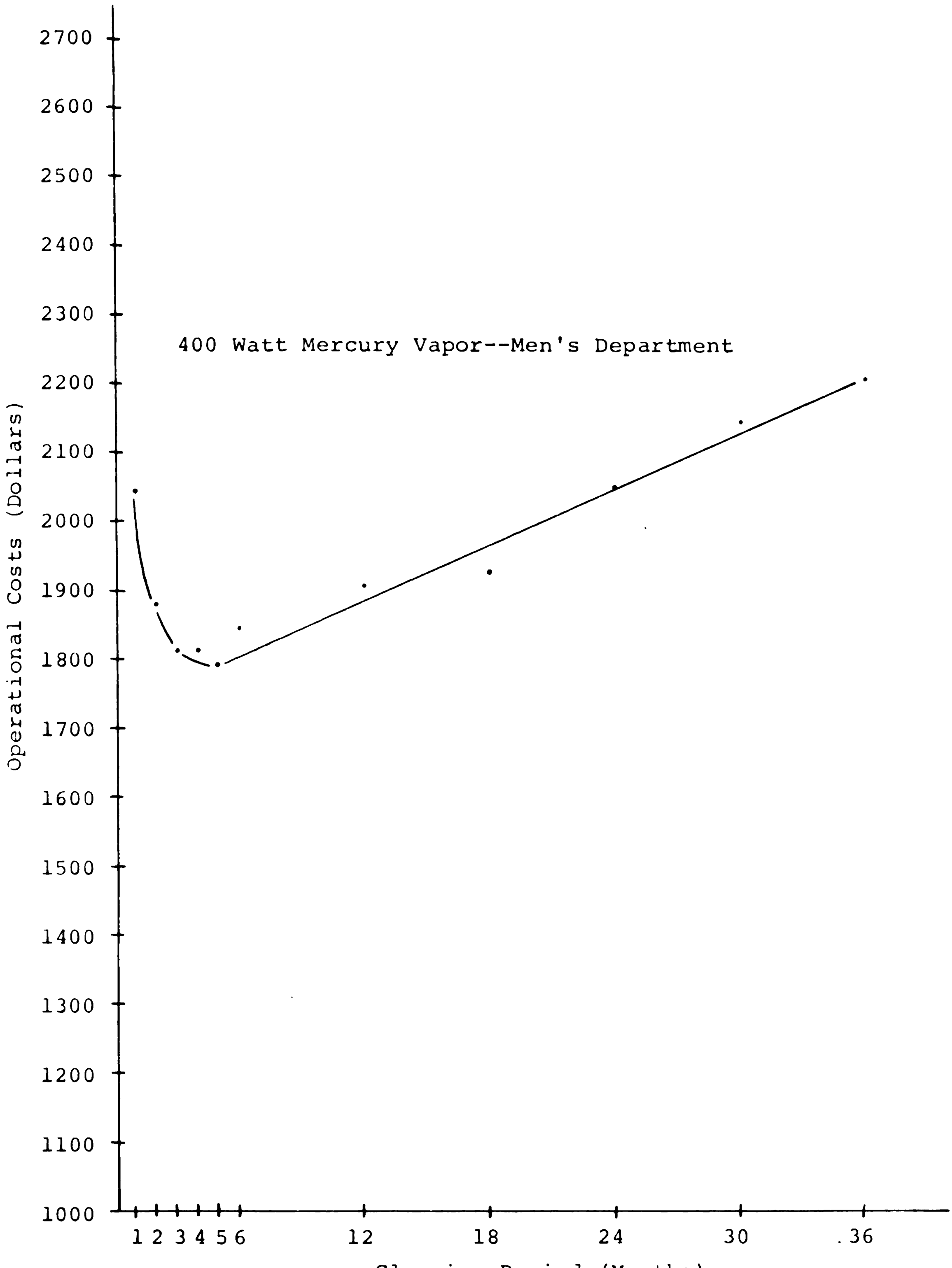


Fig. 8-5.--A graphical analysis of the operational costs of a 400 watt mercury vapor lamp, given specific time periods between cleaning.

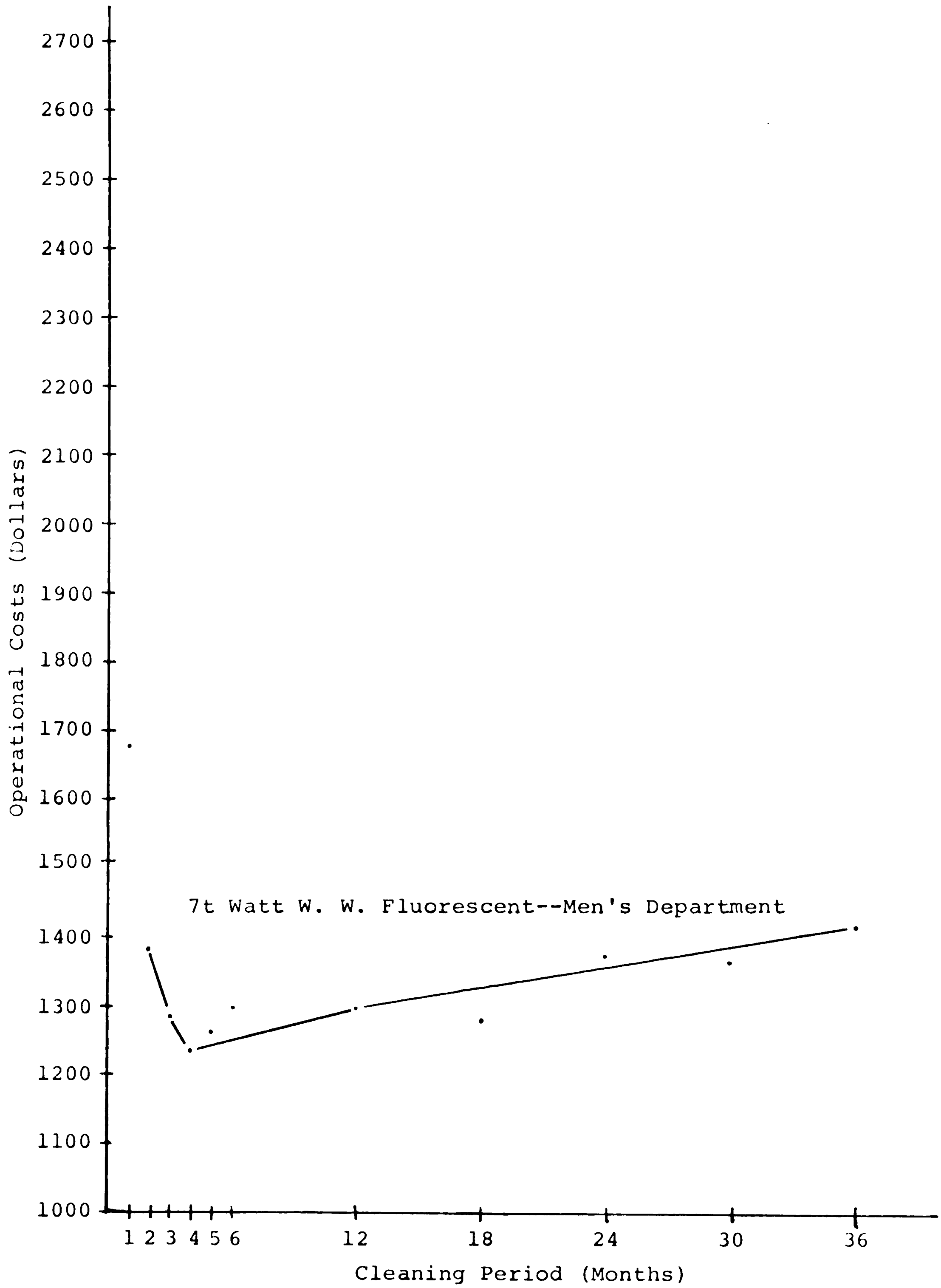


Fig. 8-6.--A graphical analysis of the operational costs of a 75 watt warm white fluorescent lamp, given specific time periods between cleaning.

unless the opportunity costs of the men are higher in some other area.

Evaluating the question about group replacement or replacing upon burnout is not a very significant question. Except for the incandescent lamps, the expected life of the other alternatives are equal to five and six years of operation.

M.V.--24,000 lamp life hrs. ÷ 3,456 burning hrs. = 6.9 years

Fluor.--20,000 lamp life hrs. ÷ 3,456 burning hrs. = 5.7 years

Therefore, replacing upon burnout would be the best alternative. Generally, the only time that group replacement can become economical is when special facilities are required to change lamps. This solution appears to be readily accepted by business because every store surveyed replaces upon burnout only.

CHAPTER IX

DESIGNING A READY-TO-WEAR LIGHTING SYSTEM

In the actual design of the optimum lighting system, all the facts and conclusions presented up to this time must be accumulated and formed into a logical pattern. The physical size of the departments have already been determined. The main questions are what illumination level to provide, what light sources to use and what maintenance schedule to follow?

The illumination level recommended by the I.E.S. appears to be too high given the actual shopping environment. Customers do not need to have enough light to perform visual tasks at the rate of five assimilations per second with a 99 per cent accuracy. Shopping in a ready-to-wear department is generally a leisurely performed task. As a result, footcandle levels can be reduced with proportional savings in operational costs.

Presently, retail stores average approximately sixty footcandles of light and this study recommends that this level is acceptable since time is such an important factor. This statement is supported by Figure 3-3 in the "Science of Seeing" chapter where it was shown that visual acuity does not significantly increase beyond the thirty footcandle level.

The type of light to be used in the ready-to-wear departments will be a mixture of incandescent and standard warm white fluorescent. The rationale for this decision is that this alternative provides more flexibility within the system. If consumer merchandising had not been the function under consideration the decision may have been different. However, when many customers are involved, flexibility is a very important element. By suspending the incandescent lamps from the ceiling and utilizing a rotating base the incandescent lamps can be arranged to emphasize specific merchandise, which is not possible with an all fluorescent system. Also, with two independently wired systems each will act as an emergency backup system for the other, in case of an electrical malfunction. This type of lighting flexibility is important in retail merchandising since presenting products in an appealing manner is closely related to the store's life line, that of selling merchandise.

The standard warm white alternative was selected because it is the most inexpensive form of fluorescent lighting (see Table 8-2) and its characteristic lack of a red element, important in merchandise enhancement, is compensated for with incandescent lamps. If a single light source were required, the deluxe warm white alternative would be used because it possesses a red element, which provides the same merchandise enhancement characteristics as the incandescent lamp. However, this study will use the dual light source concept because of the added flexibility provided by this design.

Table 8-3 indicates that the higher the percentage of incandescent lighting used, the higher the operational cost of the entire lighting system. This is obvious because incandescent lamps are the most inefficient light source presented in this study and they possess the shortest lamp life (see Table 8-2). But, the cheapest lighting system may not be the best, for merchandising functions. It is believed that lighting flexibility should be given a higher priority than operational costs. This belief will eventually result in the selection of a higher operating cost lighting system. The preceding idea may suggest that costs should not be considered in lighting design, this is false. Costs are still considered and the result is the selection of the lowest percentage of incandescent lighting that is considered beneficial to flexibility and merchandise enhancement. The author feels that the best incandescent to fluorescent ratio is approximately 30 per cent incandescent to 70 per cent fluorescent. This is a qualitative judgment. It is felt, that any incandescent percentage below 30 per cent will not adequately provide the reds required for merchandise enhancement and any percentage above this figure incurs proportional increases in operational costs.

The problem of what percentage of incandescent should be mixed with fluorescent is extremely difficult to solve. Some stores feel that a forty-sixty ratio is best. Others feel that fifty-fifty is best. It is postulated that all people involved with this problem base their decision on feeling rather than empirical data. The result is, most stores have different ratios and many stores change their own ratios. Unfortunately, the author knows of no store that has tried to correlate sales figures with lighting changes and this is the type of information that would be required to calculate an optimum ratio.

The other light source alternative is the mercury vapor lamp. It will not be used because of its initial high cost, although at some future date they may become a very strong competitor to fluorescent lamps.

The recommended maintenance schedule will be a periodic cleaning every twelve months. This decision is the result of trade-offs between optimum light levels and the opportunity costs of the maintenance department. It is reasoned that the few hundred dollars saved in lighting costs by cleaning the lamps every four months would not compensate for the other possible maintenance functions that would have to be set aside in order to maintain this frequency. This concept really has not reached the retailing world because only two of the twelve stores studied stated that they had a standardized maintenance schedule. One tried to clean the lamps every year and the other store, every three years. So here is an area where there are potential operating economies that appear to be undiscovered.

The walls of the departments will be light pastel colors. The ceilings will be white and the floors will be dark carpets to add some esthetics to the environment. These colors will help to increase light reflectance with a resulting lowering of operating costs.

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

The lighting in retail stores is adequate given the conditions under which the merchandising functions are performed. Customers generally shop leisurely so the time required to see a price tag is relatively unimportant. Therefore, illumination levels can be lowered with proportional savings in operational costs.

Retailers and packaging people can help the customer see under lower illumination levels. Retailers can assist by supplying larger price tags with better brightness-contrast between the tag and the printed price. Packagers can design their containers so that the graphics are larger and have more contrast. They should also use colors that are enhanced by the light source used. Various light characteristics were presented in Chapter V "Light Sources and Their Characteristics." These characteristics can create differential advantages for the package designer's company, if they are exploited.

This study concludes that incandescent lamps are the most expensive light source to operate, mercury vapor lamps are next and fluorescent lamps are the most inexpensive.

The implication that can be derived from this conclusion is that fluorescent lighting should be used as much as possible provided certain flexibility constraints are considered. In general this appears to be followed, since 83 per cent of the stores surveyed used fluorescent lighting.

Another conclusions is that there is a high degree of uniformity among retail stores. The above mentioned 83 per cent fluorescent usage is one example. Another example is that 60 per cent of those using fluorescent lighting used warm white lamps. This may indicate that retail stores play "follow the leader." As a matter of fact, during the data gathering process, this trait was mentioned to the author. It seems that in some stores influential executives will see a lighting system they like and will return to their own stores and duplicate the system. This practice has resulted in an almost uniform lighting system for all retail stores.

Unfortunately the author's attempt to avoid this uniformity appears to have failed. In the introduction it was mentioned that middle to high priced retailers were used. This decision was made after the author had observed the high degree of uniformity among various supermarkets and discount stores. Almost all of these stores use bare, cool white fluorescent lamps suspended approximately four feet from the ceiling. It was hypothesized that because these stores operate on a very small profit margin they were forced to use a least cost lighting system. It was felt that this operating constraint hindered innovative thinking and resulted in the high degree of lighting uniformity. For this reason, middle to high profit margin stores were investigated. The rationale behind this decision is that the higher margins would provide more working capital which should stimulate more innovative lighting designs. Regrettably, there is insufficient evidence to warrant the acceptance of this rationale because there appears to be a high degree of uniformity in these higher margin stores. What this means is either all of the stores now have optimum lighting systems or there is room for improvement in each store.

Another conclusion is that the Illuminating Engineering Society's recommended illumination levels are too high. The results of various studies show that illumination levels increase geometrically as the required reading accuracy or speed is increased. For example, a study presented in a book called the Legibility of Print written by Miles A. Tinker showed that to increase reading accuracy from 99.7 per cent to 100 per cent, using seven point type, the footcandle level had to be increased from seven footcandles to 250 footcandles. Therefore, this study concludes that the sixty footcandle level presently available in retail stores is adequate for the merchandising functions being performed and that any footcandle increase serves no useful purpose but does increase operational costs.

In summary, it is readily apparent from the above conclusions that fluorescent lighting should be the primary source of illumination and the sixty footcandles average presently available in retail stores is adequate for merchandising functions. The basic question asked in this paper is: Is retail lighting adequate for good retail merchandising? So far no optimum footcandle recommendation has emerged. Much scientific work has been done on the physical aspects of seeing, but the optimum lighting system has not been developed. The following recommendations are made in an attempt to correct this unfortunate situation:

1. Large retail stores should start to accumulate data that correlates the type of light source(s) to sales and illumination levels.
2. Maintenance schedules should be studied more thoroughly by companies using large numbers of lamps.
3. Illumination levels should be determined in the actual reading situation.
4. More innovative thinking should be invested in lighting design. For example, very little has been done with colored and/or blacklighting and both of these light sources possess a great

deal of merchandising potential for attracting customers.

With these measures set into motion, an optimistic improvement in lighting efficiency may be anticipated.

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