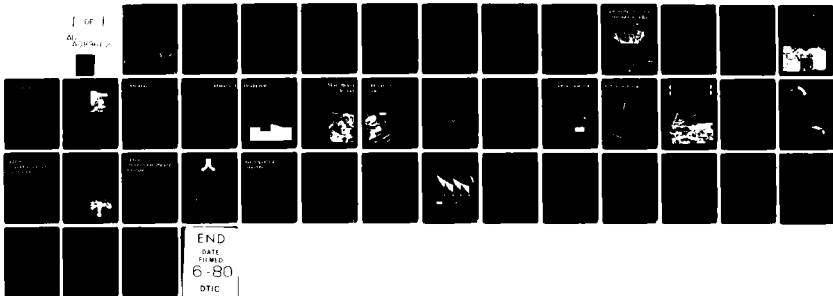
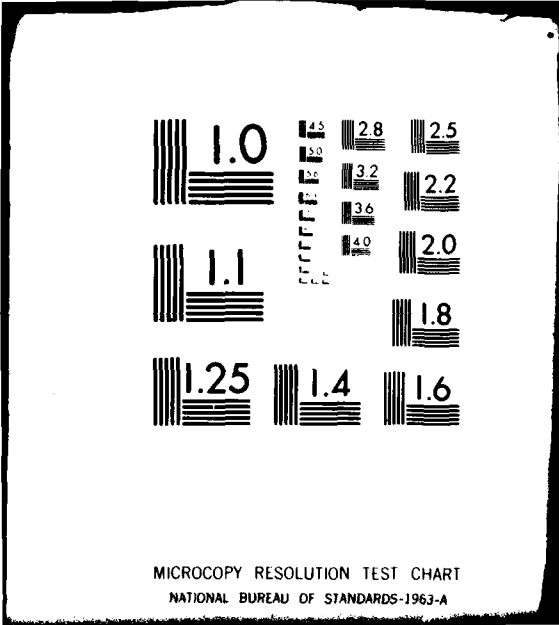


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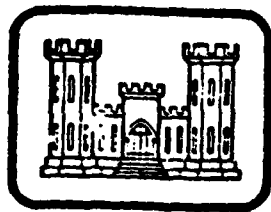


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ENERGY SAVING IN ELECTRIC LIGHTING FOR THE UNITED STATES ARMY

Alan J. Van den Berg
US Army Facilities Engineering Support Agency
Technology Support Division
Fort Belvoir, VA 22060

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ENERGY SAVING IN ELECTRIC LIGHTING FOR
THE UNITED STATES ARMY

The Facilities Engineer has been required to lower the electric usage on his Post. With the advent of the conservation program came more and more products with potentially high energy savings usually accompanied by pressures to buy the devices. Some of the devices have a definite use and place in the lighting world but none of them is without tradeoffs of some sort or other. This report is designed to augment OCE Technical Note 77-2. It is hoped that it will help the Facilities Engineer recognize and appreciate the tradeoffs of some useful devices, and to make simpler the task of devising a good lighting plan. ←

The principal objective of a good lighting, energy saving plan is not to reduce the lighting available for people to do their work. but to reduce the kilowatt hours consumed by lighting. Much of the lighting in the United States, including Army facilities, is inefficient poorly maintained, and carelessly operated. As a result of the Army's conservation efforts, there are few installations where people actually have more light on their work area than they really need to see comfortably and accurately. If the illumination is reduced below that needed for the task, the cost of the lost productivity may outweigh the energy savings by orders of magnitude.

Equally as important as is the quantity of light, is the quality of the working environment. Some lighting fixtures are glaring. Others have broken and dirty metal and plastic parts. Many of our facilities have uninteresting or inappropriate color schemes on the walls, furniture, and floors. Forgotten has been the fact that dark and dirty surfaces absorb light.

What should be done to police the facility? Clean the walls or repaint. Clean the floors. Clean the lighting fixtures (twenty to forty per cent of otherwise available light can be lost to grime). Replace broken parts or yellowed plastic (perhaps the whole lighting system should be replaced). A systematic lighting maintenance program provides more light, aids productivity, and saves energy and dollars.

What can be done by changing lamps? Do not reduce foot-candles in the work spaces below that recommended for the task. The illumination limits are prescribed in AR 11-27. The AR prescribes 50 foot-candles at the working surface of work stations, 30 foot-candles on the floor of work areas and 10 foot-candles on the floor of nonworking areas. But this 50/30/10 foot-candle requirement is the amount of light at the time you remove the lamps for replacement and clean the fixtures. If you start out with a clean fixture and new lamps, it will require at least a 50% increase at start of life for design purposes, i.e..

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75/45/15 foot-candles. Removing fluorescent lamps or using dummy fluorescent tubes has been widely, but injudiciously in some instances, recommended recently. Removing fluorescent tubes leaves the ballast unit still on the line, and in the case of a conventional ballast for two, 40-watt, 48" fluorescent tubes, this amounts to a 16-watt energy consumption without receiving any light. Replacing one tube in a two-tube F40 luminaire with a dummy tube reduces the fixture light by 75% while decreasing the power by 70%. Thus, if you can afford to lose 3/4 of the light coming from a fixture, consider dummy lamps. Also, dummy lamps cannot be used with single-lamp ballasts, pre-heat ballasts (those with "starters"), fixtures controlled by dimmer systems, and instant start systems. Dummy tubes can only be used to replace rapid start lamps in fixtures with one or more two-lamp ballasts. The "Phantom" tube is a dummy lamp containing a straight wire and a capacitor. Also available are variants of the dummy tube principle. The "Thrift-Mate" (TM) is essentially a fluorescent tube in series with a capacitor thus the light diminution is not as great as with the straight wire. Thrift-Mate tubes are available which will reduce the light by 1/3 (TM33) and by 1/2 (TM50) when used in a two-lamp fixture.¹³ It should be noted that they must be paired with an F40 conventional lamp in a fixture having a rapid start series sequence ballast (CBM type) in a minimum ambient temperature of 60°F. A comparison of power savings, light output, and cost of the lamps is given in table 1. It should be noted that the costs shown are for the lamps only. The labor costs for replacement are not included because the costs vary so widely.

Useful in most installations are the new high output fluorescent tubes which are sold under various trade names such as Supersaver, Watt-Miser, Econ-o-watt, Economiser, etc. There are two families of these lamps. The first type uses about 10 to 15 percent less power than a conventional rapid start lamp with a similar reduction in light. The second generation of these lamps saves the same percentage of energy but the light output is scarcely decreased at all. Unfortunately, the second generation lamps sell for twice the price of the original power savers. Table 1 shows the approximate power savings, light differences and cost of lamps. The use of different rated lamps fitting the same sockets may introduce a logistic problem which may be difficult or costly to solve in some installations. In such cases, it is recommended that the system the Post Office Department is using be considered -- use and stock only the new power saving, high efficiency lamps and replace the ballasts as they burn out with new, high performance ballasts which provide better light at reduced wattage (8 watts per ballast saving, over the old, 2-unit F40 ballast), and have a much longer design life. The combination of a new ballast and a high efficiency tube can save 24% of the original power cost while providing over 98 percent of the original light. If a good maintenance program is associated with the new lamps, the output light will probably exceed the average light from

the older, full wattage fluorescent lamps. If group relamping is instituted, labor costs will be reduced 80% and total operating costs approximately 5%. Group relamping, even with the first generation power saving fluorescents, can maintain as much, if not more, light for productivity as spot relamping with conventional tubes. When the reflector bulbs in baffled downlights burn out they should be replaced with lower wattage ellipsoidal reflector lamps.

What can be done with more efficient light sources? Replace incandescent general lighting with high pressure sodium lights except in mess halls, barracks, and lobbies. Replace all mercury lighting in shops, hangers, piers, parking lots, etc., with high pressure sodium lights. The payback period for the changeover is relatively short when power costs exceed 3¢/KWH.⁶ The golden-white color of the high pressure lamps is not objectionable. Low pressure sodium lights, despite their high efficiency, cannot be used indoors because the light emitted is a monochromatic yellow under which color differentiation is impossible. Moreover, the use of low pressure sodium vapor lamps within DOD is currently not authorized. Such lamps are all non-domestically manufactured; are proprietary, in that there are only two sources of manufacture, both foreign; are non-interchangeable, both physically and electrically; and require extraordinary means for disposal. They are considered unsuitable for exterior as well as interior applications within DOD for these reasons.

Avoid devices such as power saving buttons which are to be placed in the sockets of incandescent bulbs. They are merely half-wave silicon rectifiers. Tests on several manufacturers' samples gave identical results. A 100-watt incandescent bulb is reduced to 55 watts but the light output is reduced to 33% of the original light.¹⁰ The life of the bulb is prolonged but not to the almost eternal life predicted. Tungsten filament lamps fail more often from mechanical shock rather than burn-out after 1500 to 2000 hours. Long life bulbs are available for special uses such as exit lights and hard to get at sockets. For most purposes, the substitution of the next lower wattage bulb will be satisfactory and more cost effective than either using the button or a long-life bulb. Another device to avoid is the pulse or transient suppressor. This device, essentially a voltage clipper, doesn't do anything to save energy or to protect equipment from the line surges found on ordinary public utility lines.¹¹ The time of the surges is too short to do heating damage to equipment and the maximum height of the voltage pulse is too low to do insulation damage. National media ("60 minutes") has portrayed the ineffectiveness of the device and the Federal Trade Commission has tried to stop the sale of these devices because of the fraudulent claims made for them. However, they keep appearing anew under other names and with new sales forces. There are other power saving devices which operate as dimmers. Lamp current may be controlled by a number of dimming methods. These include thyratrons.

silicon-controlled rectifiers and other solid-state devices, variable inductors, autotransformers, saturable core reactors, and magnetic amplifiers. However, to be effective the cathodes of the lamps must be kept at the proper voltage regardless of the amount the lamp may be dimmed.¹² When the power to the lamp is reduced by 20% the light output will be reduced by approximately 33%. If the dimming circuit does not include a separate heater winding, apart from the voltage control of the arc, the life of the fluorescent tubes will be drastically curtailed. In fact, once you drop below 75% of rated cathode voltage, life simply drops to zero (theoretically). Cathode design accommodates for a small range of input voltages to permit proper hot spotting and adequate electron emission. Lowering the input voltage lowers both the heater current and arc voltage. Under such conditions, the lamps may not light at all, but if they do, the emissive coating on the lamp heaters will be stripped off. The ends of the lamps will blacken and the lamps and their ballasts will fail quickly. Operation below minimums is not satisfactory and should not be done. Even replacing preheat lamps (on preheat circuits) with rapid start lamps causes a loss of 25% of rated lamp life. The use of the new high efficiency lamps and ballasts is far more cost-effective. There are several automatic dimming devices on the market which purport to control the light from the lamps in accordance with the amount of light added by daylight. These controls have been on the market for too short a time to predict whether or not they will be cost-effective. If the method of dimming causes early failure of the lamps, or if the minimum time between electronic failures is short, they will not save either dollars or energy. And, if the control reacts to the light at or near the luminaire rather than at the work surface, the device may not provide proper light on the work surface. Each such device will have to be considered very carefully on its own merits before it can be recommended for use. Valid tests with correct instrumentation are necessary for verification and economic feasibility.

It is recommended that before you do anything else, you obtain a foot-candle meter and determine just what the lighting condition is in each situation. After that, and with due consideration of your logistics problems, you can more sanely approach the improvement of the efficiency of the post lighting system while maintaining the quality and quantity of lighting needed for efficient operation. Through the proper selection of lamps, luminaires, and even work area colors and surface reflectances, you can provide the proper illumination and job environment while conserving electrical energy. The attached pamphlet, "Getting the Most from Your Lighting Dollar," will help you make lighting modernization decisions in an informed and thoughtful manner.

TABLE 1. Comparison of Power Savings, Light Differences and Cost of Lamps

LAMPS	WATTAGE	LIGHT	COST*
2-F40 cool white (40 watt standard fluorescent)	100%	100%	\$ 0.74
2-F40 Lite white (high efficiency II)	85%	98%	1.96
2-F40 cool white (high efficiency)	85%	85%	0.99
1-Thrift/Mate 33 and 1-F40 CW***	61%	61%	5.36
1-Thrift/Mate 50 and 1-F40 CW***	48%	42%	5.62
1-Phantom Tube and 1-F40 CW	30%	25%	6.69 (4.77)**

NOTE: 1 = The replacement of conventional ballasts as they burn out with the new CBM ballasts will save approximately an additional 10% of the power used (old ballast loss = 16 watts, new ballast = 8 watts)

2 = High efficiency fluorescents should not be paired with TM or Phantom tubes

* = Cost is for both tubes in a two-unit fixture based on the latest GSA contract prices

*** = In two tube wraparound fixture
GSA contact price per tube in lots of less than 50 cases
(24 lamps/case)

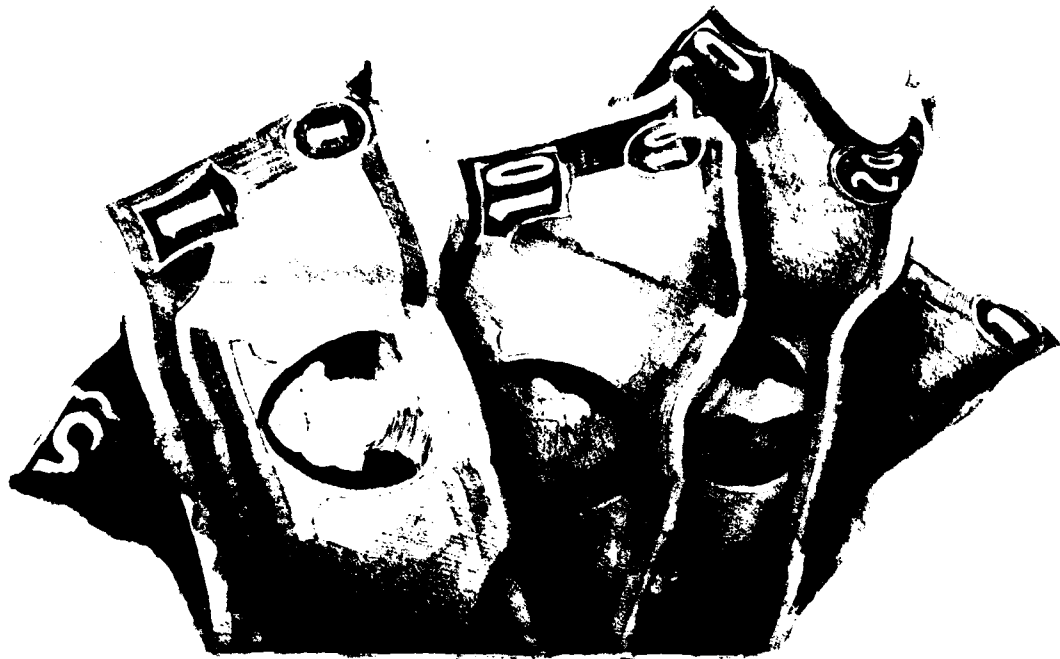
F40 CW	\$0.3712 (Westinghouse only)
F40 CW/SS	0.4950
F40 LW/RS/WM	0.9790
F40 LW/SS	0.9790
F40 CW/RS/RM33	4.99
F40 CW/RS/TM50	5.25
PT F40	6.32 (Phantom tube in lots of 1-3 cases (30 lamps/case)

** (\$4.40 in lots of over 32 cases)

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Getting the most from your lighting dollar

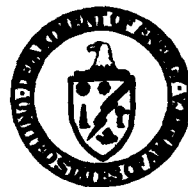


Our first goal is conservation. It is the cheapest, most practical way to meet our energy needs and to reduce our growing dependence on foreign supplies of oil. With proper planning, economic growth, enhanced job opportunities and a higher quality of life can result even while we eliminate the waste of energy.

**President Jimmy Carter
Before a Joint Session of Congress
April 20, 1977**



This report was prepared as an account of work sponsored by the National Lighting Bureau. The Department of Energy provided a technical review of the document's contents. The Department of Energy did not provide any funding for the development or publication of this document.



As you read through this booklet . . .

. . . you will find many ways in which you can readily improve the efficiency of your building or office lighting system while maintaining the quality and quantity of lighting needed for efficient operations. Through the proper selection of lamps, luminaires, associated electrical equipment, and even work area colors and surface reflectances, you can provide the proper illumination and job environment as you help the United States conserve valuable supplies of oil and gas and reduce the amount of expensive energy we have to import. While the amount of energy we use to produce light for our work environment is only a small part of our country's total energy needs, it may represent a significant percentage of energy use in your building. So, by making your lighting system more efficient, you probably can reduce the amount of your electricity bill.

Recognize that this booklet is not a comprehensive compilation of lighting design data. Rather, it is a general guide to what you can – and should – do to improve the efficiency and performance of your lighting system. There are numerous other information sources available to you from your state and local energy officials, consultants, utilities and suppliers. We urge you to use this wealth of data and resources to help you make lighting modernization decisions in an informed, thoughtful manner.

Recognize, too, that you should keep current with new developments in the field of lighting system design and research. This is especially true when it comes to the relationship of light, vision, and productivity, a matter subject to continuing investigation.

Light is for people

Everything we do every day of our lives involves use of our eyes.

In order to see, we need light. Yet most of us are almost completely unaware of light. We take it for granted. It is an essential part of a typical office layout, clothing store, drugstore, flower shop, lumber yard, law office, and doctor's office. We have lighting in food stores, barber shops and beauty parlors, and in museums, theaters, and amusement centers.

And it is there for a good reason—to help people work or play better, faster and more accurately.

Like desks, chairs, counters, pencils, and papers—even the very buildings we work in—lighting is a production tool. Good light is essential to everything we do. Unnecessary or improper lighting is wasteful and costly.

Too often a lighting designer is forced to use the least expensive design methods. This approach has led to widespread use of uniform lighting systems in many older buildings. These systems put out the same amount of light and the same kind of light in a

regular pattern throughout a building.

But light is for people; not buildings. If we put in uniform lighting, we may not use lighting most efficiently, and it gets monotonous. We must study our offices and places of business and our lighting needs to put the right amount and kind of light where it is needed, to provide variation, and to enhance the form of the room and the building. The potential results are great: you'll save money and energy, at no sacrifice in your ability to do your job, and without reducing your productivity. In fact, productivity may be improved.

How much and what kind of light should you have? There is no single answer. More light is needed for some tasks than for others. In general, we see best when the light applied is appropriate to the task we are doing.

This booklet will examine many aspects of lighting and how you can determine what can be done right now to get your job or task done with the right amount of light and still save energy and money.



Lighting facts

People waste lighting energy

We use lights and lighting systems to help us do our jobs in the best, most productive way. They are designed, installed, and maintained by people and, therefore, they are subject to use and misuse by people. Although lighting systems use energy, people have ultimate control and responsibility. We make the decisions on the type of equipment used and how it is used. We can make wise choices about the systems we use and the energy-efficient lighting available to us, or go on blaming the lights for wasting our energy.

Lighting affects productivity

Well over 80% of our impressions are visual. If we can't see accurately and quickly, the impressions our brain gets and processes may be distorted. When they are, we can, and do, make errors. Recent studies have established a definite relationship between lighting and employee productivity. In most cases, only a small increase in worker productivity can justify a good quality lighting system.

Lamps of the same wattage may not provide the same amount of efficiency or light

Efficiency of lamps commonly used indoors varies considerably—from less than 16 lumens per watt to 140 lumens per watt. For example, a 75-watt inside-frosted incandescent lamp produces only 1,190 lumens (15.9 lumens/watt). A commonly used eight-foot, standard cool-white fluorescent lamp uses 75 watts and produces 6,300 lumens (84 lumens/watt), and the energy-saving version uses 60 watts and produces 5,600 lumens (93.3 lumens/watt). A 70-watt high pressure sodium lamp produces 5,800 lumens (82.9 lumens/watt), and the 1,000-watt versions produce 140,000 lumens (140 lumens/watt).

Generally speaking, "long-life" incandescent lamps are less efficient than comparable standard lamps.

Different age groups may need different amounts of light

As we get older, our need for light may change due to physiological changes in our eyes. Some older people need more light than younger people and there may be an enormous difference between visual capabilities. Also, where there is a choice, higher task contrast may have to be provided.

Uniform lighting, although popular, may not be best

In many cases, uniform lighting wastes energy. The light level on the task should be sufficient for you to see and do the job required. Adjacent surroundings should not be too dark. Luminaires should be chosen and placed so that they put the required quality and quantity of light on the task. Lights that don't contribute to illuminating the task, or that are not required to provide the minimum brightness ratio for the surroundings, should be turned off or removed.

If it looks too bright, the amount of illumination may not be the problem

Bright lights are a source of glare independent of how much light they deliver to the task. It's the glare that may actually hinder your ability to see, not the level of illumination. Also, because bright light can be distracting, it may reduce your productivity.

Removing the diffuser from a luminaire is not a good way to save energy

Removing the diffuser (or shielding) from the bottom of a luminaire is not a good idea because it can make the fixture become a source of glare. It also changes the light distribution pattern that otherwise is controlled by the diffuser.

High intensity discharge lighting is usually less expensive

On an individual basis, the luminaires and lamps used in high-intensity discharge (HID) lighting systems generally cost more than incandescent and fluorescent types. Because fewer lamps and fixtures generally are needed, however, the initial cost of an HID system may actually be less than that of an incandescent or fluorescent one. In addition, the operating costs of HID systems tend to be lower than those of others due both to reduced equipment requirements and the generally superior efficiencies of most HID lamps. In any case, the best way to determine which lighting system has the lowest cost is to make a complete life-cycle or annual owning and operating cost study.

Some lamps should be replaced before they burn out

Over the life of a lamp—any lamp—the light output drops off with use. In some cases it may be more economical for you to replace the lamp before burnout because you are not getting the amount of light that you are paying for. An important fact to remember: the cost of energy represents about 90% of the cost of light over the life of a lamp. You should develop a lighting maintenance program that indicates when lamps should be replaced and luminaires cleaned.

Even if you can see what you are doing, you may not have enough light

The eye is a remarkable device. It can adapt to most any light situation. Whether it is functioning effectively under a given set of conditions is another matter. Although you can see what you're doing—the task—poor lighting can keep you from doing it in the most effective manner.

Four fundamental factors should be considered to evaluate the lighting required by a task. The first factor is the *TIME* it takes to see. Adequate light helps a worker complete the task faster, without errors. The second factor is *SIZE* of the detail. The smaller something is, the harder it is to see. The importance of size is evident in reading small print. The third factor is *CONTRAST* between details and their background. Tasks with low or poor contrast, such as multiple carbon copies that are common in many office tasks, are harder to see than high contrast tasks, such as original typed material. The last factor is *BRIGHTNESS*, or the amount of light reflected from a task.

This is usually the most controllable factor, because the first three are often set by the type of work that has to be done. By putting more light on a task, its brightness or reflected light can be improved, and, thus, its visibility, despite small size or poor contrast.



Lighting may affect workers' motivation

Studies, both in England and the United States, support the concept of psychological response to the lighted environment. Just as an overcast day has an effect on how we feel and respond, so too do dimly lighted areas, areas with large differences in brightness levels, and even very bright rooms. The best lighting system is one in which the lighting level on the task is geared to that task, the brightness ratios of the areas are controlled, the colors and reflectances of the ceiling, walls and floor are carefully chosen, and the people in the room are unaware of the lighting system because everything is "just right."

Lights should be turned off when not needed

As a general rule, you should turn off lights—even fluorescent—if you plan to be out of a work area for more than a few minutes. The money you save by conserving energy quickly compensates for the small wear and tear on lamps. If your wiring does not permit local switching of lights, it may be desirable to have additional switches installed to control lights in smaller work areas, perhaps down to individual offices.

Definitions-

What do we mean when we say . . .

Several of the most commonly used terms include . . .

Brightness: In common usage, brightness is the intensity of the sensation that results from viewing a surface or space from which light comes into the eye. The footlambert is a measure of brightness.

Footcandle/Illumination: A measure of light striking a surface one square foot in area on which one unit of light (lumen) is uniformly distributed. It is a measure of the quantity of light falling on a task or work surface per unit of area.

Glare: Excessive brightness. There are two types of glare: direct and reflected. Direct glare occurs when a source of brightness, such as an exposed lamp, is in the line of vision. Reflected glare occurs when brightness from the source is reflected on a shiny surface in the line of vision.

Lamp: A term that refers to light sources that are commonly called bulbs or tubes.

Lumen: A unit of light output from a lamp.

Luminaire: A complete lighting unit that consists of one or more lamps and ballast, if needed, together with other parts designed to distribute light, position and protect the lamps, and connect the lamps to the power sources.

Other lighting terms are:

Ballast: A device used with an electric discharge lamp (fluorescent and HID) to obtain the necessary electric circuit conditions (voltage and current) to start and operate the lamp.

Coefficient of Utilization: A ratio of the light delivered from a luminaire to the work surface

compared to the total light output emitted by the lamp. This ratio changes with room conditions, and configuration of the fixture.

Contrast: The relationship between the brightness of an object and its immediate background. An example of this would be the relationship between the letters printed on this page and the page itself. An example of poor contrast would be a third or fourth carbon copy of a purchase order or computer printout.

Diffuser: A device commonly put on the bottom and sides of a luminaire to redirect or spread the light from a source. It is used to control the brightness of the source and, in many cases, the direction of light emitted by the luminaire. (See also, Lens, Louver).

Lens: A glass or plastic shield that covers the bottom, and sometimes sides, of a luminaire to control the direction and brightness of the light as it comes out of the luminaire. (See also Diffuser, Louver).

Louver: A series of baffles arranged in a geometric pattern. It is used to shield a lamp from view at certain angles to avoid glare from the bare lamp.

Nonuniform Lighting: A system that has lighting located with respect to the tasks, so more lighting falls on these tasks than on surrounding areas.

Reflector: A device used to redirect the light from a lamp or luminaire by the process of reflection.

Task Lighting: The lighting, or amount of light, that falls on a given viewing task or object.

Veiling Reflection: Reflection of light from an object or task that partially or totally obscures the details to be seen by reducing the contrast between the object or task and its background.

Lighting and

People need light to see, and most people must see to do their jobs. While this may seem obvious, the relationship between light, vision, visibility, the visual task, the worker, and his or her productivity is not so obvious. If too little lighting is used, reduced output and employee errors may result, as shown in Figures 1 and 2. If too much lighting is used the work gets done, but operating costs are needlessly high and profits suffer. In between these extremes, there is some point at which the amount and kind of lighting used will help maximize profits by helping to maximize productivity.

Worker productivity is a very complex subject that involves numerous different factors. Although lighting is an important part of productivity, the specific lighting-to-productivity relationship may often be masked by the other elements involved. However, in controlled laboratory experiments that isolate lighting alone, it has been shown conclusively that improved visibility results in improved worker performance.

Some very recent job-related indicators also are helpful. One is a check-reading test designed by the Federal Energy Administration and conducted at the vision research laboratories at Ohio State University.¹ In this study, handwritten numbers, some of which were wrong, were compared to a correct check list. The task is similar to that in almost any financial operation. The lighting levels were varied randomly and the variables that affect productivity were carefully controlled. The results show that it takes less time to do the same amount of work under better seeing conditions. And it is an accepted fact that increased productivity generally saves more dollars in output costs than are expended for the additional lighting fixtures or energy costs.

But it should be emphasized that the cost of fixtures and energy needed by a lighting system that boosts productivity may be no more than that of a

¹ Lighting and Thermal Operations: Energy Conservation Principles Applied to Office Lighting, Conservation Paper Number 18, IV (C) (2) (c), "Check Reading and Verification Experiment," Federal Energy Administration.

COST ANALYSIS BASED ON TIME REQUIRED TO PERFORM WORK WHEN LIGHTING IS REDUCED FROM 150 TO 50 FOOTCANDLES.

FC	RELATIVE TIME FOR SAME WORK	LABOR COST FOR SAME WORK (\$/SQ. FT./YR.)	TOTAL COST OF LIGHT (\$/SQ. FT./YR.)	TOTAL NET COST (\$/SQ. FT./YR.)	NET LOSS (\$/SQ. FT./YR.)
150	1.0000	\$ 90.00	\$1.05	\$ 91.05	
50	1.136	\$102.24	\$0.35	\$102.59	\$11.54
		\$ 12.24	\$0.70		

Figure 1: A study of keypunch performance showed an increase of 13.6% in the time required to perform the same work when lighting was reduced from 150 to 50 footcandles.

Productivity

system that is not as good. In some cases, the cost may even be less.

Another experience—in this case a Social Security Administration building in Baltimore, Maryland²—indicated that reducing the lighting level without considering the lighting needs of the task resulted in a significant loss of production (processing of key-punch cards). During this time, employees complained of headaches and eye fatigue. When the lighting level was restored, output was returned to the original production level.

But the number of units produced is only one side of the productivity coin. The other side is a reduction in the error rate. In the FEA check-reading study cited earlier there also was a 12% reduction in errors when the lighting level was appropriately

adjusted. This is significant because an error that slips through to a customer's invoice or report filed with the government can take hours and even days to correct. In the case of an invoice error, the customer becomes upset and inconvenienced. In fact, the error can even result in loss of that customer.

The way people perceive their working conditions also relates to their motivation. With better visibility, people expend less effort. If visibility is poor, people feel that they have to expend more effort. This is true for younger workers, but even more important for older people, who, in general, are more susceptible to fatigue. And the quality of lighting is more important for older workers, too, because of physical changes to their eyes caused by the aging process. Many older people cannot see fine detail as well as younger people, and often they are bothered more by glare.

²Electrical World, June 15, 1975.

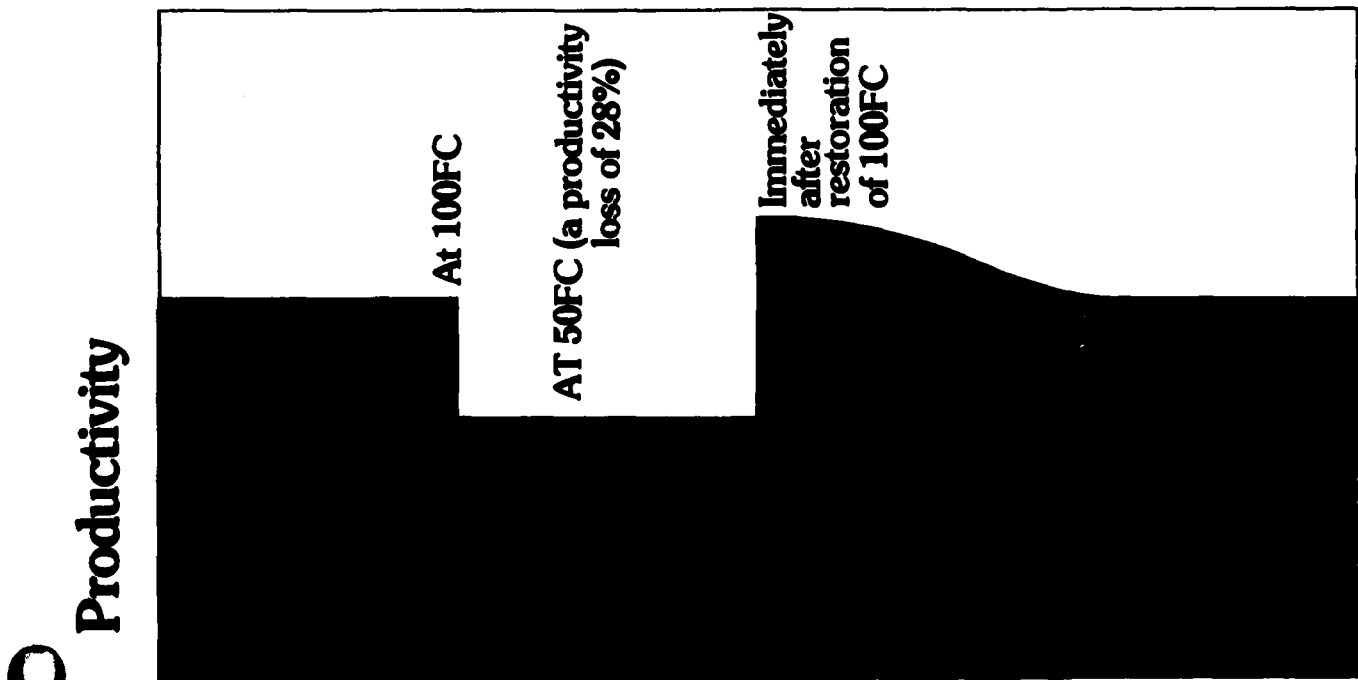


Figure 2: When the illumination level in a Social Security Administration office was reduced from 100FC to 50FC, the productivity rate fell by 28%. Productivity jumped when the 100FC lighting level was restored, then receded with time to the original rate.

More efficient It's your

Lamps and the fixtures they are used in affect not only the performance of the visual task, but also the economics of the system, the building module, the electrical wiring system, and — because all lighting energy is converted to heat — the heating, ventilating, and air-conditioning (HVAC) system.

Today, there are so many different light sources available that you should be able to choose the right energy-efficient light source for a given task. Not only are there more varieties, but now there are new groups of lamps with electrical and light output characteristics far superior to the familiar incandescent and fluorescent lamps. And today, with our important concern for energy efficiency, you'll find numerous sources of expert advice from your local utility, electrical equipment distributors and manufacturers, electrical contractors, and consulting engineers.

For most indoor commercial and industrial applications, lamps can be divided into several categories: incandescent, fluorescent, and high intensity discharge (mercury vapor, metal halide, high pressure sodium, and low pressure sodium). Their basic characteristics are shown in Figure 3. At one extreme is the incandescent lamp, the least expensive to buy, but the least efficient in converting energy to light. Its main benefits are low cost, color, and ease of installation. At the other extreme is the low pressure sodium lamp. Although it seldom is used for indoor applications, it is the most efficient converter of elec-

tricity to light. The other light sources fall between these extremes.

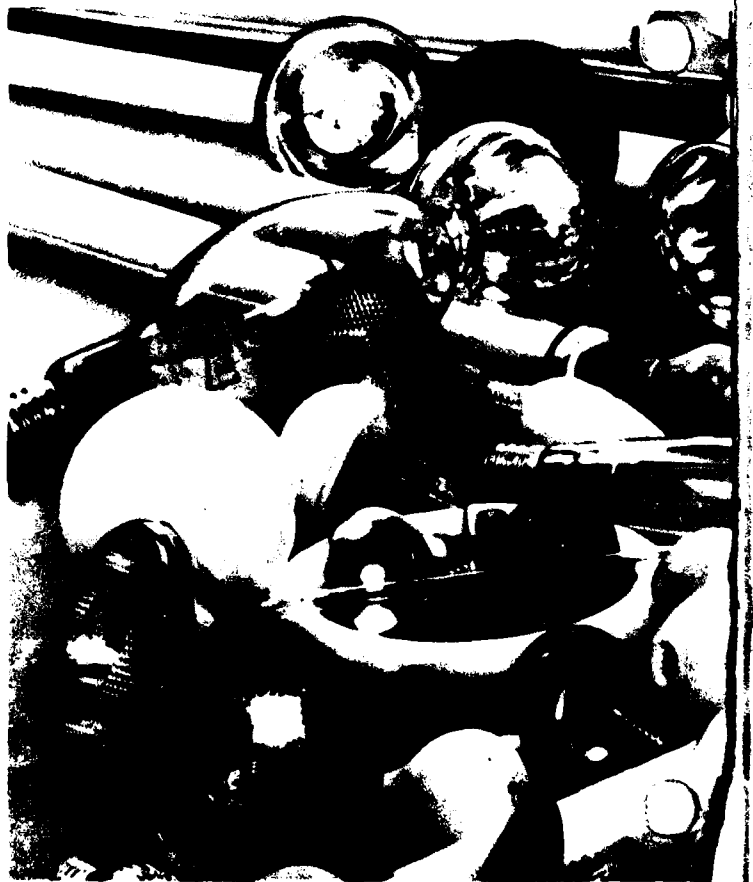
While efficiency alone should not be your only consideration in the selection of lamp type, it is an important characteristic. In most cases, a more efficient light source can be substituted for a less efficient source with little if any loss in task visibility or color rendition. The total annual owning and operating cost (life-cycle costing) savings achieved will help to lower your electric utility bill.

What is lamp efficiency?

You don't have to be told your electricity costs are increasing. What you want to know is, "What can

Type Lamp	Lamp Watts	Initial Lumens	Rated Life Hours
Incandescent	200	4,000	750
Fluorescent	40.7	3,250	12-20,000
Mercury Vapor	400	23,000	16-24,000
Self-Ballasted Mercury Vapor	450	14,500	16,000
Metal Halide	400	34,000	7.5-15,000
High Pressure Sodium	400	50,000	20-24,000
Low Pressure Sodium	180	33,000	18,000

Figure 3: Characteristics of selected lamps.

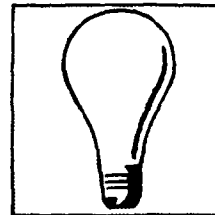


light sources: choice

"I do about it?" One thing you can do is use a more efficient light source. To do this, evaluate lamp efficiency, which is measured in *lumens per watt*. Lumens are a measure of light output from the lamp. Watts are a measure of electrical energy input. Thus, the more lumens which a lamp produces from each watt of input, the more efficient it is. The typical ranges in efficiency for the six main lamp categories are shown in Figure 4.

You can compare *lumens per watt* to another important energy efficiency indicator, *miles per gallon*: the efficiency with which a car uses gasoline.

Just as different cars have different efficiency ratings, so do lamps.



Incandescent Lamps

The incandescent lamp can be considered the basic light source, because it is the one in most common use. It also is the lamp category with the poorest efficiency (lowest lumens per

watt ratings).

The popularity of the incandescent lamp is due to the simplicity with which it can be used and the low price of both the lamp and the fixture. Also, the lamp requires no special equipment, such as a ballast, to modify the characteristics of its power supply (electricity to the fixture).

The most common types of incandescent lamps are: the "A" or arbitrary bulb-shaped lamp; the "PS" or pear-shaped lamp; the "R" or reflector lamp; the "PAR" or sealed-beam lamp, and the tungsten-halogen lamp.

The tungsten-halogen lamp, like the other incandescent lamps, uses a tungsten filament as the light source. Unlike others, however, a "family of elements" known as halogens is put into the lamp. The halogens prevent lamp walls from darkening as quickly as those of other incandescent lamps, so more light is available to the task or work surface. In other words, the light output of tungsten-halogen

Lumens per watt

Incandescent	— 20
Fluorescent	— 83
Mercury Vapor	— 63
Metal Halide	— 115
High Pressure Sodium	— 140
Low Pressure Sodium	— 188

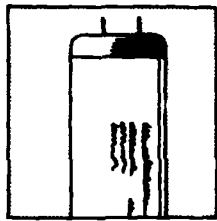
Figure 4: Comparative efficiencies (in lumens per watt) of different lamp types.



lamps does not drop off as rapidly as the light output of other incandescent lamps.

The efficiency of incandescent lamps increases as lamp wattage increases. This makes it possible to save on both energy and fixture costs whenever you can use one higher wattage lamp instead of two lower wattage lamps. For example, one 100-watt GS (general service) lamp produces more light (1740 lumens) than two 60-watt GS lamps (860 lumens each for a total of 1,720 lumens).

The specific type of incandescent lamp used and the kind of fixture involved also make a difference. For example, a 75-watt ellipsoidal reflector lamp delivers more light in a stack-baffled downlight than a 150-watt R-40 lamp.



Fluorescent Lamps

The fluorescent lamp is the second most common light source. It's found in homes, stores, offices and industrial plants. It is easily distinguished by its tubular design – circular,

straight or bent in a "U" shape. In operation, an electric arc is drawn along the length of the tube. The ultraviolet light produced by the arc activates a phosphor coating on the inside wall of the tube, causing light to be produced.

Unlike the incandescent lamp, the fluorescent lamp requires a ballast to strike the electric arc in the tube initially and to maintain the proper voltage and current to the lamp to maintain that arc. Proper ballast selection is important to optimum light output and lamp life.

Lamp sizes range from four watts to 215 watts. The efficiency (lumens per watt) of a lamp increases with lamp length (from four feet to eight feet). The reduced wattage fluorescent lamps introduced in the last few years use from 10 percent to 20 percent less wattage than conventional fluorescent lamps, depending on size.

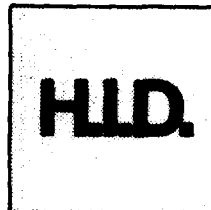
For most applications, the cool white and warm

white lamps provide very acceptable color and energy efficiency ratings.

Like the incandescent lamp, the fluorescent lamp can be operated to produce lower light levels. This is done with special ballasts and controls for dimming from 100% to 0% of output, or by multi-level ballasts that step down light output to specific levels (e.g., 75%, 50%, etc.).

Fluorescent lamp life is rated according to the number of operating hours per start, for example, 20,000 hours at three hours operation per start. The greater the number of hours operated per start, the greater the lamp life. Because fluorescent lamp life ratings have increased, however, the number of times you turn a lamp on or off has become less important.

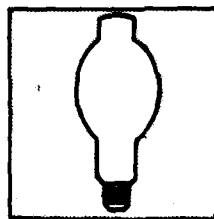
As a general rule, if a space is to be unoccupied for more than a few minutes, you should turn the lamps off.



High Intensity Discharge (HID) Lamps

"High intensity discharge" or "HID" is the term commonly used to designate four distinct types of lamps that actually have very little in common. The four

types of lamps are mercury vapor, metal halide, high pressure sodium, and low pressure sodium. Each requires a few minutes (one to seven) to come up to full output. Also, if power to the lamp is lost or turned off, the arc tube must cool to a given temperature before the arc can be restripped and light produced. Up to seven minutes (for mercury vapor lamps) may be required.



Mercury Vapor Lamps

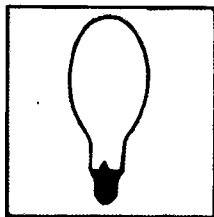
The mercury vapor lamp produces light when the electrical current passes through a small amount of mercury vapor. The lamp consists of two glass envelopes: an inner envelope in

which the arc is struck, and an outer or protective envelope. The mercury vapor lamp, like the fluorescent lamp, requires a ballast designed for its specific use. Special ballasts are required for dimming.

Mercury vapor lamps have found greatest use in industrial applications and outdoor lighting, because of their low cost and long life (16,000 to 24,000 hours).

The color rendering qualities of the mercury vapor lamp are not as good as those of incandescent and fluorescent lamps. A significant portion of the energy radiated is in the ultraviolet region. Through use of phosphor coatings on the inside of the outer envelope, some of this energy is converted to visible light. As a result, the color rendition and lamp efficiency of phosphor-coated mercury vapor lamps is better than that of their clear (no phosphor coating) counterparts. The development of phosphor-coated mercury vapor lamps has enabled lighting designers to use this type of HID lighting for many indoor applications, in lobbies and hallways, retail display areas, and many others.

Mercury vapor lamp sizes range from 40 to 1,000 watts.



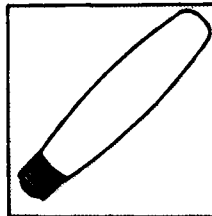
Metal Halide Lamps

The metal halide (MH) lamp is very similar in construction to the mercury vapor lamp. The major difference is that the metal halide lamp contains various metal halide additives in addition

to mercury vapor.

The efficiency of metal halide lamps is from 1.5 to 2 times that of mercury vapor lamps. Almost all varieties of available "white light" metal halide lamps produce color rendering which is equal, or superior, to presently available mercury vapor lamps.

Metal halide lamp sizes range from 175 to 1,500 watts. Ballasts designed specifically for metal halide lamps must be used.



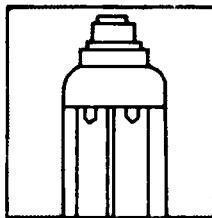
High Pressure Sodium Lamps

The high pressure sodium (HPS) lamp has the highest lamp efficiency of all lamps normally used indoors. It produces light when electricity passes through a sodium vapor. This lamp also

has two envelopes, the inner one being made of a polycrystalline alumina in which the light-producing arc is struck. The outer envelope is protective, and may either be clear or coated.

Because the sodium in the lamp is pressurized, the light produced is not the characteristic bright yellow associated with sodium, but rather a "golden white" light. Although the HPS lamp first found its principal use in street and outdoor lighting, it now is a readily accepted light source in industrial plants. It also is being used in many commercial and institutional applications as well.

HPS lamp sizes range from 70 to 1,000 watts. Ballasts designed specifically for high pressure sodium lamps must be used.



Low Pressure Sodium Lamps

The low pressure sodium (LPS) lamp is the most efficient of all, providing up to 183 lumens per watt. Unfortunately, its use indoors is severely restricted because it has a

monochromatic light output. What this means, essentially, is that reds, blues and other colors illustrated by an LPS light source all appear as tones of gray.

Low pressure sodium lamps range in size from 35 watts to 180 watts. Ballasts designed specifically for LPS must be used. The primary use of the lamps is currently for street and highway lighting as well as outdoor area and security lighting. Indoor applications such as warehouses are practical where color is not important.

Getting more from y

In almost all cases, it is possible to make some very simple changes that will improve the efficiency and the quality of illumination of your present lighting system. In making these changes, however, it is important to consider the benefits of some of the more extensive modifications. Depending on your point of view, a \$1,000 modification that pays for itself (in energy cost savings) in just one year may be less expensive than a \$100 modification that won't pay for itself for five years.

Here are some of the techniques you can use to get more from your present lighting system.

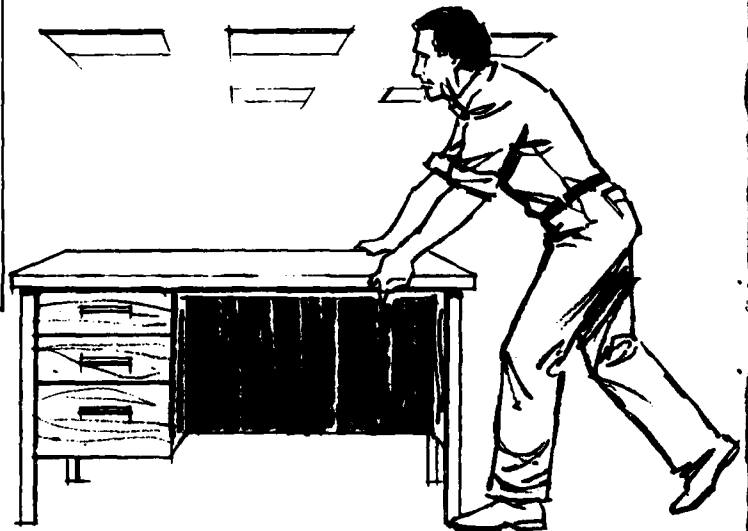
	9-5	5-12	12-6	6-9
A	ON	ON	OFF	ON
B	ON	OFF	OFF	OFF
C	ON	OFF	ON	OFF
D	OFF	ON	ON	ON
E	OFF	OFF	OFF	ON

Establish a lighting schedule

If your building is often used after-hours, either by late shifts or by maintenance personnel, consider developing a lighting schedule that tells people which lights should be on or off at certain times. All too often, for example, custodial personnel will turn on all lights in a space, even though just one or two are needed. In some cases it may be worthwhile to color-code various switches, so people know that switches painted a certain color should not be activated after 5 PM.

Reorient work stations

One of the main problems with uniform lighting is that it often provides more light than is needed to perform some of the tasks in the illuminated space. If all the tasks in the space require generally the same level of illumination, however, very little of the lighting is wasted. Can you reorient work stations in your building to take maximum advantage of an existing uniform system? If so, you may be able to save energy and money by grouping tasks requiring the same lighting levels and adjusting the light output of the system accordingly. Additional savings may be possible by placing those work stations requiring the highest level of illumination near windows, to take advantage of natural day-lighting.



our present system

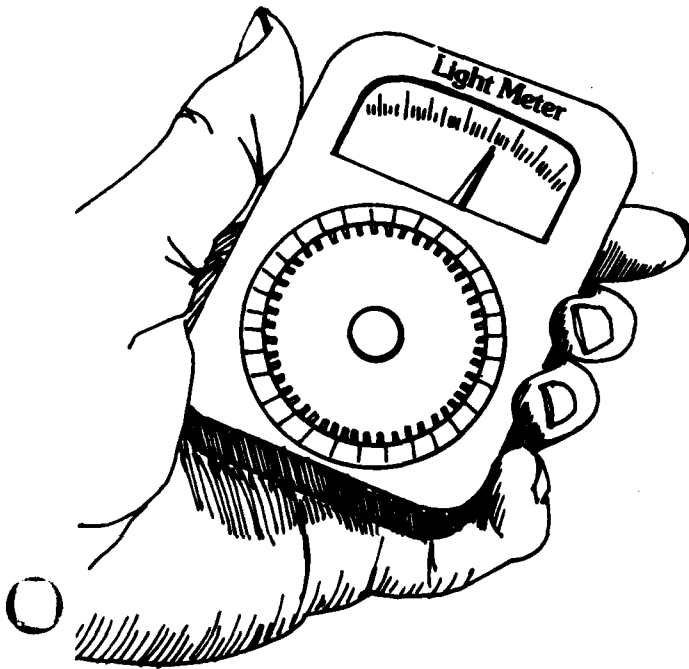
Campaign for better use

One of the major causes of lighting energy waste is leaving lights on when they're not needed. Campaign for better use with signs, posters, meetings with employees, and person-to-person individual contact. Light switch stickers which remind people to turn off lights when they leave the room can be especially effective.



Modify illumination level

Modifying the illumination level, or changing the amount of light produced by a system or fixture,



can be done by: changing the type or quantity of lamps used, changing the type or quantity of luminaires, or by adding new controls and associated equipment. In any case, illumination levels should not be adjusted at all if a change may result in lowered productivity, safety or security. Before adjusting illumination levels, therefore, the best procedure is to determine the level of illumination needed, and then conduct a lighting survey to identify the levels that are currently being supplied. This survey can be performed quickly and easily by using a standard lightmeter, and following the manufacturer's instructions for use. The condition of lamps, fixtures, and room surfaces also should be considered.

Use more efficient lamps

Lamps have already been discussed at some length. In general, the lamp that provides the most lumens per watt will be the least expensive in the long run, due to the ever-increasing cost of energy. Because more than efficiency is involved, however, many factors have to be considered before an extensive relamping program is started. Some of these factors include: the type of fixtures installed and the types of lamps that can fit into them; the light output of the lamps in relation to the amount of illumination needed; the color rendering quality of the lamps; the cost of the lamps; the cost of modifying fixtures to accept a new type of lamp, and the cost of new fixtures.

In determining what type of lamps to use in a lamp retrofit program, bear in mind that manufacturers have made significant progress in recent years. More efficient lamps of the same kind as are now installed can be used in the same fixture. In addition, certain types of lamps that ordinarily require a special fixture or ballast have been made so they are compatible with another type of luminaire.

**Standard
75-Watt 8-Foot Fluorescent, 84 L/W**

**Energy Saving
60-Watt 8-Foot Fluorescent, 93.3 L/W**

Remove unnecessary lamps

A lamp is unnecessary *only* if it can be removed without impairing the lighting system's ability to meet the illumination required to support worker productivity. This means that, once lamps are removed, the lighting system still can provide the level of illumination needed, free of glare, shadows or other undesirable viewing conditions.

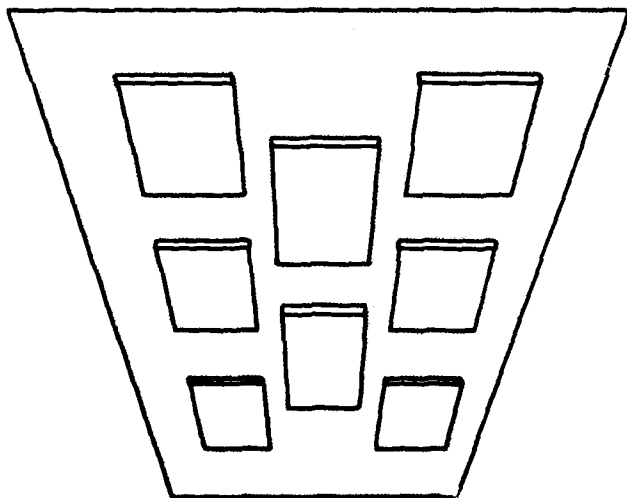
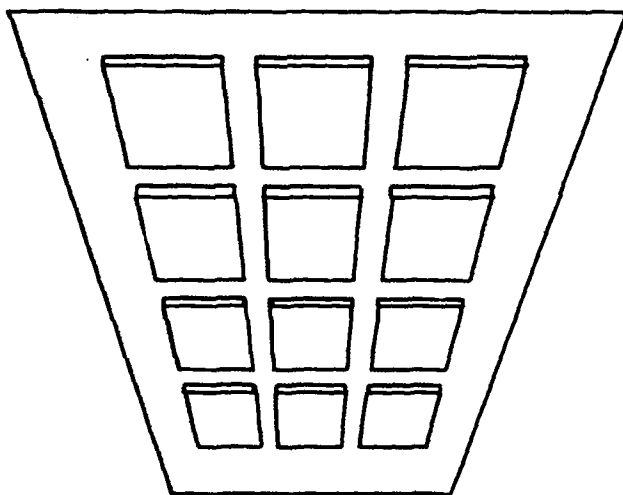
When removing fluorescent or high intensity discharge lamps, also remove the ballast, or disconnect it in place. If it is left connected to the power source it will continue to consume energy even though it serves no useful purpose. An alter-

native is to remove one lamp and insert a capacitor fluorescent lamp substitute device. When two-lamp fluorescent fixtures are mounted in a row and maintenance of a uniform system still is desired, remove lamps in alternate fixtures of the row (rather than removing one entire row) to help maintain quality lighting. Be sure to check the level of illumination once lamps are removed. It may be necessary to replace some of the remaining lamps with similar lamps having higher output. This technique will take away little from your total energy savings, and will help ensure that the system continues to provide adequate lighting.



Modify existing luminaires and their location

There are several effective ways to modify luminaires. When the luminaires involved are outdated or damaged, however, the most effective "modification" is replacement. A modern luminaire that has good cleaning capabilities and that uses

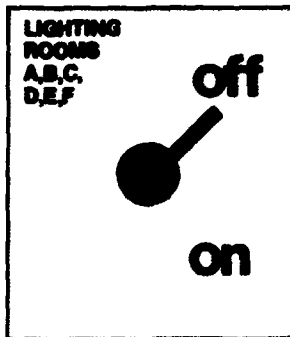


high efficiency lamps with good lumen maintenance characteristics very often will pay for itself in a short period of time. More details on what to look for in a luminaire are provided elsewhere in this publication, starting on page 19.

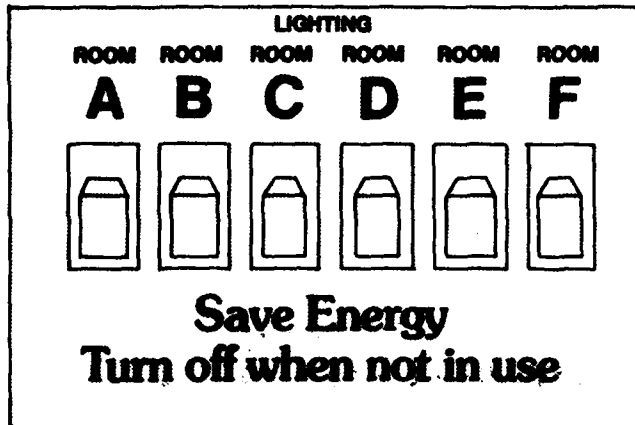
If an existing luminaire is not providing enough light, and it cannot be made to provide enough even through replacement of lamps, look into the possibility of lowering the luminaire. It may be enough to provide the illumination level needed for the task. Naturally, also consider the use of a portable desk lamp, which may be enough to do the job without modifying the luminaire at all.

If the luminaire and work station are oriented so that the person performing the task must deal with veiling reflections, consider moving the luminaire, but not before you first consider the effect of moving the work station. When possible, try to orient work stations and luminaires so the light from the luminaire falls on the task from the side. Research has shown that light from a luminaire that is above and in front of a work station tends to create veiling reflections.

In some cases, luminaire efficiency can be improved substantially by changing the lens. Discolored plastic lenses, for example, rob you of the light you are paying for. But even a lens that is in good condition may be inadequate for your needs. Look into changing luminaire lenses to one of the several different types now available that provides special light distribution patterns. For example, linear and radial batwing lenses, parabolic louvers and light polarizing materials may be able to provide better task visibility with the same or even reduced wattage. Competent technical advice is needed in this area before any decision is made, however, to determine which specific kind of lens is best for a particular lighting system and work environment involved. Be especially careful of replacing a lens with one that is much heavier. The luminaire may not be designed to handle the extra weight.



**MORE CONTROL
MEANS MORE
OPPORTUNITY
TO SAVE
ENERGY**



Modify controls

Control modifications can result in substantial cost and energy savings. In many cases, a building's light switching system was designed so that the central panel board is the only means of controlling large blocks of lighting. This arrangement presents no problem during the day, when the space is filled with workers. However, if just one or two workers stay after hours, all the luminaires in the space may have to be on, because there is no way to energize only the three or four that are needed. Localized controls, such as those near doorways that control small groups of luminaires, can be very effective. Although this kind of switching modification may be somewhat expensive, in many cases the payback—the amount of time required for savings to equal installation cost—is very short.

Other control modifications also are possible. For example, by adding dimming controls to a uniform lighting system, you can almost achieve the same benefits provided by a nonuniform system. This is especially true in the case of incandescent lighting, where dimming systems can be added easily at low cost.

In some situations photocell switching also can

be useful. In the case of spaces that receive a lot of daylighting, for example, a photocell can be used to automatically turn off certain luminaires when daylighting illumination reaches a certain level.

Change ballasts

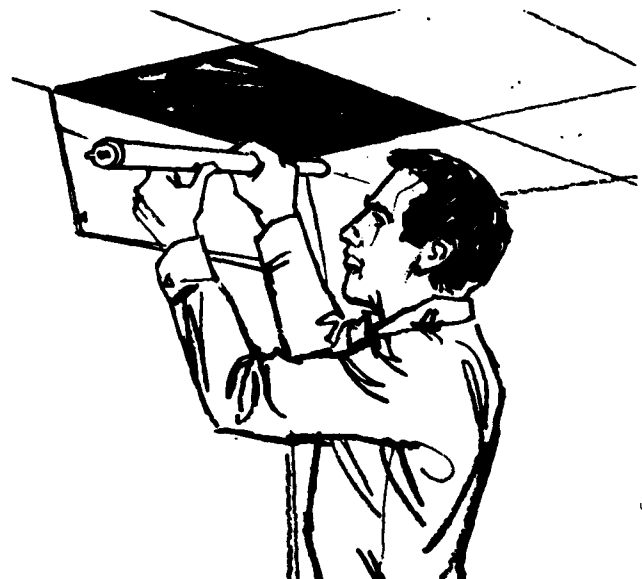
New types of ballasts now available can reduce lighting energy consumption by as much as 8 percent, without loss of light. Other new ballasts, that reduce light output to a small degree, can cut lighting energy consumption by as much as 18 percent. As such, replacing ballasts should be considered an effective lighting energy management option that can be implemented on a group rebalasting basis, or integrated into routine lighting maintenance operations.

In any event, rebalasting should be considered along with other options. If you decide to add multi-level or dimming controls, for example, special ballasts will be required.

Improve maintenance

In many cases, changed maintenance programs and procedures can result in substantial improvements. Simple techniques such as cleaning luminaires, lamps and lenses on a regular basis; following relamping schedules; cleaning surfaces in the illuminated space, and other techniques improve the quantity and quality of illumination created by the existing system, and so offer opportunities for both cost and energy savings.

This subject is discussed in more detail starting on page 21 of this publication.



Lighting in remodeling and new construction

Where lighting is concerned, the approach to remodeling is significantly different from new construction. In both instances, however, you'll find considerable expert help available and easy to get from manufacturers, lighting consultants, or electrical contractors.

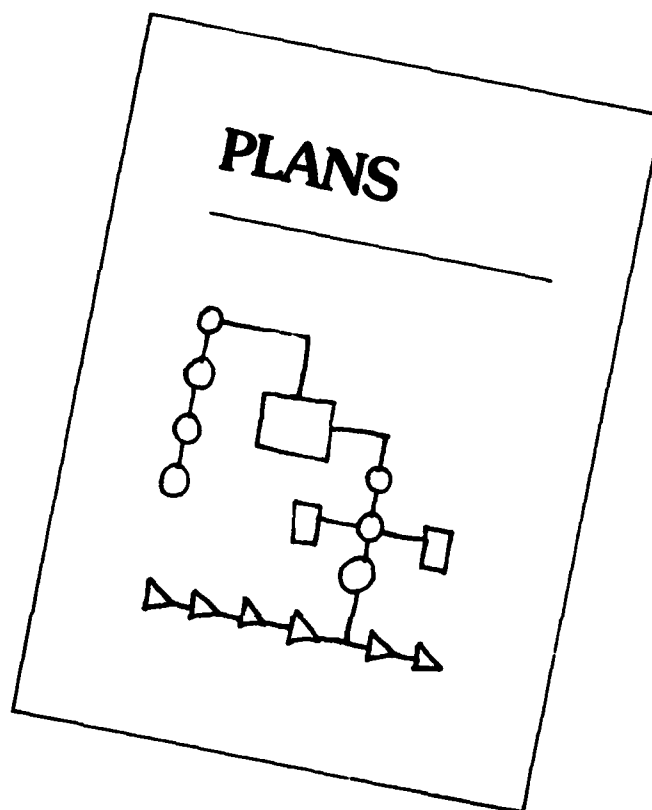
When remodeling, the basic lighting system usually remains in place. Typical modifications include rewiring for better control, substitution of more efficient light sources for less efficient ones, and relocation of existing fixtures to get better lighting on the task, and to eliminate glare, shadows, and unnecessary high or low levels of light. Nonetheless, when it comes to remodeling, what is in place is a major consideration in what, if any, changes can be made.

New construction gives you the opportunity of designing a lighting system to meet the task or working needs of the people who will occupy the space in question without consideration of an existing lighting system. Here, the lighting designer has greater flexibility to choose light sources and fixtures for maximum efficiency, color, style, architectural features, etc.

New construction also presents some basic problems. One of these is that the position of work stations seldom is known before a building is occupied and, in many cases, the type of work to be performed in a given space also is unknown. The same applies to the color and texture of walls and floors, furniture and furnishings to be used, etc., all of which influence design of the lighting system.

Until the last few years, lighting design problems associated with new construction made it virtually

impossible to design a nonuniform lighting system. And even when the needed information was available, use of a nonuniform system was considered "risky" since tasks performed in a given space often are changed. New types of lighting systems have been introduced, however, that enable the designer to specify a flexible system that can be adjusted from



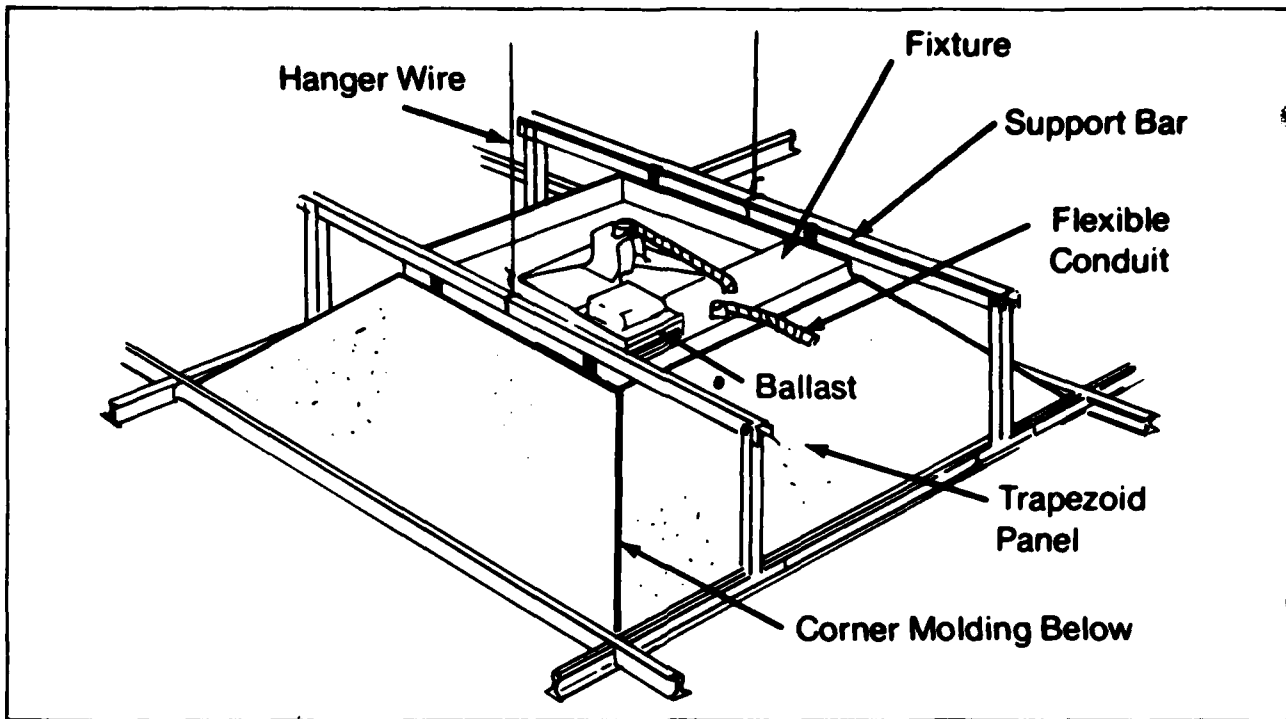


Figure 5: Movable troffered luminaire designed for "drop-in" placement in a suspended ceiling.

time to time, whenever the need arises. One of these systems, the most popular, uses a dropped ceiling. Luminaires are sized to fit into standard ceiling panel modules (see Figure 5), so they can be moved, added or removed with little difficulty for the life of the system. Another type of system has both task and general lighting built into a furniture system. As desks are moved, the lights move with them. Although this approach has merit, it requires a deviation from customary wiring practices (underfloor instead of the usual above-ceiling), and has tax and depreciation implications as well.

Specific suggestions on what to look for in luminaires, lighting applications and layouts, and lighting and energy control considerations for new construction can be found in the following sections of this booklet.



How to choose more efficient luminaires

When you choose the luminaires or fixtures you will be using, it is well to keep four basic ideas in mind.

First, and as already mentioned, the location of work stations and the tasks performed in an area are subject to frequent changes. The new lighting needs caused by these changes can be met easily only when the system is flexible enough to permit relocation of luminaires quickly, easily, and at low cost.

Second, the fixture should be an efficient source of light. As much light as possible should be able to get out of the fixture and onto the work surface. A fixture's efficiency is measured in terms of "coefficient of utilization." Manufacturers provide these data in their catalogs.

Third, the fixture should not be a source of glare. It shouldn't hurt your eyes when viewed in a normal work situation, such as when you are sitting at your desk or looking around the office. You shouldn't see the fixture or its lamps reflected on your desk or surrounding equipment, nor should light from the fixture create veiling reflections (see Figure 6).

Fourth, wherever possible, the heat generated by lighting fixtures should be integrated into the heating, ventilating, and air-conditioning system to minimize energy use.

Luminaires that consume equal amounts of energy and provide the same amount of light (lumen) output may not provide equal visibility of a seeing task. For example, a well shielded fixture can eliminate

stray light that can hinder how well you can see. Likewise, there are certain fixtures that have been designed specifically to reduce veiling reflections, and many other types, each of which is designed for specific kinds of light control (see Figure 7).

In addition to the overall design of the luminaire, selecting the right diffusing material to let the light out of the fixture is important in determining its overall efficiency. Glass and acrylic prismatic lenses generally are more efficient transmitters of light than other

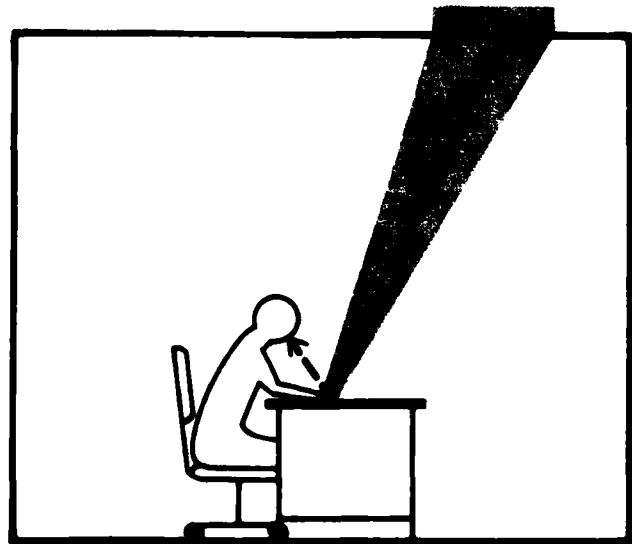
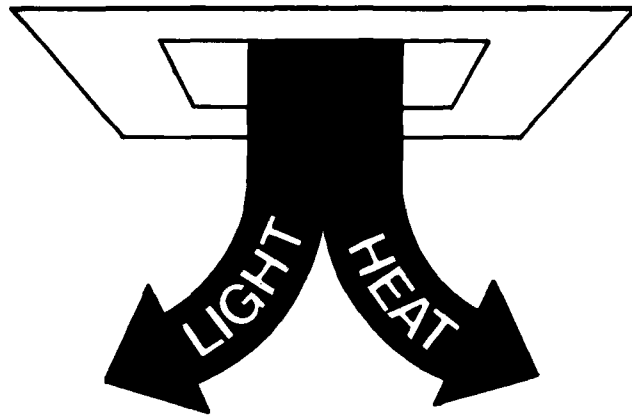


Figure 6: A veiling reflection is caused when light is reflected off the task surface into the worker's eyes, thereby lowering task contrast. This occurs when fixtures are located in the "offending zone," generally in front of the worker.



materials, although some types of louvers that control the light distribution pattern of the fixture are equally efficient.

If you are considering a major overhaul of your lighting system, remember that you also must consider the relationship of lighting to your heating, ventilating and air-conditioning (HVAC) system. In most cases the heat generated by lighting was considered when your building's HVAC system was designed. This heat—called “heat of light”—comes from the lamps and ballasts. As room air passes over the outside of the fixture, it is warmed by the heat of light, thus increasing the temperature in the space.

There are techniques available for removing heat of light before it affects the conditioned space. Recessed air handling fixtures placed in the ceiling, as shown in Figure 8, can capture and remove this heat before it becomes a problem. In some cases this heat can be used elsewhere in the building. This

method helps avoid using still more energy.

There are two other factors that should be considered when choosing a lighting fixture. The first is the finish of the fixture, which should be suited to the environment of the space in which it will be located. If dampness or excess dirt is a consideration, your fixture's design and finish should minimize corrosion and accumulation of dirt.

The second factor is the ease with which the fixture can be cleaned. It should not be difficult to remove the diffuser to get at the lamps and inside surfaces of the fixture.

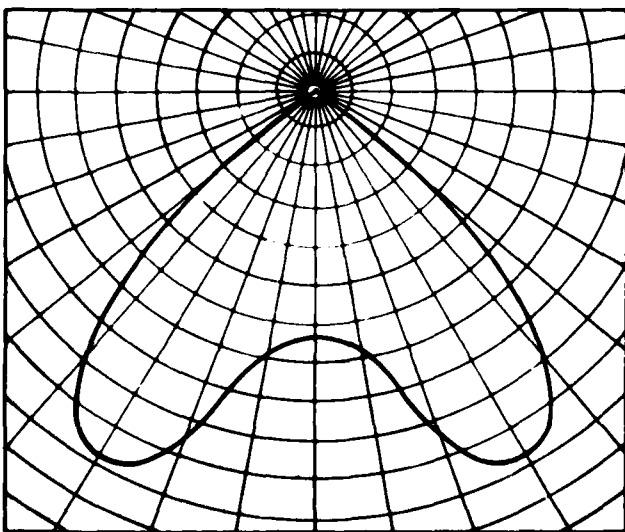


Figure 7: Typical batwing distribution, designed to deliver light at angles less likely to produce veiling reflections.

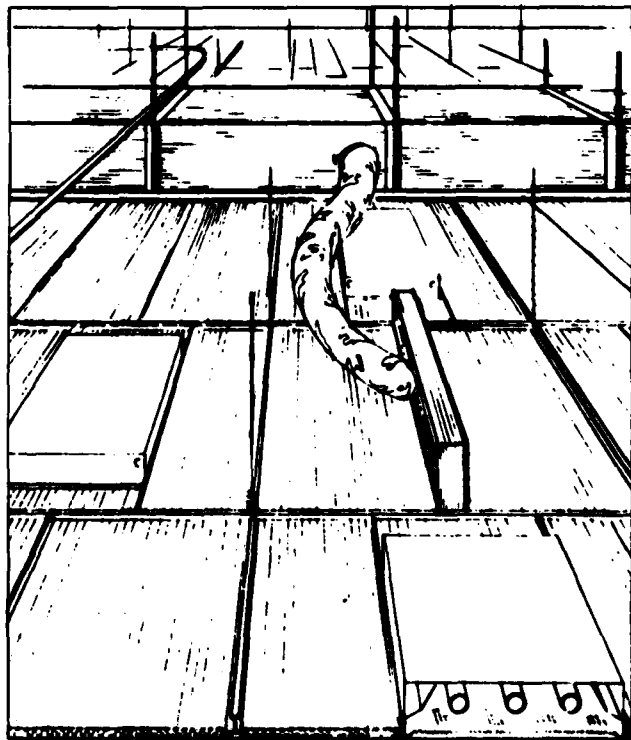


Figure 8: Plenum view of an integrated ceiling system that extracts heat of light.

Two important concepts:

Maintaining your lighting investment and life-cycle costs

Maintaining your lighting investment involves two basic ideas: (1) buying the lighting system that gives you the most for your lighting dollar, and (2) ensuring that it continues to give you the light you originally purchased and continue to pay for in your electric bill.

These two ideas go hand in hand. It doesn't do any good to buy the quantity and quality of light that you and your employees need to work, then do nothing to make sure the lighting system will continue to perform the way it was intended.

The method to use to determine which lighting system will give you the most for your lighting dollar can be summed up in three words: LIFE-CYCLE

COSTING. Life-cycle costing is regarded as a truer measurement of the impact of a system on economics and the environment than any other yardstick. It considers the total dollars spent on buying, installing, operating, and *maintaining* a piece of equipment or a system during its lifetime.

It is well known that, in the purchase of many products and facilities, greatest emphasis has been placed on lowest first cost. While this approach had its merits and adherents when energy was both cheap and plentiful, it no longer is smart business. The system that is least expensive to buy often is the most expensive to operate and maintain (see Figures 9 and 10).

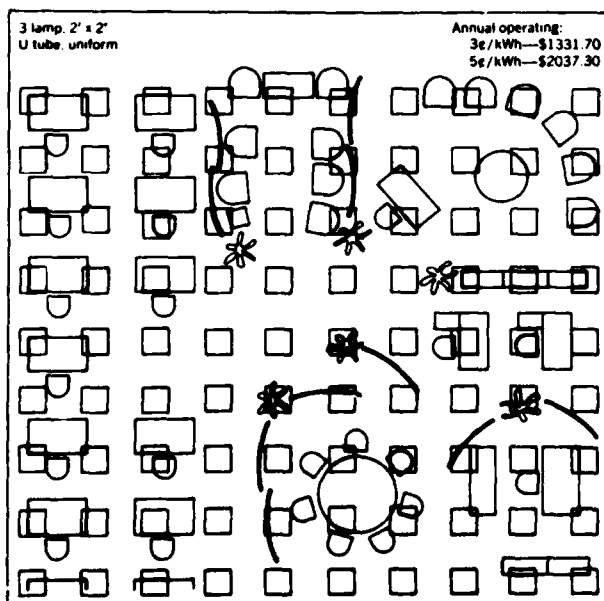


Figure 9: A regular pattern of two-foot by two-foot troffers with three U-shaped lamps, as they might be used in a building module approach to supply 100 footcandles.

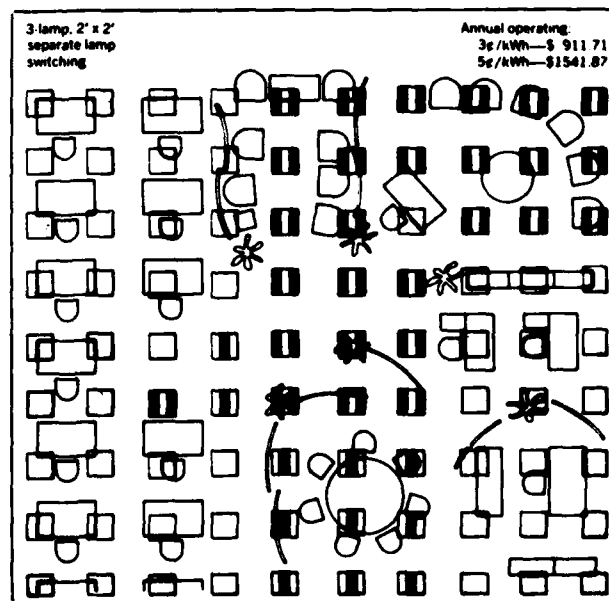


Figure 10: A modification of the pattern in Figure 9 that involves switching lamps individually to provide illumination appropriate for the area. Darkened portions at the luminaire indicate either one or two lamps extinguished. The additional initial investment for this system—about \$300 or so—would probably be paid back in less than one year.

Data for calculating life-cycle costs have long been available from many companies in the lighting industry. In fact, the lighting industry has been one of the leaders in this regard. Until the onset of the nation's new energy awareness, the life-cycle costing concept generally was followed only by larger corporations.

When it comes to lighting, life-cycle cost should be evaluated in terms of the total system. For example, the cost of a high pressure sodium lamp is more than that of a metal halide or mercury vapor lamp. However, the high pressure sodium lamp is so efficient that it reduces the number of lamps and fixtures (as well as wiring costs) required to supply a given amount of lights. These savings can therefore make the life-cycle cost of an HPS system lower than for any other system commonly used indoors. The form provided in Figure 11 can be used to compare an existing system with a new system, or two alternative new systems, on the basis of life-cycle costing.

In February 1972, before the Middle East embargo on petroleum shipments to the United States, the Illuminating Engineering Society (the technical society devoted to all phases of lighting research, design, and applications) prepared 12 recommendations for better utilization of energy used for lighting. This was part of the important national effort to have the public realize the need to avoid wasting energy, and that quality lighting could be

obtained with reduced energy levels. Each of the 12 recommendations, outlined in the box, should be considered when modifying an existing lighting system or designing for new construction or remodeling. For example, IES has quality and quantity recommendations for the light on the task. Where practical, a distinction should be made between task lighting and lesser needs for circulation. In this way, designers can develop approaches that can be more esthetically pleasing, or more cost-effective, or more energy efficient than conventional approaches.

Maintenance of the lighting system involves three steps: (1) periodic cleaning of the lighting fixtures and lamps; (2) spot or group replacement of lamps based on the economics of the system, and (3) periodic repainting or cleaning of the room surfaces (ceiling, walls, and floor) to maintain optimum light reflection characteristics.

Each of the steps outlined above is designed to put more light on the task (desks, assembly lines, store displays, shelves, etc.). Although all are valuable, research indicates that periodic cleaning and lamp replacement before lamp failure play the most significant role in maintaining the amount of light you originally bought and continue to buy each day. In fact, just cleaning your lighting fixtures once a year can be a very worthwhile investment, although more frequent cleaning may be needed if the location is very dirty or dusty (see Figure 12).

The 12 IES recommendations

1. Design lighting for expected activity (light for seeing tasks with less light in surrounding non-working areas).
2. Design with more effective luminaires and fenestration (use systems analysis based on life cycle).
3. Use efficient light sources (higher lumen per watt output).
4. Use more efficient luminaires.
5. Use thermal controlled luminaires.
6. Use lighter finish on ceilings, walls, floor and furnishings.
7. Use efficient incandescent lamps.
8. Turn off lights when not needed.
9. Control window brightness.
10. Utilize daylighting as practicable.
11. Keep lighting equipment clean and in good working condition.
12. Post instructions covering operation and maintenance.

Lighting Cost Comparison

Lighting Method #1

Lighting Method #2

Installation Data

Type of installation (office, industrial, etc.) _____
 Luminaires per row _____
 Number of rows _____
 Total luminaires _____
 Lamps per luminaire _____
 Lamp type _____
 Lumens per lamp _____
 Watts per luminaire (including accessories) _____
 Hours per start _____
 Annual burning hours _____
 Group relamping interval or rated life _____
 Light loss factor _____
 Coefficient of utilization _____
 Footcandles maintained _____

Capital Expenses

Net cost per luminaire _____
 Installation labor and wiring cost per luminaire _____
 Cost per luminaire (luminaire plus labor and wiring) _____
 Total cost of luminaires _____
 Assumed years of luminaire life _____
 Total cost per year of life _____
 Annual interest on investment _____
 Annual taxes _____
 Annual insurance _____
 Total annual capital expense _____

Operating and Maintenance Expenses

Energy expense
 Total watts _____
 Average cost per kWh _____
 Total annual energy cost _____

Lamp renewal expense
 Net cost per lamp _____
 Labor cost each individual relamp _____
 Labor cost each group relamp _____
 Percent lamps that fail before group relamp _____
 Renewal cost per lamp socket per year** _____
 Total number of lamps _____
 Total lamp renewal expense per year _____

Cleaning expense
 Number of annual washings _____
 Man-hours each (est.) _____
 Man-hours for washing _____
 Number of annual dustings _____
 Man-hours per dusting each _____
 Man-hours for dustings _____
 Total man-hours _____
 Expense per man-hour _____
 Total annual cleaning expense _____

Repair expenses
 Repairs (based on experience, repairman's time, etc.) _____
 Estimated total annual repair expense _____
 Total annual operating and maintenance expense _____

Recapitulation

Total annual capital expense _____
 Total annual operating and maintenance expense _____
 Total annual lighting expense _____

*Total annual energy cost = $\frac{\text{Total watts} \times \text{burning hours per year} \times \text{cost per kWh}}{1000}$

**The following formulas give the annual cost per socket for lamps and replacement. They also can be used to determine the most economical replacement method.

Individual replacement = $\frac{B}{R} (c + i)$ dollars/socket/year.

Group replacement (early burnouts replaced) = $\frac{B}{A} (c + g + KL + K_i)$ dollars/socket/year.

Group replacement (no replacement of early burnouts) = $\frac{B}{A} (c + g)$ dollars/socket/year.

- where B = burning hours per year
- R = rated average lamp life, hours
- A = burning time between replacements, hours
- c = net cost of lamps, dollars
- i = cost per lamp for replacing lamps individually, dollars
- g = cost per lamp for replacing lamps in a group, dollars
- K = proportion of lamps failing before group replacement (from mortality curve)
- L = net cost of replacement lamps, dollars

No general rule can be given for the use of group replacements; each installation should be considered separately. In general, group replacement should be given consideration when individual replacement cost i is greater than half the lamp cost c and when group replacement cost g is small compared to i.

Figure 11: Lighting cost comparison form.

SYSTEMATIC LIGHTING MAINTENANCE

- Provides More Light
- Aids Productivity
- Saves Energy and Dollars

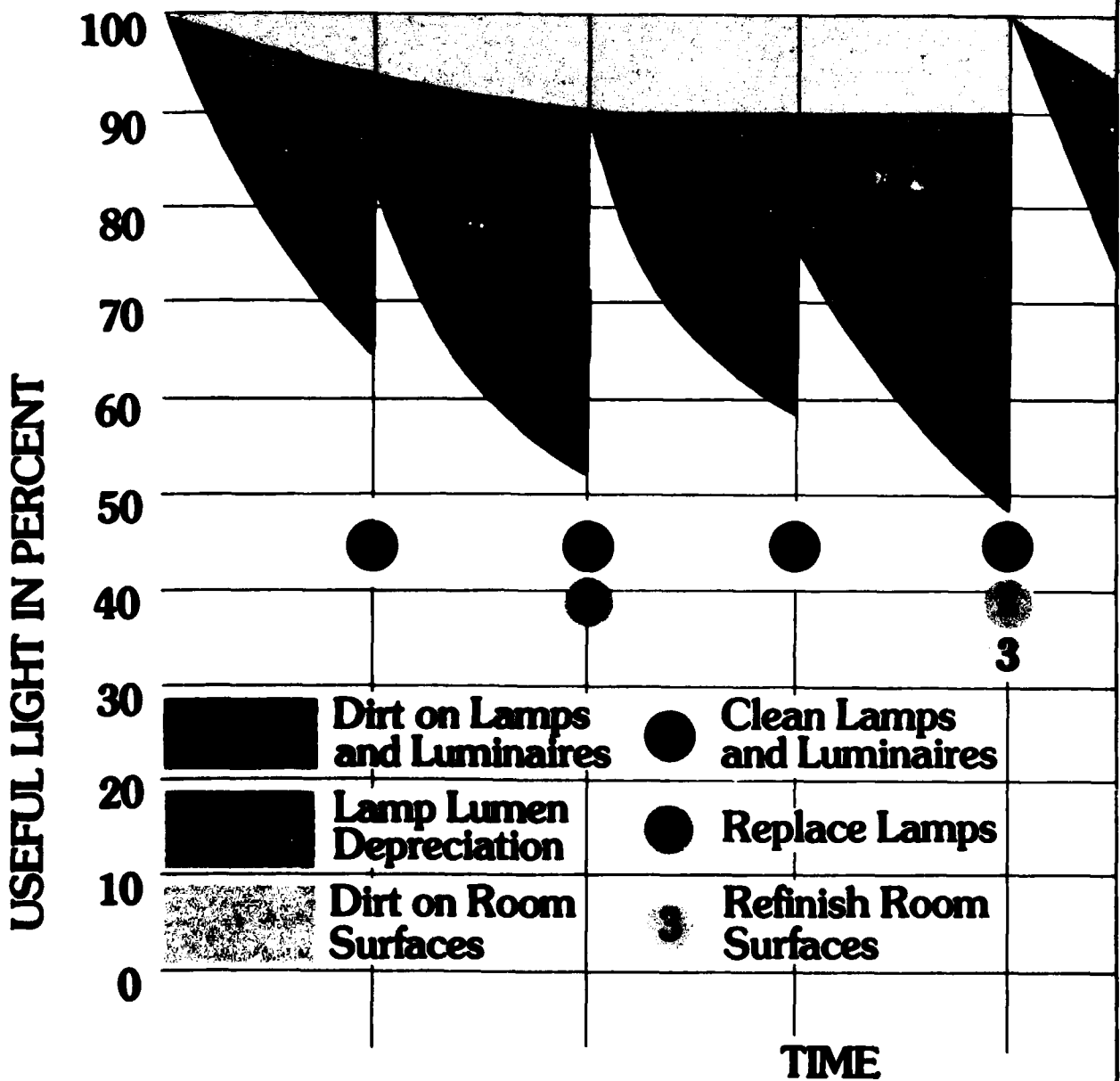


Figure 12: Chart indicating how good maintenance is essential for good lighting.

For additional information . . .

For more information on what you can do to improve the efficiency of your lighting system, without detracting from the many benefits provided by lighting, refer to the numerous publications prepared by the federal government and numerous national associations, and consider contacting, among others: representatives of your local electrical utility, electrical contractors, consulting electrical engineers and lighting system designers, and representatives of lighting system and component manufacturers.

This document is available from the National Lighting Bureau, 2101 L Street, N.W., Suite 300, Washington, D. C. 20037 at a cost of \$1 each, prepaid. Bulk prices on request.

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