ENERGY
MANAGEMENT
SERIES

2

FOR INDUSTRY
COMMERCE
AND INSTITUTIONS

Lighting

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canadä

PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture, a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples of how to save energy.

For further information concerning the manuals listed below or material used at seminars/workshops including actual case studies, please write to:

Business & Government Energy Management Division
Energy Conservation Branch
Department of Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario
K1A 0E4

Energy Management/Employee Participation
Conducting an Energy Audit
Financial Analysis
Energy Accounting
Waste Heat Recovery
1 Process Insulation
2 Lighting
3 Electrical
4 Energy Efficient Electric Motors
5 Combustion
6 Boiler Plant Systems
7 Process Furnaces, Dryers and Kilns
8 Steam and Condensate Systems
9 Heating and Cooling Equipment (Steam and Water)
10 Heating Ventilating and Air Conditioning
11 Refrigeration and Heat Pumps
12 Water and Compressed Air Systems
13 Fans and Pumps
14 Compressors and Turbines
15 Measuring, Metering and Monitoring
16 Automatic Controls
17 Materials Handling and On-Site Transportation Equipment
18 Architectural Considerations
19 Thermal Storage
20 Planning and Managing Guide

Available in Canada through

Associated Bookstores
and other booksellers

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

Catalogue No. M91-6/2E — Canada:
ISBN 0-662-14154-7 — Other Countries:

Price subject to change without notice

TABLE OF CONTENTS

APPENDICES

INTRODUCTION

This Lighting module is part of an Energy Management series available from Energy Mines and Resources Canada, designed to aid the process of adapting Canadian industrial, commercial and institutional enterprises to today's higher energy costs. Lighting plays an important role in an organization's overall energy management strategy. In the case of large office buildings, approximately 60 per cent of the total electrical energy consumption is used by the lighting system. Experience has shown lighting cost reductions of 50 per cent or more are achievable. Other benefits, such as improved lighting quality and reliability, may result from the proposals and suggestions contained herein. The entire field of lighting is in a phase of active development corresponding to its perceived potential in today's new energy environment.

Lighting, as a production tool, is as important to the efficiency of industry as the most expensive, up-to-date machinery, particularly when the use of human resources is concerned.

Increasing energy costs have resulted in a review of high general lighting levels, with a new emphasis on task lighting. This means emphasizing the proper quantity and quality of lighting only where it is needed. This perspective, coupled with new energy-efficient lighting equipment, creates a genuine potential not only for cost reduction, but also for the improvement of existing lighting systems.

Purpose

The following summarizes the purpose of this module.

• Review lighting fundamentals and provide basic tools for informed energy management decision-making.

• Examine the use of currently available lighting equipment for the reduction of lighting costs.

• Make building owners and operators aware of the potential energy and cost savings available through the implementation of energy management opportunities.

• Provide methods of calculating the potential energy and cost savings, using worked examples.

• Provide a set of worksheets that can be used to perform calculations for existing and/or proposed systems to establish energy and cost savings potential.

Contents

The contents have been subdivided into the following sections. • *Fundamentals* of lighting, with examples where necessary, are used to provide a basic understanding of the concepts needed to work with common equations and calculations.

• *Equipment/Systems* describes lighting equipment and materials used in the industrial, commercial and institutional sectors.

• *Energy Management Opportunities* are described and supported by energy, cost savings, and simple payback calculations.

• *Appendices* includes a glossary of common lighting terms and blank worksheets.

FUNDAMENTALS

While the basic approach of this lighting module is to present practical, readily implemented lighting techniques, there are a few basic lighting fundamentals that cannot be ignored. It is necessary to understand these lighting fundamentals in order to be able to apply simple energy management techniques. The purpose of this section, therefore, is to provide the reader with an overview of the potential for lighting energy savings through energy management techniques.

Lighting Quantities and Units

An understanding of a few basic lighting terms and their interrelationships is important. What follows, then, is a brief explanation of some common lighting terms.

Because the units for measuring lighting are referenced to the visual processing capabilities of the human eye, these units are quite different from all the other fundamental units of physics.

Candela

The candela (cd) is the fundamental unit from which all other lighting units are derived. Candlepower (the intensity of light in a specified direction) is measured in candelas. An ordinary wax candle, for instance, has a candlepower of about 1 candela, as its name suggests.

Lumen

To measure light intensity in candelas, both light and direction must be specified. Without the directional aspect, the pure luminous flux or rate of flow of light energy is expressed in lumens (abbreviated lm). The mechanical analogy of the lumen would be the rate of flow of electricity, which is the watt. An important way of characterizing a lamp is to determine the amount of light, measured in lumens, produced for each watt of power the lamp requires.

Lux

The object of any lighting system is to produce light, or illumination. Illumination is the amount of luminous flux per unit surface area. A unit of illumination is called a lux (lx). One lux equals one lumen per square metre. Table 1 shows the range of recommended illumination for different categories of tasks. Rising energy costs have led to the downward revision of the minimum required levels of illumination in many task categories.

Dalx

Dalx is an abbreviation for decalux; deca means 10 times; lux refers to how much light is falling on a workstation.

Effect of Lighting on Productivity

It is almost an accepted fact that lighting gives people the illumination they need to perform given functions. It has been well-documented, however, that the quantity and quality of illumination provided has an impact on how well these functions are performed. Because of this, it is important to consider the relationship between lighting and worker productivity.

The ultimate goal of energy-efficient lighting is to maintain adequate levels of good quality illumination in order to promote maximum worker productivity. There is, after all, a balance that must be struck between energy conservation and worker productivity.

For example, a significant decrease in worker productivity occured when illumination levels in a government office building were reduced from 100 dalx to 50 dalx. Table 2 demonstrates the extent of financial loss in a similar case involving an illumination reduction from 1500 dalx to 500 dalx. The data in this table, derived from a separate controlled study, shows that lowering the illumination level resulted in a worker taking 13.6 per cent more time to accomplish the task. In the final analysis, energy savings of $22.90 per square meter, per year, were achieved at the expense of a decrease in worker productivity worth $401.50 per m², per year. This study concluded that by lowering the illumination from 150 dalx to 50 dalx a net loss of $378.60 per m², per year was the result.

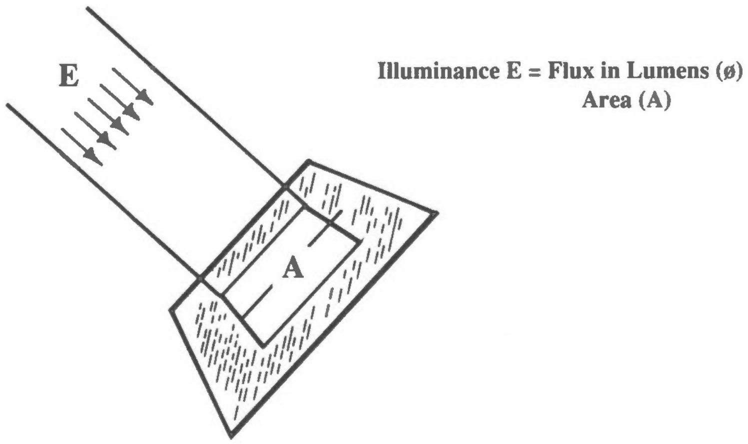
Illumination and Luminous Flux

The relationship between illumination and luminous flux is expressed by the following equation, and is illustrated in Figure 1:

$$E = \frac{Ø}{A}$$

where:

E = the illumination measured in lux
Ø = the luminous flux measured in lumens
A = the area measured in m^2



Illumination and Luminous Flux
Figure 1

For example, if a light meter indicates 70 dalx of illumination at all points on a 2 m² surface, then the luminous flux falling on this area would be 1,400 lumens.

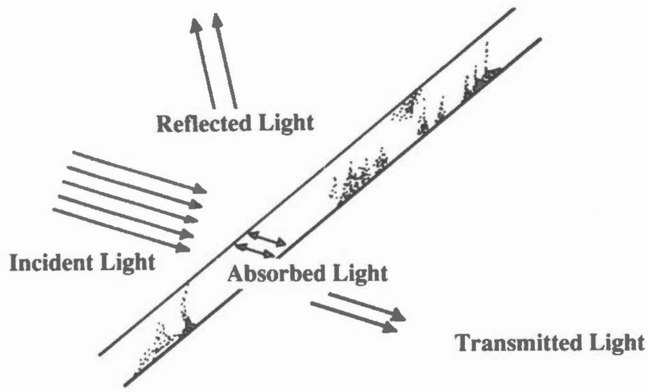
Reflectance and Transmittance

Some lighting energy is always lost when it is reflected from or passing through any material. This is illustrated in Figure 2. A light meter can be used to measure both original (incident) light and reflected (transmitted) light. In this way, it is possible to compute the loss of lighting energy.

To measure the amount of light reflecting from a surface, the light meter should be held face down, close to the surface. It should be drawn away from the surface until the reading becomes constant. This constant reading is the amount of light per area reflected from the surface (measured in lm/m²). Care must be taken not to throw shadows on the surface while performing this measurement.

Finding the Reflectance of a Surface

Reflectance is the ratio of light reflecting from a surface to the light falling on it. To measure reflectance, the light meter should be held against the surface, facing away. The illumination, which is the amount of light falling on a



Incident and Reflected Light

Figure 2

surface, is then read. Following this measurement, the amount of light reflecting from the surface can measured by turning the light meter toward the surface, as described above. The reflectance (R) is then calculated as:

$$R = \frac{\text{reflected light}}{\text{incident light}}$$

For example, if the light meter facing a wall indicates 25 dalx and indicates 50 dalx facing away from the wall, then the wall can be assumed to have a reflectance of 0.50. Colour gives a good indication of the reflectance of a surface:

Reflectance vs Colour

0.75 White and very light tints
0.50 Medium blue-green, yellow or gray
0.30 Dark gray, medium blue
0.10 Dark blue, brown, dark green and wood finishes

A simple and effective means of ensuring efficient use of lighting energy is to specify room surfaces with high reflectances:

Recommended Minimum Reflectances

Ceilings 70-90%
Walls 40-60%
Desk tops 25-50%
Floors 20-50%

Transmittance

When light passes through a given material, it is called transmittance. To measure the transmittance of a sheet of material, calculate the ratio of two meter readings: one meter reading with the sheet covering the light meter and one reading without the material covering the light meter. The transmittance (T) is therefore expressed:

$$T = \frac{\text{transmitted light}}{\text{incident light}}$$

If a meter reads 20 dalx through a sheet of coloured glass and 30 dalx with the sheet of glass removed, the sheet of glass would have a transmittance of 0.66.

Reflectors And Lenses

Reflectors and lenses are specially designed devices with specific reflectance and transmittance properties that are used to control and direct the light from a light source. Basically, light bounces off a reflector and passes through a lens.

Lighting fixtures often contain reflectors, lenses, or both to direct luminous flux. While they do absorb some of the light produced, they can, if properly selected, help increase the overall efficiency of a lighting system by directing the light where it is required. In addition to directing light, lenses can also help to reduce glare.

Measuring The Light Output Of An Incandescent Lamp

In order to gain a practical appreciation of these basic lighting concepts, consider the following experiment using a common household incandescent lamp and a common cell-type lux meter in a totally black, non-reflecting room. A totally black room is necessary to ensure that only the light emitted directly from the lamp is measured. (In an energy-efficient, light-coloured room, a large amount of light is reflected off the walls, the ceiling and the floor.) When placing the meter 30 cm away from a 40 W incandescent lamp, the meter would indicate 700 lx. What is the total luminous flux output (rate of flow of light) from the lamp?

The meter is far enough away from the lamp (i.e. 5 times the largest source dimension) to allow approximation as a uniform point source. Using the previous formula:

$$E = \frac{Ø}{A}$$

or

$$Ø = E \times A$$

The total flux equals:

= (meter reading) x (area illuminated)
= (700) x (area illuminated)
= (700) x (area of 30-cm-radius sphere)
= (700) x (4π 0.30 m2)
= 792 lm

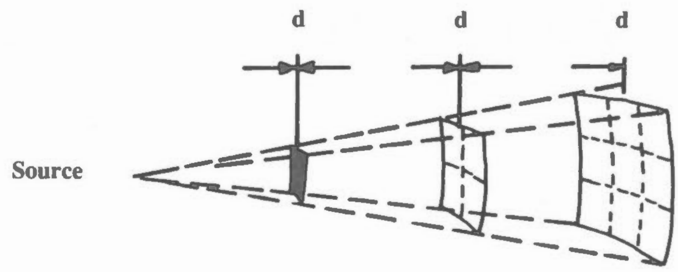
What would the meter read at a distance of 60 cm from the lamp? Having calculated the lamp's total light output, the above equation can be used to calculate a meter reading at any given distance:

$$E = \frac{Ø}{A}$$

Meter Reading = 792 / (4-π x 0.60 x 0.60)
= 175 lx

The meter reading changes according to its distance from the lamp. This effect is referred to as the "Inverse-Square Law", since the meter reading varies inversely as the square of the distance from the lamp. For example, as a light source is moved away, illumination decreases as follows:

Distance From Source	Illumination
1 m	E or 100 lx
2 m	E/4 or 25 lx
3 m	E/9 or 11 lx
4 m	E/16 or 6 lx



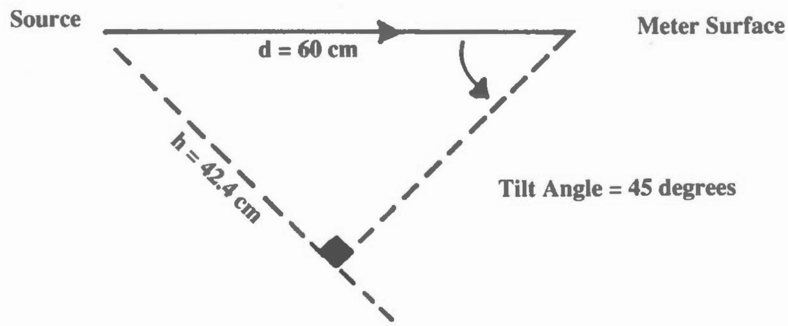
Measuring Source Light Flux
Figure 3a

Notice in Figure 3a how the area necessary to capture a fixed amount of source light flux increases as the square of the distance from the source also increases. The farther away one is from a light source, the smaller the useful lighting contribution one receives.

What then would the meter read at a distance of 60 cm, if, instead of being held directly facing the bulb, it was tilted at a 45 degree angle?

Considering Figure 3b, the meter reading will be scaled down by a factor of h/d to account for the reduced amount of incident light per meter of surface area:

$$\text{Meter Reading} = 175 \times (42.4 \text{ cm} \div 60 \text{ cm})$$
$$= 124 \text{ lx}$$



Measuring Reduced Incident Light
Figure 3b

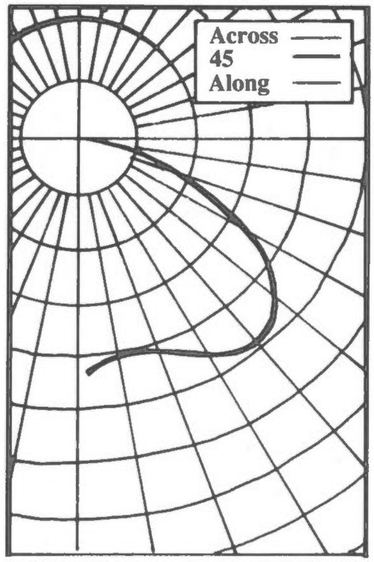
This emphasizes the point that a fixture placed directly above a workplace will make a greater contribution to task illumination than a similar fixture no further away but not directly facing the task surface.

Intensity Distribution Curve Of A Lamp

In the above example, we used the point source approximation for a 40-W lamp. However, most cases do not permit this convenience. Therefore, lighting manufacturers publish intensity distribution curves for their lamps and luminaires. An intensity distribution curve is a plot of light intensity (measured in candelas) in all directions along which luminous flux is emitted. Figure 4 is an example of a "batwing" intensity distribution, specially designed for low-bay fixtures.

Luminous Efficacy Of A Lamp

A crucial factor in selecting light sources for different applications is luminous efficacy. The efficacy of a lamp is determined by the quantity of light, measured in lumens, produced for each watt of electricity the lamp requires. Selecting high-efficacy lamps can therefore reduce electricity consumption.



"Batwing" Intensity Distribution

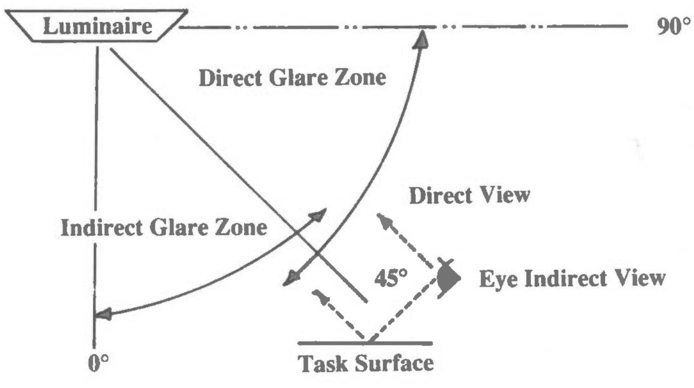
Figure 4

Lighting Quality

Lighting encompasses two complementary aspects namely, the quantity and the quality of the light provided. There are many different ways to illuminate a workstation with the same quantity of light. Some of these ways have been found to be better than others in that they create a more comfortable and effective visual environment for most people. Collectively, these differences fall under the general heading of "lighting quality". In the broadest sense, lighting quality touches upon architectural and aesthetic considerations. In more practical terms, however, it can be viewed as the control of glare and the ability to distinguish colours. A high-quality lighting system produces a minimal amount of glare. This is because glare counteracts the benefits of proper illumination levels and therefore generally reduces worker productivity.

Visual Comfort Probability

A productive lighting installation is a visually comfortable one. A measure of visual comfort is visual comfort probability (VCP) which expresses the percentage of people who find a particular field of view acceptable in terms of direct glare. Direct glare is light that reaches the observer's eyes directly from the glare source. Figure 5 shows the difference between direct and indirect (reflected) glare. Lighting manufacturers publish VCP tables for their lighting fixtures. A VCP value of 70 or higher usually provides an acceptable visual environment for a typical office application.

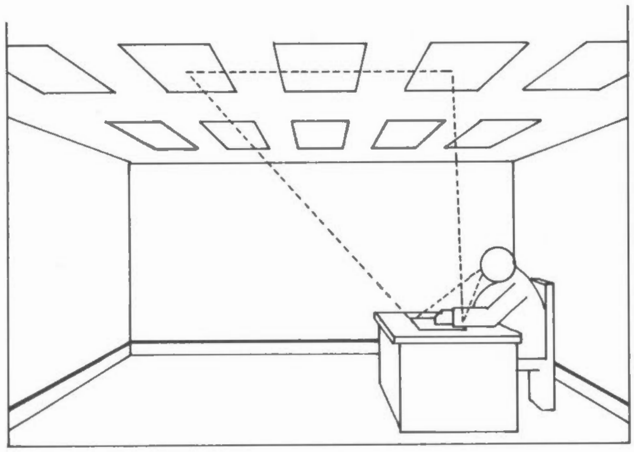


Direct and Indirect Glare Zones

Figure 5

Indirect Glare

Indirect glare occurs when light is reflected off a surface into the worker's eyes (Figure 6). When the offending reflection comes from the task surface itself, a form of indirect glare known as "veiling reflection" results. Veiling reflection is so named because its effect is similar to placing a thin veil over the task. Countering indirect glare involves planning a room layout in such a way that illumination from in front of the worker (from the offending zone) is minimized. Most illumination should come from behind the worker's right and left side so that no light could be reflected from the task area back into his eyes. Note that this goal is more likely to be achieved in the case of tubular lamps by orienting the tubes perpendicular to desks or task areas.



Veiling Reflection Offending Zone

Figure 6

Colour Rendering Index (CRI)

The ability of a lamp to allow proper or standard colour perception is indicated by its colour rendering index. An ideal lamp has a colour rendering index of 100. The CIE (Commission Internationale de l'Eclairage) has published an approved procedure for specifying the CRI of a lighting source. The CRI of a reference source is set at 100 and the CRIs of all other sources are less than 100. A standard fluorescent white lamp has a CRI of 50. At the other end of the scale, a low pressure sodium lamp has a CRI of -45.

Lighting manufacturers have developed lamps to make colours appear as people prefer them. The meat counter at the local supermarket, for instance, is equipped with a specially designed lamp that gives meat an attractive colour appearance. The customer, when viewing the choice cut at home, may notice that the meat has a slightly modified colour to that in the supermarket.

In many industrial locations it is not necessary to distinguish colours with any significant degree of accuracy. This permits the choice of particularly energy-efficient lamps among which low pressure sodium is the most economical. Because of the psychological effects of the monochromatic colour, low pressure sodium lighting should be avoided in indoor areas where people are working for extended periods of time.

Lighting System Power Requirement

How energy efficient is your lighting system? Does your system represent the best that can be done, considering your lighting requirements?

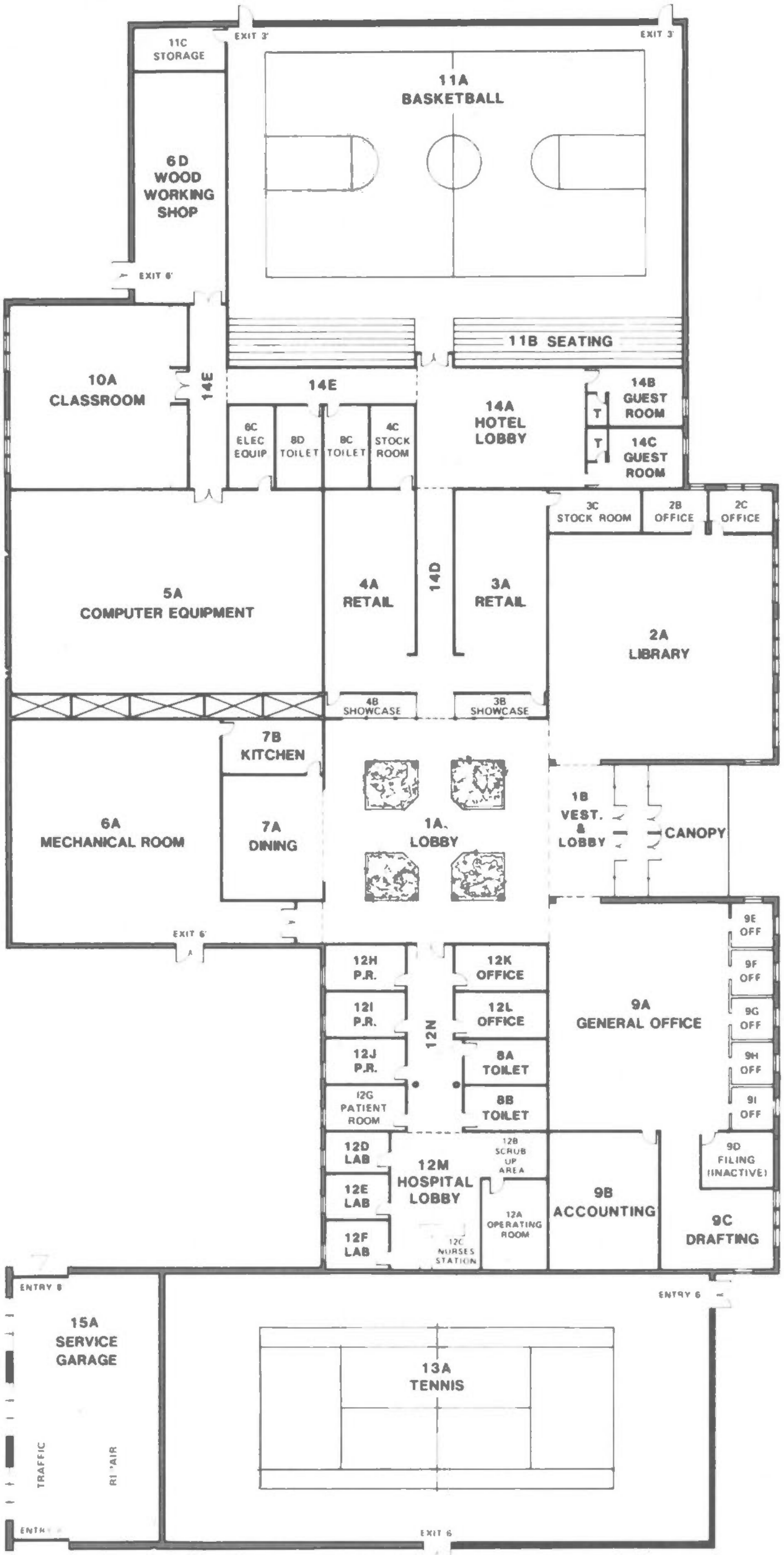
The Illuminating Engineering Society (IES) has prescribed a UPD (Unit Power Density) procedure to determine proper corrective action.

Maximum Allowable Lighting Power For Each Room

Table 3 (four pages) indicates the lighting power allowance in units of watts per square metre. For each room, the power budget is calculated in the following way:

Maximum allowable lighting power:

= UPD Table Power Density x Task Area (tA) x Room Factor (RF) x Space Utilization Factor (SUF)



NO.	SPACE DESCRIPTION	DIMENSION (FT) L x W x H	NOTE
1A	LOBBY	50x50x16	
1B	VEST & LOBBY	22x30x8	
2A	LIBRARY	50x50x9	30% STACKS 70% READING
2 B-C	OFFICE	10x14x8	2 TASK AREAS READING
3 & 4 A	STORE	45x20x9	50% MERCH 50% CIRCULATION
3 & 4 B	SHOW WINDOW	5x20x8	
3 & 4 C	STOCKROOM	10x20x8	
5A	COMPUTER EQUIPMENT	70x45x9	
6A	MECHANICAL RM	50x50x10	
6C	ELECTRICAL EQUIPMENT RM	18x10x8	
6D	WOOD WORK SHOP	20x50x10	
7A	DINING AREA	20x30x9	
7B	KITCHEN	10x20x9	
8 A D	TOILET	10x18x8	
9A	GENERAL OFFICE	40x50x9	25 TASK AREAS
9B	ACCOUNTING	25x30x9	10 TASK AREAS
9C	DRAFTING	20x25x9	4 TASK AREAS
9D	FILING	10x15x8	INACTIVE
9 E I	OFFICE	10x10x8	2 TASK AREAS READING
10A	CLASSROOM	40x40x9	
11A	BASKETBALL CT	100x60x25	COLLEGE AND HIGH SCHOOL
11B	SEATING	15x100x25	
11C	STORAGE	20x10x8	ACTIVE BULKY
12A	OPERATING ROOM	20x15x8	
12B	SCRUB UP AREA	10x15x8	
12C	NURSES STATION	10x13x8	
12 D F	LABORATORY	10x14x8	
12 G J	PATIENT ROOM	10x18x8	INCLUDE BATH
12 K L	OFFICE	10x20x8	3 TASK AREAS READING
12M	HOSPITAL LOBBY	22x20x8	
12N	CORRIDOR	42x10x8	
13A	TENNIS COURT	60x120x35	CLUB
14A	HOTEL LOBBY	24x36x8	
14 B C	GUEST ROOM	12x20x8	
14D	CORRIDOR	50x8x8	
14E	CORRIDOR	80x8x8	
15A	GARAGE SERVICE	32x80x20	35% TRAFFIC 65% REPAIR

Building Plan to Illustrate Use of UPD Procedure
Figure 7

Example of UPD Procedure Worksheet

Figure 7 shows the floor plan of a building which has a number of different lighting applications. Table 4 is 2 pages of completed UPD worksheets listing the lighting power budget for each room represented in the floor plan. Table 5 is a worksheet that summarizes the results for the building.

UPD Details

To illustrate the application of the UPD method, consider the vestibule and lobby (1B) indicated in Figure 7.

The vestibule and lobby (1B) has a length of 9.1 m, a width of 6.7 m and a ceiling height of 2.4 m. The room area (6.7 x 9.1) is equal to 61 m^2. Turn to Table 6 (two pages titled "Room Factors") and find the closest given width. This is 6.1 m. The closest length on the table is 9.1 m. The room factor, therefore, is 1.15. This means the task is equal to the full area of the room and the SUF would be calculated as 1. The UPD table power density from Table 3 for the vestibule and lobby is 10.76 watts per m^2. Therefore, the maximum allowable lighting power for this room is:

UPD Table Power Density x tA x RF x SUF
$= 10.76 \times 61m^2 \times 1.15 \times 1$
$= 755$ W

Complying With the Recommended UPD Budget

The UPD procedure described above is an energy management tool. A worksheet covering the following three steps is provided in the Energy Management Opportunities section.

There are three important steps:

1. Determine the maximum lighting power for a given space using the UPD procedure.
2. Determine the actual connected lighting power in each room. This includes lamp watts, ballast watts, dimming device losses and the power for portable and supplementary lamps. These wattages can either be found on lighting system plans or can be read directly on lamps, ballasts and dimmers.
3. If the actual connected power for lighting exceeds the calculated UPD limit, those spaces which are presumably the most inefficient can be targeted for closer examination.

Three Qualities of a Good Lighting System

The UPD connected lighting power limit is only one of the qualities of a good lighting system. A good lighting system:

1. Meets the UPD connected lighting power limit;
2. Produces light according to the quantity requirements of the space; and
3. Produces good quality light, creating a visually interesting and comfortable environment.

Space Lighting Requirements

What quantity of light is best for a particular location? In determining how much light is needed for a particular room, four characteristics can be considered:

1. Area activity (type of visual task);
2. Age of worker;
3. Importance of speed and accuracy in visual performance; and
4. Task background reflectance.

To determine how much illumination is required:

1. Determine the type of activity (e.g. reading typed originals) and the location of the work plane.
2. Using Table 7 (three pages), find the illuminance category for the activity. Because of the nature of the tasks in categories A to C, these categories are applied over the entire area of the space considered. On the other hand, categories D to F should be applied selectively to particular work stations. Categories G to I are rare and difficult lighting applications (e.g. sewing black thread on black cloth).
3. From Table 8 determine the appropriate weighting factor for each characteristic. For illuminance categories A to C, if the sum of the weighting factors is -1 or -2, use the lowest of the three illuminances listed in Table 7. If it is +1 or +2, use the highest value; otherwise, use the middle value. For illuminance categories D to G, use the same approach with -2 and -3 and +2 and +3.

Finding Recommended Illumination Levels

As a working example, consider a conference room which is being remodelled to become an engineering office where engineers and their clients will review drawings and specifications. The room is finished in wood paneling and dark carpeting. Task background reflectance is medium. To arrive at the recommended illumination for the conference room, refer to Table 1. This table indicates category E for medium lighting tasks such as an engineering office. (Note that the category for conference room is D, therefore the remodeling involves an increase in the quantity of light needed in the engineering office.) People of all ages will be present (including those over age 55), speed and accuracy are important, and the reflectances are 30 to 70 per cent. From Table 8, a weighting factor of +1 is obtained. Applying this weighting factor to the range of prescribed illuminances for Category E in Table 1, a recommended illumination of 750 lx is indicated.

Calculating the Number of Lighting Fixtures Required

The "zonal-cavity method" is a prescribed procedure for calculating the number of lighting fixtures required to illuminate the entire horizontal plane 76 cm above the floor (the workplane), with a prescribed amount of average illumination. The factors which affect the number of lighting fixtures required are:

1. The efficiency of the particular lighting fixture in delivering light to the workplane;
2. The efficiency of the room sufaces in reflecting light onto the work plane; and
3. The ability of the lamps to keep producing light as they age.

The procedure effectively demonstrates that lamp efficiency is only one part of overall lighting system efficiency. Equally important is the proportion of the generated light that reaches the work plane. This proportion of "usable" light is called the co-efficient of utilization (CU) and is given by the manufacturer for each different lighting fixture type. The CU expresses the efficiency of a lighting fixture in delivering its light to the work plane.

The procedure also demonstrates the importance of high-surface reflectances in producing an efficient lighting system. Figure 8 shows the results of a lighting study which illustrates the above points in a quantitative manner. As can be seen, a lamp produced an average illumination level of 80 lx with the starting colour scheme. After adding ceiling trim to the walls to create a high-reflectance ceiling cavity and improving the other room reflectances, the same lamp supplied an illumination level in excess of 400 lx. A step-by-step example of the zonal cavity method is shown in the Energy Management Opportunities section.

Vertical Illumination

It should be noted that the zonal cavity method is concerned with providing average illumination on a horizontal plane only. The manner in which lighting technology has evolved has caused the recommended horizontal plane design to be applied in some factory situations where it is inappropriate. In such cases, the visual environment can be improved and energy saved by measuring lighting levels on the appropriate plane and positioning fixtures to obtain the desired results in the actual work plane.

With proper vertical illumination, vertical surfaces of machines, people, walls and objects in the field of view would appear brighter. In some locations, this would constitute a tangible improvement.

Task Lighting Without Any Overhead Lighting

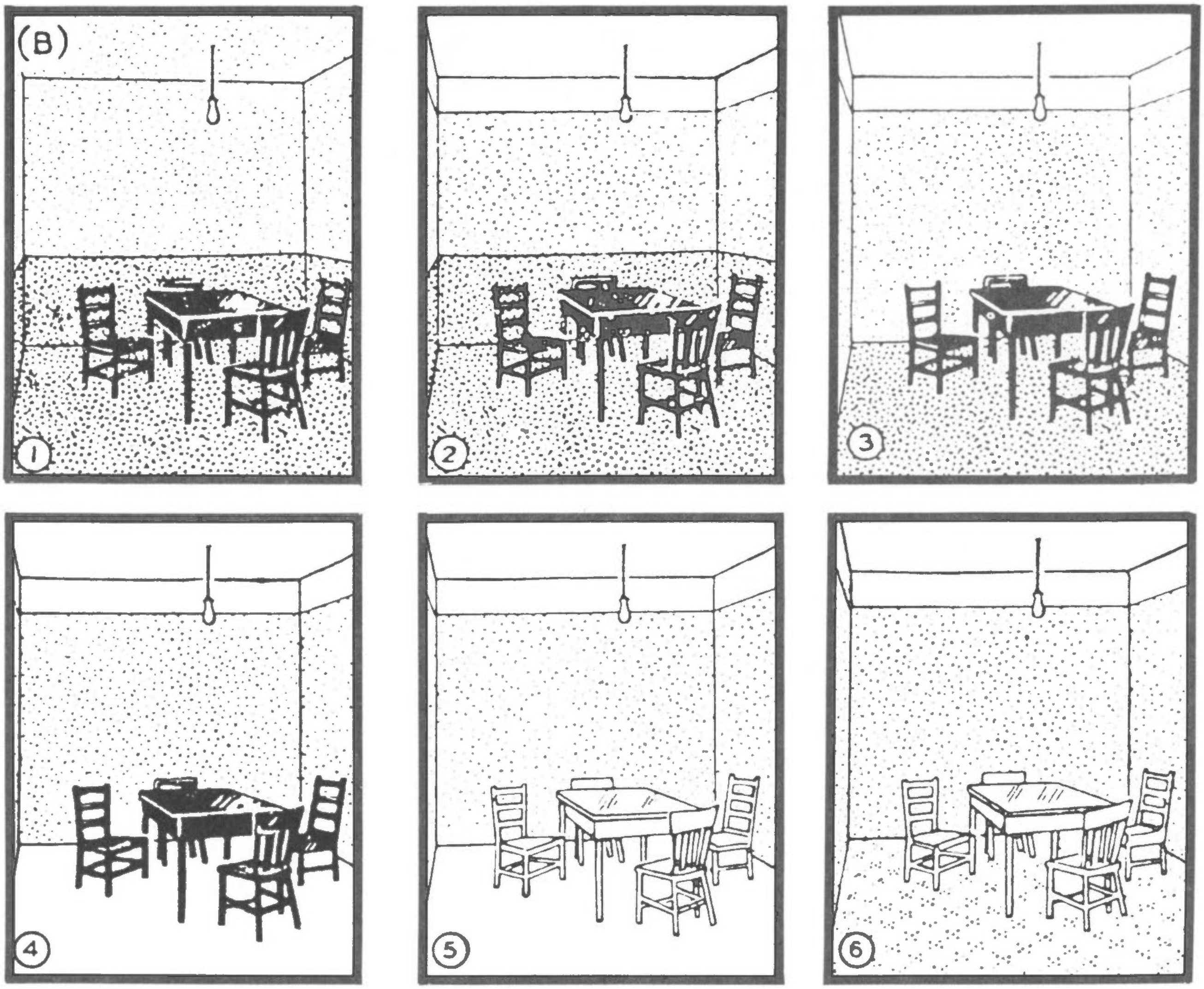
A combination of task and overhead lighting is the most economical means of providing high, local levels of illumination. The sole use of in-furniture lighting, without the use of any overhead lighting, is not energy efficient..

When furniture-mounted lighting fixtures are used to make up for a reduced number of overhead lighting fixtures, a greater variety of lamps and fixtures are required in inventory. This may tend to complicate a maintenance program and make quantity-discount prices less obtainable. Savings disappear rapidly when a poorly-informed maintenance person installs the incorrect lamp in a fixture.

Also, higher wattage, high intensity discharge (HID) lamps are more efficient and have longer lives than smaller wattage lamps. However, there are limits as to the size of lamp that can be used near a person's desk.

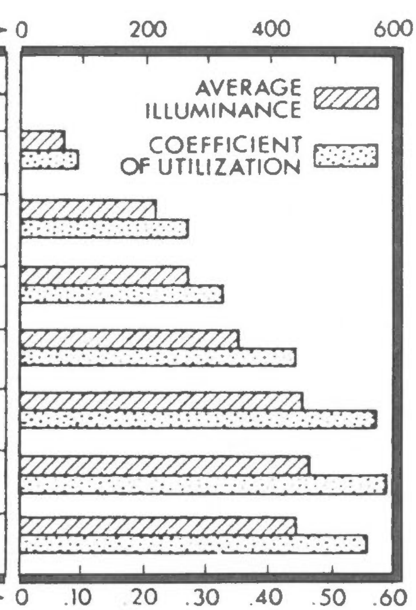
An energy-efficient, overhead lighting design in the under 20 W/ m^2 range can be produced with existing technology. Such is usually not the case when designing with an in-furniture, task-lighting concept with no overhead lighting.

In order to minimize energy losses in feeders, lighting loads should be served by as high a voltage as is practical and safe. Canadian Electrical Code compliance restricts the voltage permissible for in-furniture fixtures.



STEP	CEILING			WALLS		FLOOR		FURNITURE	
	HEIGHT	COLOR	ρ*	COLOR	ρ*	COLOR	ρ*	COLOR	ρ*
START	12 FT	WHITE	30						
1	10 FT		65	WHITE AND GRAY	40				
2	10 FT		85			DARK RED	12	DARK OAK	28
3	10 FT	CREAM	85						
4	10 FT		85	GREEN	72	WHITE	85		
5	10 FT		85					BLOND	50
6	10 FT		85			WHITE AND RUSSET	70		

*REFLECTANCE



(D)

Importance of High-Surface Reflectances
Figure 8

Task-ambient lighting not only produces its light in a working space but also converts all its power consumption into heat in the working space which results in the need for more frequent air changes and a more difficult (more energy-consuming) ventilation task.

Energy Audit Methods

An energy audit is essential to the successful implementation of any energy management program and the identification of energy management opportunities

Three types of information are required with regard to a lighting system.

1. The amount of energy the system requires.
2. The amount of illumination the system produces.
3. The amount of illumination required to execute the necessary visual tasks.

The type of lamp and luminaire, the input power and method of control, the visual tasks performed and their location and the operation and maintenance schedules are all relevant and important energy management considerations.

Walk Through Audit

The initial overall appraisal of a location's lighting energy consumption is called a "Walk Through Audit".

Diagnostic Audit

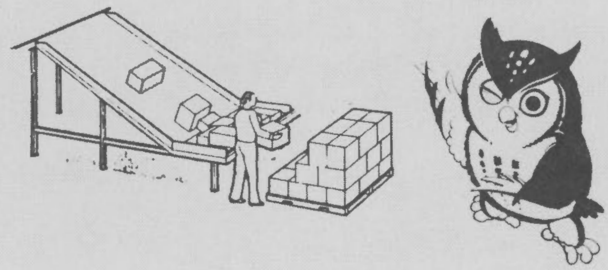
Improper illumination levels or inadequate lighting system performance uncovered in the Walk Through Audit would result in a Diagnostic Audit to mathematically establish the potential for reduction in energy consumption and cost savings. Using the ideas in this module, various forms of corrective action are compared and evaluated. These energy management opportunities can be divided into three categories:

1. Housekeeping opportunities refers to an energy management action that is repeated on a regular basis. Examples would be operation and maintenance schedules.
2. Low-cost opportunities refers to an energy management action that is done once and for which the cost is not considered great.
3. Retrofit opportunities refers to an energy management action that is done once and for which the cost is significant.

Note that the division between low cost opportunities and retrofit opportunities is ultimately a function of both the size and type of the organization as well as its cash flow position.

The Module in this series on "Conducting an Energy Audit" should be referred to for further information on undertaking an energy audit.

EQUIPMENT SYSTEMS



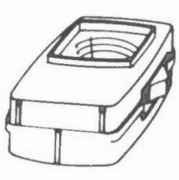
The field of lighting technology is rapidly evolving. The past 10 years have witnessed substantially new ideas and lighting products. Consider, for example, the fact that there are nearly 6,000 different types of lamps being manufactured today. In addition to lamps, there have been innovations in other products such as ballasts, lenses, luminaires, fixtures, switches, controls and emergency-backup power equipment for lighting applications. This section reviews and summarizes the technology involved in each of these product categories.

Portable Light Meters

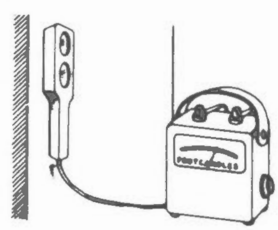
Lighting measurements are commonly made with small, low-cost portable light meters (Figure 9). These devices contain a light-sensitive cell which utilizes the photovoltaic effect to produce an illumination readout. Frequently, the light cell of a light meter takes the form of a separate light panel connected to the display via an extension cord (Figure 10). This enables the user to read the meter without imposing a shadow on the cell face. Light meters are available in a variety of lux ranges to suit a variety of applications.

Note that readings of a portable light meter have ±15 per cent accuracy. Even under favourable conditions, portable light meters are not precision instruments, therefore the following precautions are necessary when taking field measurements:

1. Use only calibrated instruments.
2. Ensure that the light meter is fitted with a colour-correcting filter (to approximate the response of the human eye).
3. Ensure that the light meter has a diffusing cover plate over the cell so that light arriving from all directions is properly evaluated. This feature is commonly called "cosine correction".
4. The light meter should be allowed a sufficient time span for the reading to stabilize before any measurements are recorded, particularly at high illumination levels.



Portable Light Meter
Figure 9



Light Meter With Extension
Figure10

Lamps

As shown in the Table 9, there are six different types of lamps. Incandescent lamps do not require a ballast but all other lamps do. These other lamps are called discharge lamps, meaning that light is produced through the excitation of gases located inside the lamp. Discharge lamps include fluorescent lamps, low pressure sodium (LPS) lamps, and high intensity discharge (HID) lamps. All gas discharge lamps require a ballast.

Luminous Efficacy

The maximum theoretical luminous efficacy of a lamp is 683 lumens per watt, corresponding to a lamp that emits all of its input power as luminous flux at the wavelength at which the human eye is most sensitive (555 nm). The LPS lamp which radiates strongly at 589 nm, comes closest to this ideal giving its characteristic amber light at an efficacy of 180 lumens per watt. Table 9 shows a lower value which reflects the additional ballast power. However, colour rendering is non-existent under this highly monochromatic (single colour) light. The maximum theoretical luminous efficacy of a good colour rendering (white light) source is 250 lumens per watt.

Per Cent Lumen Depreciation

All lamps fall off in light output as they age, a process of deterioration known as "lumen depreciation". The ability to maintain light output is called "lumen maintenance", and is expressed as the ratio of lumens emitted at some specified age (e.g. 70 per cent of rated life) to lumens emitted when new. Hence, if the rated life of a 100 W incandescent lamp is 1,000 hours and its initial lumen output was 1,200 lm, its output at age 700 hours would be 1056 lm. Given this, the percentage of lumen depreciation would be (1200 - 1056) ÷ 1200 or 12 per cent. Lumen maintenance would be 88 per cent.

Colour Appearance Of A Lamp

Lamp manufacturers classify the colour appearance of lamps with the words "warm" and "cool":

Warm: Similar to the light of filament lamps; preferred in cold climates and where the warm colour of filament lamps is traditionally accepted, such as in hotels and restaurants.

Cool: Similar to daylight with sunlight; preferred in warm climates and where a cool effect with good colour rendering is required, such as in executive offices and retail stores.

Incandescent Lamps

The incandescent lamp is the most commonly used lamp today. It is also the lamp with the lowest luminous efficacy and the shortest life. The lamp and fixture is popular because of its relatively low initial cost and ease of use as no ballast is required.

Incandescent lamps produce light by heating a small filament wire. This is a completely different method to that found in gas discharge lamps. Because of heat losses, light production by incandescent lamps is inherently inefficient (15 lm/W).

The incandescent lamp is designed so that its lamp life may be extended to almost any desired value. But efficiency decreases with increased lamp life. For instance, a lamp designed for long life is inherently inefficient because of lumen depreciation. Since the cost of energy consumed by a lamp during its life is anywhere from six to 25 times its own cost, lamp efficiency is also six to 25 times more important, economically, than lamp life. At $0.06/kWh, the energy consumed by a 100 W lamp costing $0.50 and having a life of 750 hours, would cost $4.50.

Energy cost savings make a review of all filament lamp installations necessary, especially in general lighting installations.

Some common incandescent lamp applications include spot and flood lighting, as well as indoor and outdoor decorative and security lighting in meeting rooms, lobbies, corridors and restaurants. For aesthetic reasons, there are always some applications for incandescent lamps. The way to meet these situations in a realistic, energy-efficient manner, is to consider either the tungsten-halogen or the ellipsoidal reflector (ER) variations of the incandescent lamp.

Tungsten-Halogen Lamps

The halogen gas in the tungsten-halogen (or quartz) lamp causes a chemical reaction which keeps the interior of the bulb clean and thus makes for a more energy efficient lamp. Lamp life is also extended by the chemical reaction cycle which redeposits vapourized tungsten back on the remaining tungsten filament. Unfortunately, all the tungsten does not redeposit itself on the spots from which it vapourized. Hence, this lamp also has a finite life. A 1,200 W tungsten-halogen lamp costs some 20 per cent more than the conventional 1,500 W lamp that it replaces. Over its 2,000 hour life, it saves about $36 (at $0.06/kWh) despite its initial extra cost.

Reflectorized Lamps

Reflectors and lenses are sometimes fitted to lamps to produce a reflectorized lamp. These lamps are of two-piece, heat-resistant glass construction. One piece is used for the parabolic reflector and the other for the lens. A reflectorized lamp can direct and concentrate light on a task surface where it is needed. For example, a 75 W ER (Ellipsoidal Reflector) lamp delivers more light to the task surface than a 150 W, R-40 lamp when the lamps are mounted in a downlight type fixture.

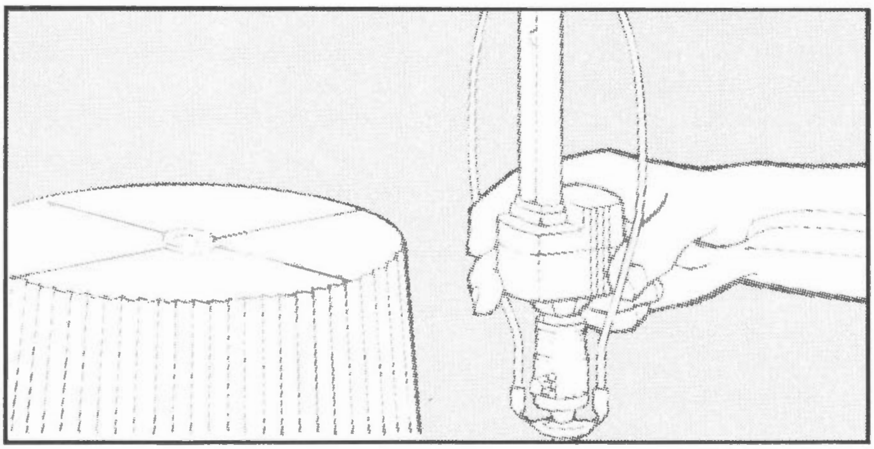
The three types of reflectorized lamps most widely used: Reflector (R), Parabolic Aluminized Reflector (PAR), and Ellipsoidal Reflector (ER). PAR lamps (Figure 11) are made of hard, heat-resistant glass and thus are suitable for outdoor as well as indoor use. The special shape of the ER lamp focuses the exiting light a couple of inches away from the bulb, allowing very little light to be trapped by the fixture baffles.

PAR Lamps

Figure 11

Using Other Types of Lamps in Incandescent Fixtures

Ordinary incandescent fixtures can be made energy-efficient with small (seven inches long, three-inch diameter and including an integral, disposable ballast) MH (metal halide) and fluorescent lamp replacements for incandescent lamps (Figure 12).

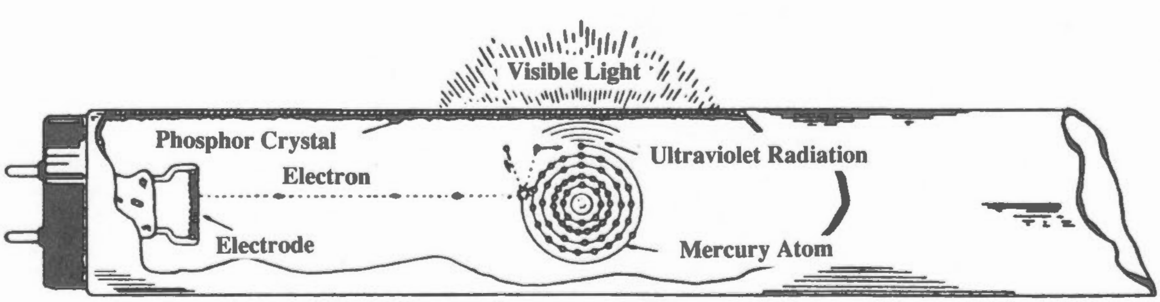


Replacements For Incandescent Lamps

Figure 12

Fluorescent Lamps

The fluorescent lamp is a low pressure, mercury vapour discharge lamp. It efficiently emits ultraviolet radiation which is transformed into visible light by a phosphor coating on the interior of the lamp (Figure 13).



Fluorescent Lamps

Figure13

Types of Fluorescent Lamps

Many different models of fluorescent lamps are available:

CW — Cool White
WW — Warm White
CWX — Cool White Deluxe
WWX — Warm White Deluxe
ES — Energy Saving
HO — High Output

Fluorescent Lamp Uses

The fluorescent lamp is the second most commonly used lamp and is typically found in stores, offices, industrial plants, stores, schools, hospitals and other institutions.

Operating Temperature Considerations

If a fluorescent tube is operated at an ambient temperature above 35° C, such as in an enclosed luminaire, then special purpose, amalgam lamps should be used. Otherwise, light output may be reduced by as much as 30 per cent. The fluorescent tube amalgam is composed largely of mercury and argon.

Energy-saving lamps are not recommended for use where the ambient temperature may fall below 16° C. Low ambient temperatures can result in a flickering of light emitted by the energy-saving lamp. Also, light output can be reduced, the ends of the lamps can discolour, and lamp life can decrease.

Energy-Saving Fluorescent Lamps

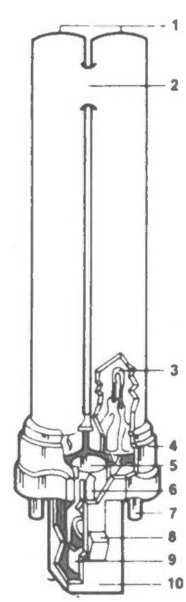
Typically, a 100 W krypton-filled, energy-saving fluorescent lamp is used in place of a regular 125 W fluorescent lamp. While there is a 10 per cent reduction in luminous flux, there is also a 20 per cent reduction in electrical consumption which makes the energy-saving fluorescent more energy efficient than the standard fluorescent tube.

Another type of energy-saving fluorescent lamp is the reduced diameter (26 mm compared to the normal 38 mm) tube with multi-layered phosphor. 40 watt bulbs are typically replaced with 35 watt bulbs, for a 12.5 per cent energy saving.

Small Dual-Tube Fluorescent Lamps

Figure 14 shows another type of fluorescent lamp. This single-base, dual-tube lamp is an energy-efficient compact (one-eighth of the old tube length) lamp which, because of its small size, allows for new design possibilities. These dual-tubes are all fitted with an integral power factor correcting capacitor. A special adaptor allows the lamp to fit directly into an incandescent lamp socket. This means a 60 W incandescent can be replaced with a 10 W dual tube which can last as much as 10 times longer.

1. **Cool Spots**
2. **Bridge Welding**
3. **Electrodes**
4. **Aluminum Cap**
5. **Starter**
6. **Bi-Metal Strip**
7. **Two-Pin Electrical Connection**
8. **Retention Notch**
9. **Capacitor**
10. **Housing**
11. **Ballast Base Enclosure**
12. **Ballast**
13. **Ballast Plate**
14. **Lampholder**
15. **Ratchet Medium Base**

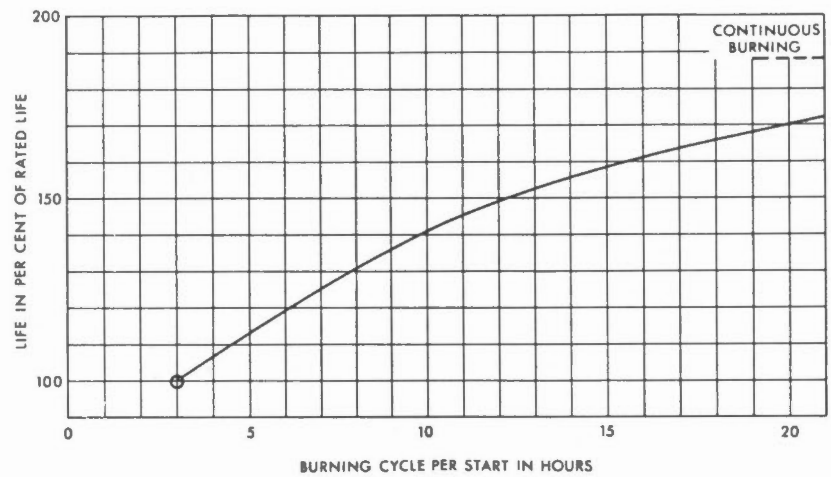


Dual-Tube Fluorescent Lamp

Figure 14

Fluorescent Lamp Life

Fluorescent lamp life depends on the average number of hours the lamp is burned each time it is started (Figure 15). The ranges given in Table 9 are based on three burning hours per start. Preheated fluorescent lamps have life ratings at the low end of the range, namely 7,500 or 9,000 hours. Instant-start lamp life is 12,000 hours and rapid-start lamp life is rated at 18,000 or 20,000 hours.



Fluorescent Lamp Life

Figure 15

Fluorescent Lamp Percentage Lumen Depreciation

Referring to Figure 15, the 100 hour lumen value for the fluorescent lamp (referred to as the initial lumens) and lumen depreciation are calculated from that point onward, assuming 3 hours per start. Two lumen depreciation factors are often given. One is the percentage of initial lumens expected at 40 per cent of rated life, which gives average lumens between relampings for use in economic studies. The other is the percentage of initial lumens at 70 per cent rated life, which gives the minimum lumens between relampings for use in determining the number of luminaires required.

Fluorescent Lamp And Ballast Replacement

Because the fluorescent lamp is so widely used, a lighting energy management program usually involves the analysis of lamp replacement possibilities with either a more efficient fluorescent lamp or ballast or a different type of lamp altogether.

The pseudo or "phantom tube" is a replacement fluorescent tube that produces no light and reduces electrical consumption by one half on a two-lamp fluorescent ballast. Why not just remove one of the lamps? There are two problems with such an approach. Since the ballast is wired in series, removing one lamp will extinguish the other. Also, the original power factor of 0.96 is reduced to 0.20 by removing one lamp. (Low power factor wastes energy and could result in higher electric utility charges.)

Replacement of fluorescent lamps with energy-saving lamps can take place either at spot lamp replacement or during group relamping operations. Group relamping has inherent labour savings and is examined more closely in the Energy Management Opportunities section.

In lighting fixtures with two lamps per ballast, low-wattage lamps should not be mixed with standard efficiency lamps on the same ballast. The imbalance in voltage and current can result in premature lamp failure.

Caution should be used in installing low-wattage lamps on ballasts which are more than 15 years old. These ballasts may fail prematurely with low-wattage lamps.

Ballast replacement is generally only economical when the existing ballasts need to be replaced anyway. A high rate of ballast failure denotes that existing ballasts are close to their end of their life and hence require replacement.

Conversion of fluorescent fixtures to HID fixtures requires a complete replacement of housing, ballast and lamp. The mounting height may also have to be changed.

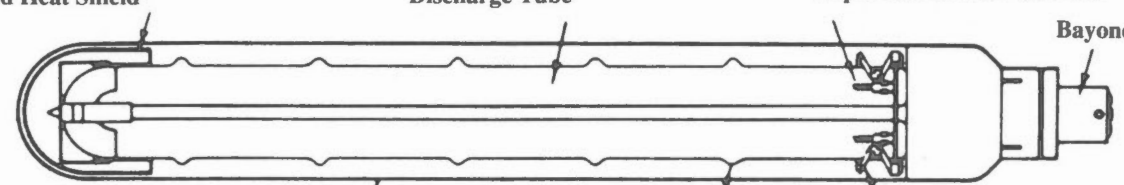
Low Pressure Sodium (LPS) Lamps

Low pressure sodium lamps (Figure 16) are easily identified by the green-yellow light they produce. Colour rendering of low pressure sodium lamps is non-existent. Only shades of gray are seen with all colours except green-yellow.

The rated life for all low pressure sodium lamps is 18,000 hours, with a burning time of five hours per start. Warm up time is seven to 15 minutes. Hot re-ignition is good and most low pressure sodium lamps will restart immediately after power interruption.

There is no depreciation in light output over the life of the lamp. Efficacies range between 137 and 183 lumens per watt, depending upon wattage. Maximum efficacies including wattage loss of ballasts, are high — about 150 lumens per watt.

Low pressure sodium lamp applications are found where colour rendering is not important, e.g. roadways, parking areas, and storage areas.



Low Pressure Sodium Lamps

Figure 16

High Intensity Discharge (HID) Lamps

High intensity discharge (HID) is the term used to designate three distinct lamp types: mercury vapour (MV), metal halide (MH) and high pressure sodium (HPS).

As in all discharge lamps, HID lamps produce light by establishing an arc between two electrodes. In HID lamps, however, the electrodes are only a few inches apart. Arc tube lengths range from a few centimeters for general lighting applications to only a few millimeters for very compact, high-brightness sources. As with all HID lamps, starting involves establishing a discharge current path with an adjacent starting electrode until the temperature rise allows the main discharge to ignite. Therefore, HID lamps require one to seven minutes to come up to full light output after being energized. If power to the lamp is lost or turned off, the arc tube must cool before the arc can be restruck.

Mercury Vapour (MV) Lamps

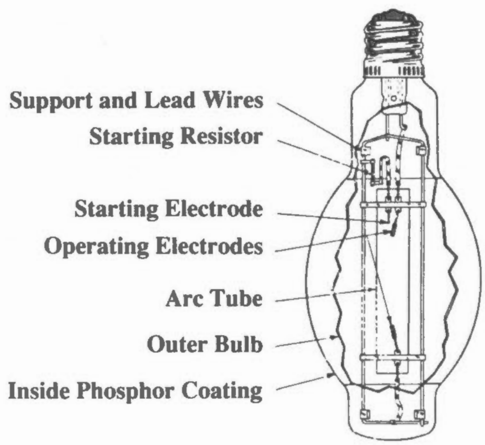
By increasing the pressure of the the low pressure mercury fluorescent tube to one to two atmospheres, a mercury vapour discharge can be made to directly emit visible light. In this case, the characteristic UV (253.7 nm) mercury radiation is re-absorbed and a bare tube emits only five per cent of its input power in UV. Phosphors are used but unlike fluorescent lamp phosphors these are required to absorb long-wave UV radiation and emit light in the orange-red part of the visible spectrum in order to improve the lamp's colour performance.

High pressure mercury lamps (Figure 17) normally require a ballast but in so-called "blended lamps" a tungsten filament is included in series with the arc tube in lieu of an ordinary ballast. These blended lamps provide a useful plug-in replacement within the same fixture for incandescent lamps with a four-fold increase in lamp life. The principal advantages of self-ballasted mercury lamps are simplicity of installation and long-rated average life. This is generally between 12,000 hours and 16,000 hours, with the added benefit of eliminating capital investment in new fixtures and auxilliary equipment that usually accompanies a conversion from incandescent to high intensity discharge lighting.

The mercury lamp life rating of 24,000 hours is not the 50 per cent survivor point. Rather, it is the point at which the lumen output has dropped so low that the lamp is no longer economically viable.

With all HID lamps, as well as fluorescent lamps, initial lumens are all taken after burning 100 hours because a brand new lamp contains impurities which are burned away during this initial period. Because of these impurities, a completely new lamp emits significantly less light.

Mercury vapour lamps are commonly used in the floodlighting of parking areas, industrial applications, streets and highways, high-ceilinged offices and transportation terminal buildings.



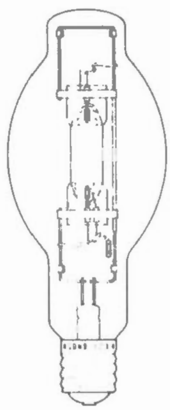
High Pressure Mercury Lamps
Figure 17

Metal Halide (MH) Lamps

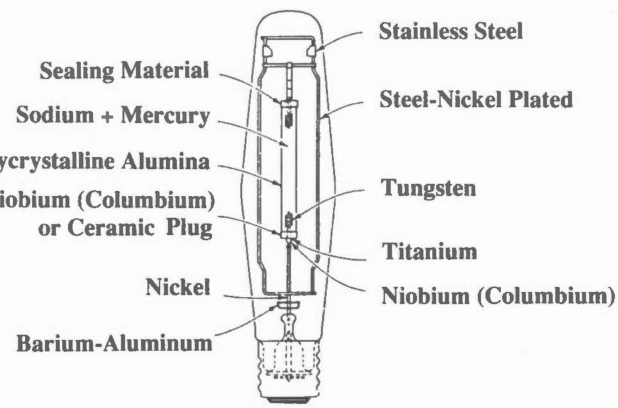
There has always been interest in using metals other than mercury in arc discharge lamps to improve a lamp's colour performance. Mercury vapour lamps produce a bluish-green white light with no reds or oranges. Phosphors are applied to the inside of the outer glass bulb to convert UV radiation into red visible light. Attempts to efficiently produce visible radiation in this manner were prevented by technical difficulties until the metal halide lamp was discovered in 1960.

Metal halide lamps (Figure 18) have a high luminous efficacy and good colour rendition. They offer an alternative to fluorescent lamps where a compact light source is preferred. Its unique capabilities have led to increased applications in floodlighting where it can be dimmed to 40 per cent without change in its colour temperature. Metal halide lamps also show greater lumen depreciation than other HID lamps. This is caused by a shift in the chemical balance of the halide additives as the lamps age.

A lighting energy management program should favour metal halide and high pressure sodium lamps, as they are the most energy-efficient lamps that also offer good colour rendition. Metal halide lamps are commonly used in colour television and film, playing field floodlighting, as well as in public, commercial and industrial locations.



Metal Halide Lamps
Figure 18



High Pressure Sodium Lamps
Figure 19

High Pressure Sodium (HPS) Lamps

The high pressure sodium lamp (Figure 19) offers a good compromise between luminous efficacy and colour rendition. The lamp should be burnt in purpose- designed luminaires to achieve correct operating temperature and thus optimize efficacy and life (50 per cent survival in excess of 24,000 hours). Conventional HPS lamps have been used successfully for commercial interior lighting. Saturating with 1,000 lx of illuminance and using colours that are enhanced by HPS, creates the impression of white light.

High pressure sodium lamps are recommended for use in a wide variety of applications including roadways, the floodlighting of large surfaces, airports, parking lots, and industrial and commercial interior locations.

Ballasts

If ballasts are required to start or operate a lamp, the watts dissipated by the ballast should be charged to the lighting system. If a fluorescent lamp, for example, emits 3,000 lm and consumes 40 W, and its ballast consumes 10 W, the lamp/ballast efficacy would be listed as 60 lm/W, not 75 lm/W.

Since the resistance of a gas discharge is negative, a ballast containing current-limiting control gear is always required with gas discharge lamps. Note that different lamp types each have specially designed ballasts. Therefore, different ballasts are not normally interchangeable.

Ballast Functions

A ballast has six functions in addition to the fundamental function of limiting current in the negative resistance arc. These six functions are to:

1. Provide sufficient voltage to initiate the arc.
2. Regulate the lamp current against line voltage change.
3. Re-light the lamp on each half cycle of the applied ac voltage.
4. Minimize power loss.
5. Establish the proper lamp operating temperature.
6. Provide high power factor.

For lamps operating on dc (direct current), a simple series resistance might serve as a ballast. With ac (alternating current), reactive ballasting avoids resistor heat-power loss.

Energy-Efficient Ballasts

Since a ballast consumes 20 per cent of a lighting system's power, special energy-saving versions of the traditional magnetic ballast have been developed to compete with the high-efficiency electronic ballasts now on the market. While the greater cost of the electronic ballast does not automatically justify resultant energy savings (e.g. 10-year payback), combination systems consisting of both a lamp and a ballast which contains some electronics are sometimes viable (two-year payback) energy conservation options.

The following ballast features are available on the market and illustrate what has been accomplished technically with energy-saving electronic ballasts:

1. The energy-saving electronic ballast operates fluorescent lamps at 27 kHz, thereby causing the lamp to produce more lumens with less energy. Note that an ordinary ballast operates at the power-line frequency (60 Hz).

2. Since the ballast uses less energy, the energy-saving electronic ballast operates at a cooler temperature, which in turn translates into longer life. The projected lifespan is 55 years, based on 4,000 hours of annual operation.

3. The energy-saving electronic ballast is fully interchangeable with a conventional ballast.

4. A simple manual adjustment on each ballast enables tailoring the light output to individual task requirements.

5. Lamp power is automatically increased when the lamp is dimmed in order not to compromise lamp longevity.

6. The energy-saving electronic ballast can be used with an automatic energy control system. This is not the case with a conventional ballast which provides only a fixed output.

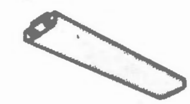
Significant progress has also been made in the development of more energy efficient magnetic fluorescent ballasts. Energy-saving fluorescent ballasts used with standard lamps can reduce lighting energy consumption by as much as nine per cent, due to decreased wattage loss within the ballast's steel core and copper windings. The lower operating temperature of these ballasts results in an average ballast life that is two to three times longer than the 12-15 year life of ordinary ballasts.

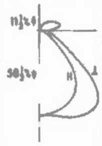
In addition, other ballast variations are also available. These include reduced light output ballasts which reduce both light and energy consumption; dual-level ballasts which permit the option of full or reduced light output by changing the ballast connections; and dimming ballasts for use with fluorescent lamps.

Fixtures

Fixtures have a significant impact on both the energy efficiency and quality of lighting. The basic distinguishing feature of a fixture is the percentage of its light that it reflects up toward the ceiling and down toward the task (Figure 20). As the earlier discussion of the coefficient of utilization (CU) stressed, an important consideration in lighting system efficiency is having an efficient fixture with a high CU which directs most of its light directly down onto the task surface. A fixture's CU is roughly inversely proportional to its visual comfort probability (VCP). Nonetheless, some manufacturers offer high-quality fixtures which provide both high efficiency and good glare control. These are the fixtures that should be specified.

Another consideration in fixture selection is the fixture's resistance to dirt accumulation. As noted in the zonal-cavity calculation, luminaire dirt depreciation (LDD) factor affects the number of luminaires required to achieve a targetted average horizontal illumination in a given space.





Typical Luminaire	Typical Intensity Distribution and Per Cent Lamp Lumens		ρ_{cc} →	80			70			50			30			10			0	
			ρ_w →	50	30	10	50	30	10	50	30	10	50	30	10	50	30	10	0	WDRC
	Maint Cat	SC	RCR ↓	Coefficients of Utilization for 20 Per Cent Effective Floor Cavity Reflectance (ρ_{fc} = 20)																
6	V	1 5/1 2	0	81	81	81	78	78	78	72	72	72	66	66	66	61	61	61	59	—
			1	71	69	66	69	66	64	64	62	60	59	58	56	55	54	53	50	204
			2	64	59	56	61	58	54	57	54	51	53	51	49	49	48	46	44	184
			3	57	52	48	55	50	47	51	48	45	48	45	42	45	42	40	38	168
			4	51	46	41	49	44	41	46	42	39	43	40	37	41	38	35	34	156
			5	46	40	36	44	39	35	41	37	34	39	35	32	37	33	31	29	147
			6	41	35	31	40	35	31	38	33	30	35	31	28	33	30	27	26	137
			7	37	31	27	36	31	27	34	29	26	32	28	25	30	27	24	23	129
			8	33	28	24	32	27	23	30	26	22	29	25	22	27	24	21	19	122
2 lamp prismatic wraparound			9	30	24	20	29	24	20	27	23	19	26	22	19	24	21	18	17	116
			10	27	22	18	26	21	18	25	20	17	23	19	16	22	18	16	15	110

Coefficient of Utilization (CU)

Figure 20

Fixture Lenses And/Or Louvers

Most fixtures can be ordered with any one of several different lens or louver grid options. Some fixtures are designed for use without any type of shielding or diffusing media. These are generally used at high-mounting heights to lessen glare and the likelihood of lamp breakage.

As a minimum standard of quality, all fixture lenses should be specified as 100 per cent virgin acrylic plastic with a useful life of 15 to 20 years. For non-critical task areas, high VCP can be ensured with tinted prismatic lenses at a relatively small additional cost. For critical task areas, the more expensive and energy efficient refractive grid lens is recommended. This high-performance lens provides good-quality lighting which can reduce worker fatigue, in computer terminal rooms, for example.

Lenses and louver grids are made to distribute light in specific patterns and directly influence the VCP and the CU of a fixture. Table 10 illustrates the important characteristics of a typical standard fluorescent troffer. Ranges of VCP and percentage efficiency are shown. A given lens will have different effects in different fixtures because a fixture's shape and the nature of its reflective surfaces also affect light distribution.

Some lenses are particularly appropriate for illuminating vertical tasks because they distribute more light from top to bottom than they do from side to side.

It may be said that the distribution of light is even more important outdoors than it is indoors because there are no walls or ceilings that can be used for control purposes. Special tamper-proof lenses are available for areas subject to vandalism.

Dynamic Air-Handling Fixtures

Many benefits can be obtained by passing return air through the lighting fixture compartments:

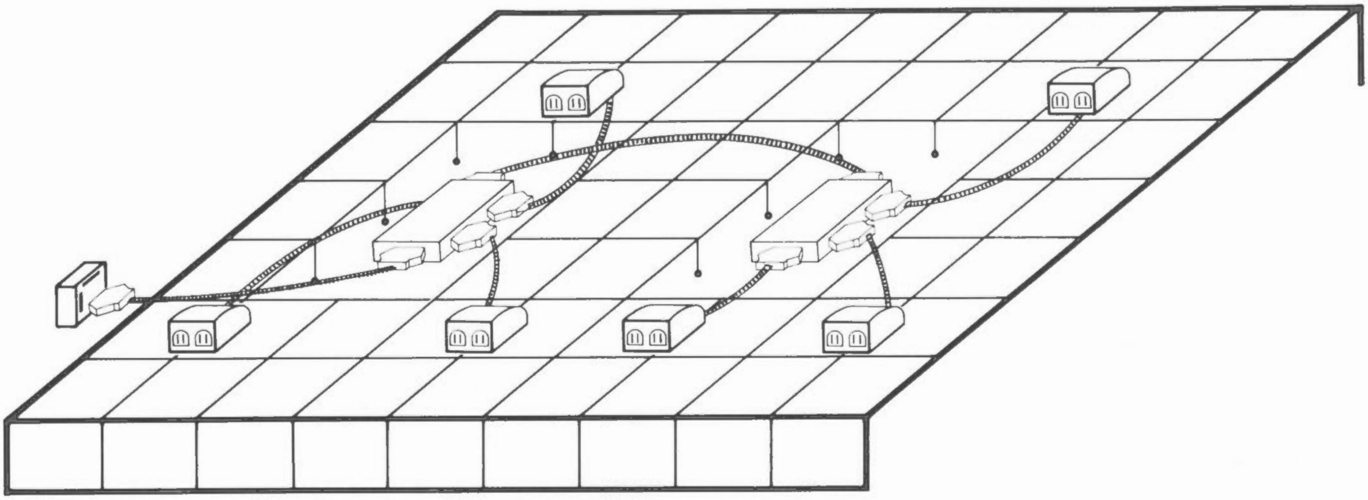
1. Fluorescent lamps experience a 25 per cent increase in luminous efficacy. (Fluorescent lamps emit more lumens at lower temperatures. HID lamp efficacy is not affected at all.)

2. All types of lamps and ballasts will run cooler and therefore have longer lamp life.

Modular Wiring Systems for Lighting

When designing a new building or retrofitting an existing one, consideration should be given to the installation of a modular wiring system (Figure 21) for overhead lighting. A modular wiring system is an alternative to more traditional conductor and conduit type of electrical wiring system. The modular type more easily facilitates lighting fixture layout changes. A modular wiring system cuts by 50 per cent the cost of layout changes and permits liberal use of the energy-efficient task lighting. This means providing the quantity and quality of light only in the immediate area where the actual requirement exists, as opposed to providing lighting everywhere to meet the highest illumination requirement of the entire area.

Because modular wiring systems can be completely and conveniently removed from a building, they are not considered part of the building but rather, tangible personal property like other office equipment and furnishings. As such, they may receive favorable tax treatment which should be carefully considered in any cost/benefit analysis.



Modular Wiring Systems

Figure 21

Lighting Controls

Lighting controls play a key role in lighting system energy management. A simple switch in the proper place can bring about important energy savings. Controls can be divided into two basic categories, namely manual and automatic.

Panelboard Controls

A lighting system is energized through an electrical service panelboard. Therefore, the lights can always be turned on or off by switching the appropriate breaker in the electrical panel. Since no additional controls are needed there is an additional saving on initial equipment and wiring costs.

Common Wall Switches

Local snap switches can permit selective use of lighting. A key factor is the convenience of the switch location which in turn is governed by the type of occupancy.

Key-Activated Switches

Key-activated switches prevent unauthorized use of certain lighting circuits and are particularly recommended for use with HID lamps.

Controls for Multi-Level Illumination

The same area might require different levels of illumination at different times. For example, a high level of illumination may be needed for normal office hours, while a low level of illumination may be needed for janitorial maintenance activities. Controls should therefore be arranged in such a way as to provide even illumination at all levels by either switching adjacent fixtures or adjacent lamps. In four-lamp fluorescent fixtures, the two inner lamps powered from a separate two-lamp ballast can be switched off to provide uniform low level illumination.

Telephone Signal-Activated Lighting Controls

Push-button, tone dialing telephone circuits permit the remote control of individual lighting groups via telephone. The user dials the telephone number of the control device, hears a beep, and punches in a code. This action results in the remote control of the lighting system.

Low-Voltage Switching Systems

A low-voltage switching system (24 V or less) consists of relays, switches and transformers. When a switch is toggled, it sends a low-voltage "command" to a relay which in turn energizes the lights. The relays can also be wired with local overrides.

Solid-State Dimmers

Solid-state dimmers reduce energy consumption when the lights are dimmed, as compared to rheostat dimmers which waste energy through heat loss. Some dimmers operate with standard ballasts while others require a special dimming ballast.

Ballast Load Switching Systems

Controls are also available which send control signals over existing lighting circuits, typically at 30-52 kHz.

Hi-Lo Switching

Instead of the continuous range of dimming provided by dimming controls, Hi-Lo alternate ballast switching provides only two levels of illumination: full and half. Energy is saved because maintenance functions can easily be performed at half normal illumination.

Hi-Lo switching is accomplished by wiring the outboard tubes of a 4-tube fixture to the "Hi" switch and the inboard tubes to the "Lo" switch (normally specified as the switch closest to the door jam). When only the Lo switch is activated, there is both a 50 per cent energy saving and a 47 per cent reduction in lighting output because the luminaire delivers light from the inboard tubes more efficiently than from the outboard tubes. Some successful office lighting designs have Hi-Lo switching to each individual fixture, giving the occupant the alternative of adapting the lighting to individual needs and therefore possibly saving energy.

The cost of Hi-Lo switching involves the initial cost of extra wiring. For a new installation this involves running two wires instead of one. Retrofit costs are often significant.

Time Switches

Time switches are extensively used for outdoor lighting applications, as well as for indoor applications, to activate lighting at a preset time. An astronomic dial used with time switches adjusts the control for changing hours of daylight and darkness throughout the year. Many are equipped with battery packs or spring-wound mechanisms to maintain calibration despite utility power interruptions. Most are programmable on a weekly basis.

Photoelectric Cells

Photoelectric cells react to ambient lighting levels. Already used extensively outdoors, these controls are now finding more indoor applications to control lamps near windows and skylights.

Occupancy Sensors

Personnel detection for lighting control is available in three different varieties: ultrasonic controls based on physical movement; infrared controls based on heat energy given off by humans; and acoustic controls activated by sounds within a prescribed range of frequencies limited to "human activities".

Automatic Energy Control Systems (AEC)

The light output of a lamp gradually declines over its lifespan. As previously shown, this factor is taken into account when determining light loss factor (LLF). The result is that the initial lumens of a brand new system are greater than the requirements, since allowance has been made for light loss as time progresses. (Systems are usually designed around lamp output at 70 per cent rated life). An AEC system measures the light output and dims the lamp to provide only the required illumination level, thus saving energy. With AEC, lamps can be utilized to the end of their life cycle with consequent impact on maintenance costs.

Emergency Backup Lighting

Fluorescent

An energy-efficient approach to the provision of emergency backup lighting for fluorescent lighting installations is the use of fixture-installed, inverter-rectifier battery packs. These units are not sold directly by the major lighting manufacturers to the end user. Rather, the battery packs can be obtained from lighting OEMs (original equipment manufacturers).

High Intensity Discharge

For HID (High Intensity Discharge) lighting installations, the recommended energy-efficient approach is to employ a centrally-located, inverter-rectifier system which is similar to a UPS (Uninterruptible Power Supply). Unlike a UPS, however, an inverter-rectifier system allows a temporary power loss when the utility service is interrupted. Nevertheless, the limited power of the inverter-rectifier unit batteries will keep the emergency lights on and costs less per watt than a UPS.

(If the lights were permitted to go off, then a 10 minute cool-down period before restriking would be required. In addition, an additional eight to 10 minutes would be required to allow the lamp to reach full intensity. This would compromise the safety of building occupants. It should be noted that HID lighting is often key-switched in order to prevent accidental shut down.)

Another energy efficient way to backup HID lighting is to provide a sparse layer of emergency fluorescent lamps which can provide low-level illumination.

Outdoor Equipment

The following recommendations may result in more energy-efficient lighting installations:

1. The use of conventional 40 W fluorescent lamps in a two-lamp ballast fixture offers a 17.4 per cent energy saving, compared to the use of two single 40 W lamps. In order to retain the 28,860 hours rated life-span (at 10 hours burn-time per start), VHO (very high output) lamps should not be specified. VHO lamp use can result in both higher installation and higher maintenance (life-cycle) costs.

2. The use of plastic or fiberglass fixture bodies can be the best defence against luminaire dirt depreciation (LDD), a prime consideration in outdoor installations. By using plastic fixture bodies, shock hazard can be eliminated.

3. The use of 100 per cent acrylic plastic for the fixture lenses is recommended. The sun tends to yellow less-expensive polystyrene lenses in two or three years, degrading light transmission and leading to more expensive compensation elsewhere in the system.

4. The use of wraparound lenses with gaskets enclosing the lamps and a -18° C ballast. The -18° C ballast ,when enclosed, is suitable for even the coldest applications. It can eliminate the need to resort to a more expensive minus 29° C ballast. The gasketted enclosure may also ensure that the lamp efficacy is not reduced to unacceptable levels as a result of an inappropriate lamp operating temperature.

The following recommendations could result in more energy efficient parking lot and industrial yard lighting installations:

1. Clear lamps are preferred to using phosphor-coated lamps. This permits better optical control and more efficient lighting distribution.

2. Taller light standards permit the use of more efficient, higher wattage lamps. This in turn decreases the number of poles required.

3. Select a luminaire that directs light downward. This controls glare and light spillage. Another parking lot visual task to be considered here is keyhole location.

4. Insufficient colour rendition of an HPS lamp could unduly complicate car identification, a common parking lot visual task.

5. Plan for timely daytime switch off (e.g. astronomic dial-time switch which automatically accounts for seasonal

changes in daylight time or photocontrol).

Security Lighting

Lighting for fenced, guarded, perimeters involves aiming the luminaire away from the guarded facility straight into the surrounding field. Energy conservation in this situation would probably concentrate on the potentially-expensive lighting backup system which would have to cope in the event of a utility service interruption.

There are three important factors to be considered with typical night-lighting applications.

1. To provide safety exit lighting;
2. To provide an attractive, aethestically pleasing building exterior; and
3. To discourage vandalism.

Apart from installing standard exit lights, which are often required by law, an effective way to address the second and third factor while at the same time conserving energy, is to flood the exterior walls with light from a wide-distribution luminaire aimed up at the building. Intruders are easily distinguished in silhouette. The same idea is useful for creating safe, secure walkways at energy levels of 0.014 W/m^2.

ENERGY MANAGEMENT OPPORTUNITIES

Energy Management Opportunities is a term used to identify various opportunities for improving energy efficiency and, consequently, reducing operating costs.

For the purpose of this module, this section on Energy Management Opportunities has been divided into three categories: Housekeeping Opportunities, Low-Cost Opportunities, and Retrofit Opportunities. Detailed worked examples have been incorporated to assist the reader in the implementation of energy management activities. This is not a complete listing of the energy management opportunities available for lighting systems. It is intended to provide ideas for management, operating and maintenance personnel who are responsible for developing and maintaining energy management programs.

Housekeeping Opportunities

Housekeeping opportunities are energy management opportunities that are undertaken on a regular basis and never less than once a year. The following actions are typical housekeeping energy management opportunities:

1. Initiate a record-keeping system. This will provide a basis for informed, energy-management decisions. Such a system should indicate the recommended lighting levels for each area, the field-measured lighting levels, the connected lighting power and any remarks concerning the current status of the lighting installation. This documentation forms the basis from which potential improvements can be planned.

2. Reduce light levels. The record-keeping system might indicate over-illuminated areas. Reducing illumination to recommended levels is clearly the first housekeeping measure to be performed. Another measure which is often possible is to take advantage of increased daylight transmitted through windows during the summer months. Certain fixtures can be switched off during the summer months and a location can still maintain recommended lighting levels.

3. Modify patterns of use. For example, plan to turn off lights during unoccupied times. Here, again, good records can help pinpoint energy management opportunities. Since the number of lamp switch cycles can impact on lamp life, manufacturers' data should be used to calculate the economic benefits of planned shutdown periods.

4. Refine the lighting system maintenance program. Lighting system degradation is caused by various factors, including the lamp operating temperature and voltage, the lumen depreciation, the deterioration of luminaire surfaces, lamp burnouts and dirt accumulation on luminaires and room surfaces. A comprehensive lighting maintenance program can influence some or all of the factors involved in lighting system degradation.

Housekeeping Worked Examples

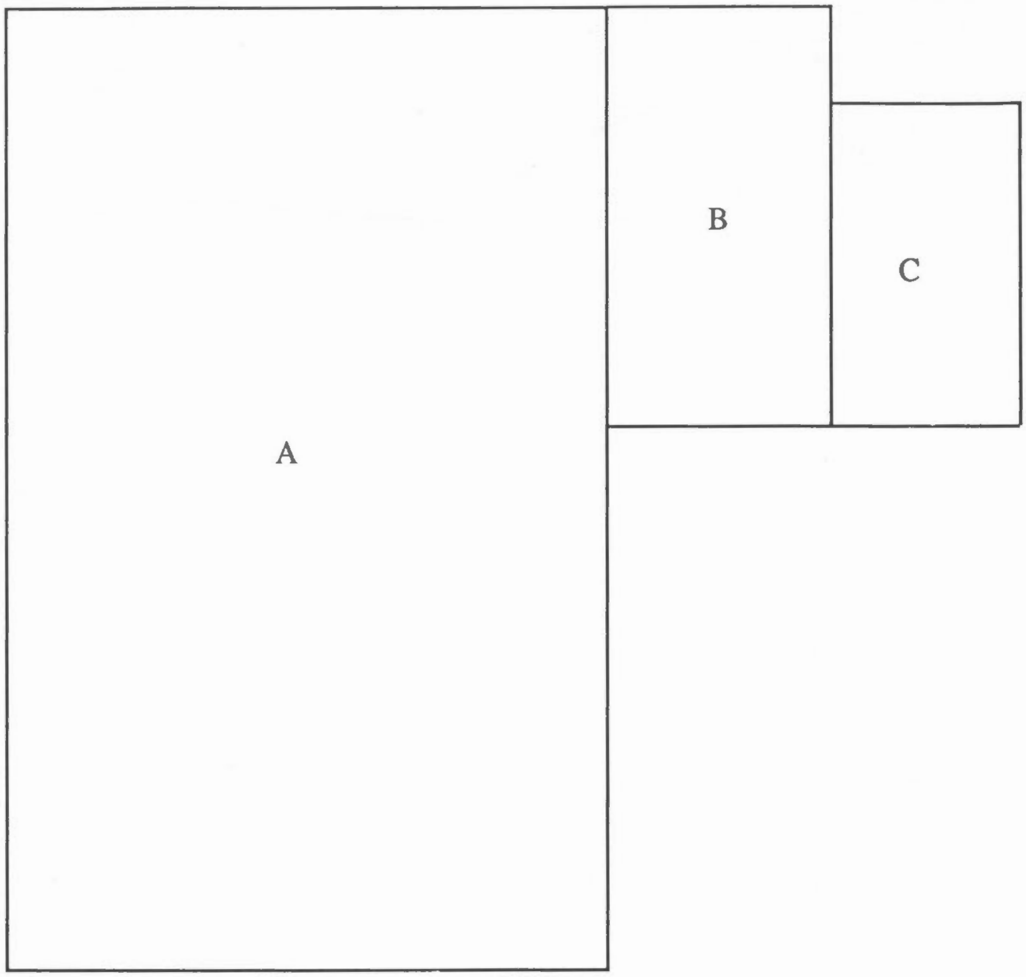
1. Initiate a Record-Keeping System

A lighting energy management program begins with a lighting survey, as is outlined in Worksheet #1. A lighting energy management program is an ongoing management concern and its effectiveness can best be tracked through documentation and proper record keeping.

For the purpose of completing the sample worksheet, refer to Figure 22. This room is an office and computer center filled with desks and computer equipment and five full-time workers.

Referring to the recommended illuminance Table 7, illuminance category E is selected based on the following observations:

1. The office has an internally-illuminated CRT screen (Category B).
2. The office is equipped with a light table (Category E).
3. The office has impact printers (Categories D and E).
4. A common task is keyboard reading (Category D).



Office and Computer Centre Layout

Figure 22

From the above considerations, the visual tasks normally conducted in this sample room can be accommodated with illuminance Category E.

The weighting factors, determined from Table 8 would be:

1. Some workers over 55 years of age	1
2. Speed and accuracy are important	0
3. Reflectance of task background >70%	-1
The total weighting factor:	0

From this, it could be summarized that the recommended level of illumination would be 750 lx. Field measurements taken at various places in the room yield values in the range of 300 lx (next to some dark gray filing cabinets) up to 600 lx. The room is therefore "under illuminated" for the more demanding visual tasks which could possibly arise. Portable supplementary lighting would be required for tasks conducted in the less well illuminated areas.

To apply the UPD procedure in order to calculate the room's lighting power budget, the room can be divided into 3 rectangular rooms A, B and C. This is shown in Figure 22.

To calculate the actual connected power, note that each fixture contains 2 x 40 W fluorescent lamps and a ballast which dissipates 12 W, giving a total of 92 W per fixture.

In order to calculate the room power budget, refer to the Lighting System Power Requirements Worksheet #2.

Power Budget For Space A	= UPD Table x Area x RF x SUF
	= 23.68 x 18.59 x 11.73 x 1.1 x 1
	= 5,680 W
Power Budget For Space B	= UPD Table x Area x RF x SUF
	= 23.68 x 3.96 x 7.62 x 1.40 x 1
	= 1,000 W
Power Budget For Space C	= UPD Table x Area x RF x SUF
	= 23.68 x 3.66 x 5.94 x 1.42 x 1
	= 731 W

The UPD number of 23.68 W/m^2 selected from Table 3 refers to a "typing and reading area", which represents the visual tasks performed in this area.

The UPD results are as follows:

Space	Power (W)	
	Budget	Connected
A	5680	4692
B	1000	694
C	731	552

In this room, glare is a problem. Because the ceiling is encumbered with pipes, ducts and cable trays, individual fixtures are suspended at different heights from the floor. The fixtures consist only of a porcelain enamel top reflector (no baffle, louver or diffuser). On a number of occasions, a worker's field of vision includes the bare fluorescent tubes. From this scenario, it would be best to install some shielding at least on those fixtures closest to the floor which are most likely to enter a worker's field of view.

When completing a lighting survey, very rarely does one encounter a completely uniform surface. Remember that zonal-cavity calculations are based on this assumption. Therefore, in order to keep the calculations accurate, a weighted average should be employed in calculating surface reflectances. An extra worksheet should be used, showing all the components of the average surface reflectance for easy updating and reference.

2. Reduce Lighting Levels

By modern standards, many facilities are overlit. This problem can easily be corrected by disconnecting lamps and ballasts in areas that are over illuminated. Often both fluorescent and incandescent lamps can be safely removed by qualified, in-house personnel.

Fluorescent lamps, as a rule, are connected in pairs and wired in series. If one lamp of the pair is removed, the other usually will not start, depending on the ballast and capacitor wiring. In any case, both lamps should be removed. Remember that typical power factor for a two-lamp ballast operating with only one lamp is 0.27. Also, the ballast itself should be disconnected, as it continues to draw 7-10 W even with no lamp installed. Incandescent fixtures, of course, have no ballast and consume no power when lamps are removed. Removing lamps may be unnecessary if adequate switching is available. The energy cost savings are directly proportional to the total wattage removed.

Cost saving = Reduction in Lighting Power x Lighting hours x Electricity Rate

For example, a reduction in lighting levels by 20 per cent can be obtained by disconnecting 73 of the 294 existing

2-lamp, four-foot fluorescent fixtures, which each consume 92 W. To calculate the yearly savings, assume lamp operation 5 days per week, 10 hours per day, at an electricity rate of $0.06 per kWh.

$$\text{Cost Saving} = 92 \times 73 \times 52 \times 10 \times 5 \times \frac{\$0.06}{1{,}000} = \$1{,}047.70$$

Reduce Daytime Lighting

Field measurements can uncover opportunities for seasonal adjustments in lighting switch settings.

Cost Saving = Reduction in Lighting Hours x Wattage Affected x Electricity Rate

For example, consider an office that has one wall of windows. Light meter measurements indicate that one third of the lights can be turned off for five hours during the winter months, 10 hours during the summer and for seven hours during the spring and fall months each. The total lighting load is 5 kW. Calculate the yearly energy savings at $0.06/kWh.

Yearly Cost Saving

$$\begin{aligned}
&= \text{W} \times \text{hours/year} \times \$/\text{Wh} \\
&= 1/3 \times 5{,}000 \times (365 \div 4) \times (5 + 10 + 7 + 7) \times \frac{(\$0.06)}{1{,}000} \\
&= .33 \times 5{,}000 \times 91.25 \times 29 \times \frac{\$0.06}{1{,}000} \\
&= \$262/\text{year}
\end{aligned}$$

3. Modify Usage Patterns

Devise a strategy to turn lights on and off. This plan has the advantage that it can be tailored to individual spaces and implemented both immediately and inexpensively. The key element of such a plan is to construct a lighting schedule related to the occupant usage patterns. Personnel should be assigned, trained and made responsible for the efficient utilization of lighting by means of established schedules.

It is also important to properly define the exact nature of the occupancy and tasks for each time period, which includes determining the amount of light needed for the tasks involved. The amount of light should also be determined for safety and security requirements. Following this, a set of detailed instructions for lighting operation can be given to responsible employees by means of charts, posters or colour coding of switches. A chart should be posted near each light switch identifying which lights are controlled by the switch. This encourages the user to be selective when turning lights on and reduces trial-and-error which consumes energy and wears out lighting equipment.

Short-Term Shutdown Considerations

In most cases, turning lights on and off will have an adverse impact on lamp life. On the other hand, energy is saved during the shutdown period. Despite this, there is a balance that can be struck. The following rule is sometimes used:

Minimum Shutdown Time (minutes)	Lamp Type
0	Incandescent
15	Fluorescent
60	High Pressure Discharge

The following calculation presents a more precise way of comparing increased lamp cost due to extra switch cycle versus decreased operating cost.

Short-Term Shutdown Method

Case 1. Short Term Shutdown

The comparison cost (CS) is the lamp and electricity costs for a day of operation:

$CS = (C \div HS + OC/T) \times (tD - tS)$

Where:
CS: lamp and electricity costs for a day of shutdown-type operation
C: cost of lamps for the installation
HS: reduced lamp life due to the extra switching cycle in hours
OC/T: operating cost (i.e. cost of electricity per hour)
tD: normal period of continuous operation, measured in hours
tS: shutdown time in hours

Case 2. No Shutdown

Again, the comparison cost (CD) is the lamp and electricity costs for a day of operation,

$CD = (C \div HD + OC/T) \times tD$

CD: lamp and electricity costs for a day of no shutdown
C: cost of lamps for the installation
HD: present lamp life, measured in hours
OC/T: operating cost (i.e. cost of electricity per hour)
tD: normal period of continuous operation, measured in hours

Short-Term Shutdown Worked Example

An office lighting arrangement of 18 fluorescent luminaires (each containing two 40-W fluorescent tubes) operates each day for the duration of two shifts:

First Shift — 8 a.m. to 4 p.m.
Second Shift — 6 p.m. to 2 a.m.
Because the office is vacant from 4 p.m. to 6 p.m. each day of the seven day week, management wishes to examine the short-term shutdown possibilities.
The operating cost per hour (based on an electricity rate of \$0.06/kWh) is:

$$\begin{aligned} OC/T &= W \times hours \times \$/Wh \\ &= 18 \times 2 \times 40 \times 16 \times \frac{\$0.06}{1{,}000} \\ &= \$1.38/h \end{aligned}$$

tD is the time from the beginning of the first shift to the end of the second shift, which is 18 hours.
tS is the proposed shutdown time between shifts, which is 2 hours.
Examination of manufacturer data sheets reveals:

HD = 28,000 hours, and
HS = 24,000 hours

At \$12. per lamp, the cost of lamps is calculated to be:

$$\begin{aligned} C &= \$.lamp \times lamp/fixture \times \#\ of\ fixtures \\ &= \$12 \times 2 \times 18 \\ &= \$432. \end{aligned}$$

The comparison costs would be:

$$
\begin{aligned}
CS &= (C \div HS + OC/T) \times (tD - tS) \\
&= (432 \div 24{,}000 + 1.3824) \times (18 - 2) \\
&= (1.4004) \times (16) \\
&= \$22.41
\end{aligned}
$$

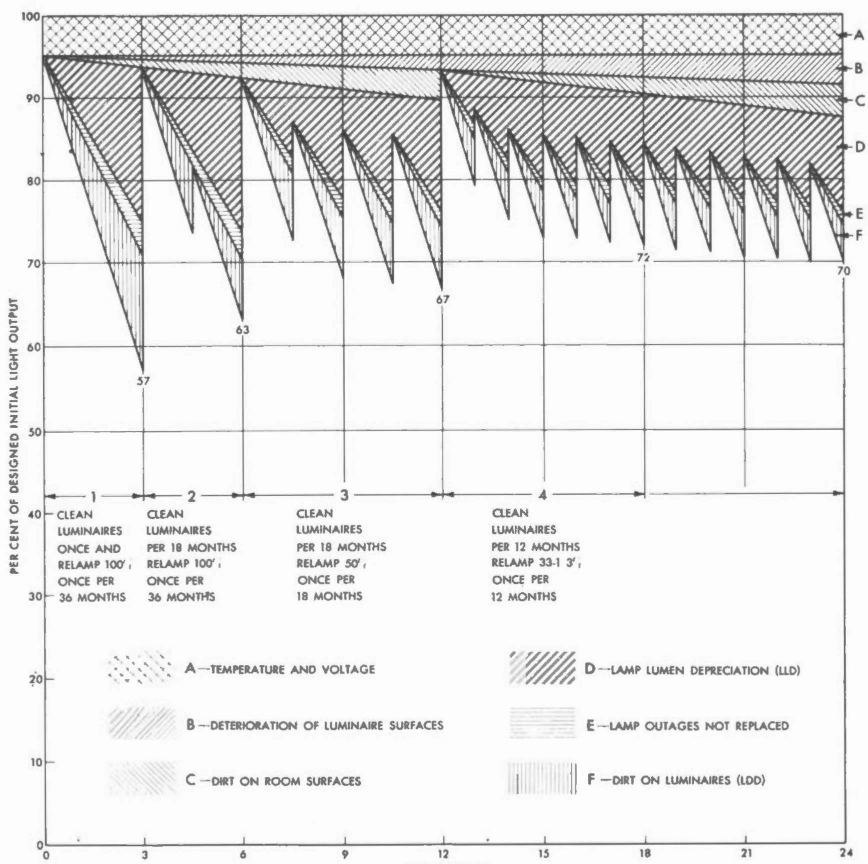
$$
\begin{aligned}
CD &= (C \div HD + OC/T) \times tD \\
&= (432 \div 28{,}000 + 1.3824) \times 18 \\
&= (1.3978) \times 18 \\
&= \$25.16
\end{aligned}
$$

Therefore, it can be estimated that approximately $3/day could be saved by turning off the lights between shifts.

4. Refine the Lighting Maintenance Program

If a building owner's lighting maintenance program involves washing and cleaning of lamps, luminaires and room surfaces on a frequent basis, a reduced lighting load can be accommodated, thus conserving energy. Clean lamps and luminaires produce more light and less heat. This more energy-efficient operation also leads to longer lamp life. Also, clean interior surfaces absorb less light. Figure 23 compares the light output over time under 4 possible maintenance plans.

The deterioration in illumination output due to temperature and voltage are controllable by lighting maintenance procedures. Hence, these are referred to as "unrecoverable parts of the total light loss factor". Variations in temperature, above or below those normally encountered in interior locations, have little effect on illumination output from incandescent and HID lamps but have an effect on illumination output from fluorescent lamps. High or low voltage will affect the illumination output of most lamps.



Light Output Comparison Over Four Maintenance Programs

Figure 23

For example, a comparison can be made using a typical factory area of 930 m^2. The annual lighting energy consumption during a two-plant-shift period, measured at 50 decalux, with regular cleaning, would be 61,000 kWh. Without cleaning, the consumption would be 88,000 kWh. The potential annual lighting energy savings would therefore amount to 27,000 kWh or $1,620., based on an electricity rate of $0.06/kWh.

Considering the cost of labour, it may be more cost effective to schedule cleaning together with relamping.

Calculating the Number of Fixtures Required in a Room

The following basic lighting calculation will acquaint the reader with the factors needed to evaluate and modify an existing lighting layout which may no longer be appropriate or energy efficient. Such factors include: dimensions (length, width and height) of the space to be lighted, the reflectances of the surfaces involved, the type of lighting fixture utilized; the desired illumination level, the lamp burn-out rate, the gradual loss in light output from a lamp, as well as the dirt accumulation on lamps, fixtures and room surfaces.

Since 1964, the Illuminating Engineering Society's recommended procedure for interior lighting is called the "zonal cavity method". The objective of this procedure is to illuminate the horizontal plane (work plane) 0.76 m from the floor, with a desired average amount of lumens. This method accounts for surface reflectances by collapsing a cavity reflectance into an equivalent effective plane reflectance. The optimum reflectance of a cavity is the ratio between the total flux from the cavity opening and the total flux into the cavity opening. Figure 24 shows an example of ceiling and floor cavities, each becoming a single equivalent surface reflectance.

In Figure 24, three cavities are identified:

1. *The ceiling cavity*. The ceiling cavity extends from the fixture plane to the ceiling. If the fixtures are flush with the ceiling, then the effective ceiling surface reflectance is equal to zero.
2. *The room cavity*. The room cavity extends from the fixture plane to the work plane.
3. *The floor cavity*. The floor cavity extends from the work plane to the floor.

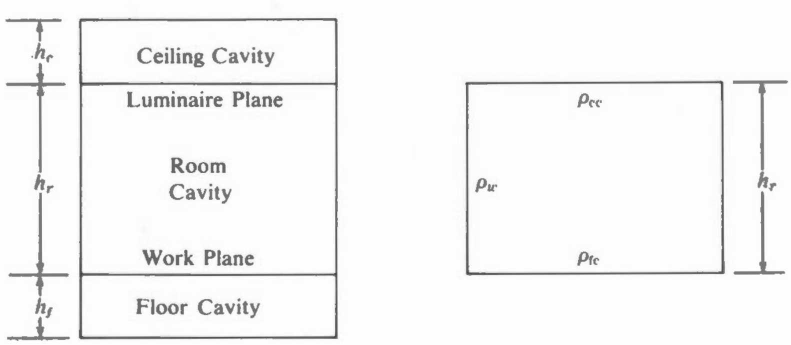
For example, consider a training centre room that measures 13.7 x 6.1 x 3.0 m. The surface reflectances are calculated as: ceiling 80 per cent, walls 50 per cent and floor 30 per cent. The task is to correctly determine the number of lighting fixtures required in order to achieve the best illumination level. In this case, a two 40 W lamp, wrap-around prismatic fixture (Figure 20) should be specified.

The desired maintained illumination level is 50 decalux. Allowance is made for 5 per cent of the lamps to burn out before replacement.

From this, the effective surface reflectance of a cavity can be calculated from Table 11.

Step 1. Determining Cavity Ratios

In order to use Table 11, the reflectances of the walls and of the base (ceiling for ceiling cavity and floor for floor cavity) of the cavity, as well as the "cavity ratio" need to be determined. The cavity ratio expresses the ratio of the amount of vertical surface area in the cavity to the amount of horizontal surface area. A multiplier of five is included to give cavity ratios greater than one for most rooms:



Three Cavities Used in Zonal Cavity Method
Figure 24

CR = 5h x (l+w) ÷ (l x w)

where: CR is the cavity ratio
h is the cavity height
l is the cavity length
w is the cavity width

Example: Training center cavity ratios

Ceiling cavity ratio (CCR)

Because the luminaire selected is fitted directly on the ceiling, there is no ceiling cavity and the CU table will be entered at an effective ceiling cavity reflectance equal to the ceiling reflectance which was measured at 80 per cent.

Room Cavity Ratio (RCR)

Since the workplane is 0.76 m from the floor, the height of the room cavity becomes 3 - 0.76, or 2.24 m. Therefore, the room cavity ratio is calculated as follows.

RCR = 5h x (l+w) ÷ (l x w)
= 5 x 2.24 x (13.7 + 6.1) ÷ (13.7 x 6.1)
= 2.7

Floor Cavity Ratio (FCR):

FCR = 5h x (l+w) ÷ (l x w)
= 5 x 0.76 x (13.7 + 6.1) ÷ (13.7 x 6.1)
= 0.9

Step 2. Finding Effective Cavity Reflectances

Once the cavity ratios are determined, the next step is to find the effective cavity reflectances for the ceiling and floor cavities in Table 11.

Example: Finding the Effective Floor Cavity Reflectance

On the top line of Table 11, the percentage base reflectance, which in this case is the floor reflectance, has been measured at 30 per cent. On the second line, the percentage wall reflectance has been measured at 50 per cent. Knowing the floor cavity ratio of 0.9 in the left-hand column, the effective floor cavity reflectance is seen to be 27 per cent.

Step 3. Finding the Coefficient of Utilization (CU)

The coefficient of utilization, or CU, is a factor used to determine the efficiency of a fixture in delivering light to the work plane. The CU is the ratio of fixture light output that reaches the workplane. This information is provided by the fixture manufacturer for each fixture for uniform lighting layouts. CU data for non-uniform layouts are best determined by computer analysis. Most major manufacturers will provide these studies without charge.

The importance of having an efficient fixture cannot be overstressed. For example, suppose the selected training room fixture of Figure 20 yields a CU of 0.50 and requires 100 fixtures. If a more efficient fixture can be used with a CU of 0.75, then as few as 67 fixtures would be required. Fewer fixtures result in both first-cost and life-cycle cost savings.

Example: Training center room CU

In Table 11, the top line is the effective ceiling cavity reflectance (80 per cent). The second is the wall reflectance (50 per cent). The RCR is the room cavity ratio. Interpolating for the calculated 2.7 RCR of the training room, a CU of 0.59 is obtained.

Step 4. Finding the Light Loss Factor (LLF)

The light loss factor (LLF) accounts for both the fall-off in lamp light production with age (lamp lumen depreciation or LLD which is the percent of the initial lumens at 70 per cent of rated life) and the accumulation of dirt (luminaire dirt depreciation factor or LDD). Also included in the LLF is the LBO (lamp burnouts) since it may not be feasible to replace burnt out lamps immediately (the LBO is the smallest ratio of remaining lamps to total lamps) and the RSDD (room surface dirt depreciation) which depends on the luminaire flux distribution as well as the maintenance category of the room.

LLF = LBO X LLD X LDD X RSDD

Example: Finding training center room LLF

Lamp Burnout (LBO)

Assume that the following lamp replacement policy is adopted for the training room: when five per cent of the room lamps are burnt out, the burnt out lamps will be replaced. Therefore, LBO equals 0.95.

Lamp Lumen Depreciation (LLD)

The LLD for incandescent lamps is the lumens at 100 per cent rated life divided by the initial lumens. The LLD for fluorescent and high intensity discharge lamps is taken at the 70 per cent life point using the lamp lumens at 100 hours as a base. In the case of the training room, manufacturer's data of Table 12 for the fluorescent lamps selected gives 100-h (i.e. initial) lumens of 3,150 and 70 per cent-rated-life lumens of 2650.

LLD = 2650/3150
= 0.84

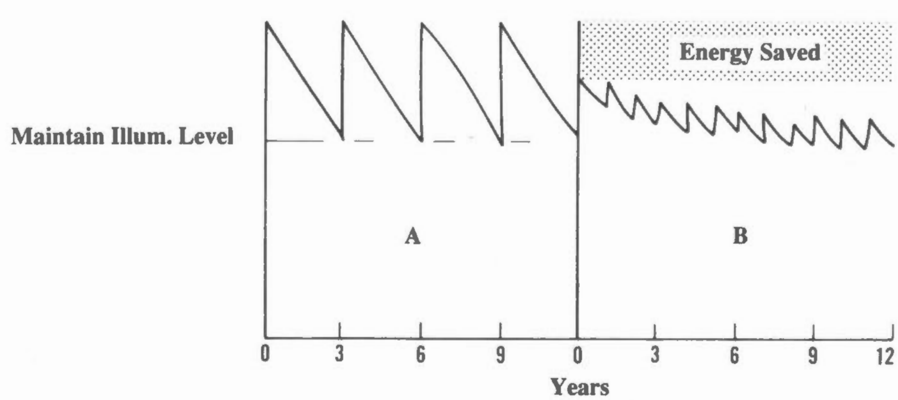
Luminaire Dirt Depreciation (LDD)

Dirt accumulation on a luminaire will reduce the reflectance of luminaire surfaces and the transmittance of luminaire lenses and diffusers. This effect is accounted for with the LDD (luminaire dirt depreciation) factor. One way of minimizing the LDD and saving lighting costs is to select fixtures designed to limit dust accumulation. Very often lighting designers will add space capacity (compensatory illumination) to a lighting system on the assumption that lighting maintenance will be neglected. For the training center room example, let us assume the lighting designer has estimated LLD = 0.83.

Room Surface Dirt Depreciation (RSDD)

Dirt on room surfaces reduces the reflected component of luminous flux and thus the illumination on the workplane. Figure 25 shows the effect of the lighting maintenance program on lighting energy use. The maintenance program for system A consists in cleaning and relamping every three years, while Program B calls for yearly cleaning and replacement of 1/3 of the lamps. Maintenance Program B permits reduction of connected lighting power by 15 per cent over Program A.

Assume that the training center room lighting designers have set the RSDD to equal 0.93.



Effect Of Lighting Maintenance Program On Energy Use
Figure 25

Example: Calculating LLF

The LLF for the training center room is calculated as follows

LLF = LBO X LLD X LDD X RSDD
= 0.95 X 0.84 X 0.83 X 0.93
= 0.61

Step 5. Finding the Number of Luminaires Required

With the CU and LLF defined, the number of luminaires required can now be calculated as:

N = (E x A) / (CU x n x LLF)

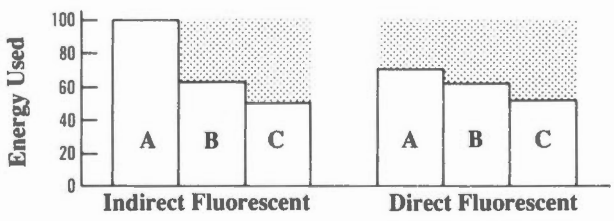
where E is desired illumination in lux (lx)
o is initial lamp lumens (lm)
A is work plane surface area (m2)
N is the required number of luminaires
n is the number of lamps per luminaire
CU is the coefficient of utilization
LLF is the light loss factor

N = (500 x 83.6) ÷ (0.59 x 3150 x 2 x 0.61)
N = 19

The zonal cavity method calculation Worksheet #3 summarizes the training center room lighting calculations and illustrates the importance of the various factors which contribute to the efficiency of a lighting installation. For example, the use of higher reflectance finishes will reduce the number of fixtures required and save energy. Figure 26 shows the decreased energy needs for equal illumination in a medium sized room with improved reflectances. The reflectances are

	Ceiling	Walls	Floor
A	50	30	10
B	80	40	20
C	90	60	40

The hashed area shows the percentage energy savings.



Energy Use According To Illumination Level

Figure 26

Low-Cost Opportunities

Low cost energy management opportunities are considered low-cost actions that are taken usually once. The following are typical low cost energy management activities.

1. Install Energy Efficient Lamps

When relamping, replace standard 40, 60, 75, 100 and 150 W lamps with more energy saving 34, 52, 67, 90 and 130 W lamps. For example, the newer 34 W fluorescent lamps will justify their increased cost in 9.6 months, when burned 60 hours per week (based on an electricity rate of $0.06/kW.h and a $0.90 cost premium per lamp). Note that reduced illumination requirements may allow the replacement of a 60 W lamp not with its 52 W energy-saving counterpart, but with a 34 W. This is really implementing two energy-saving measures in one relamping and results in greater savings.

2. Install Lighting Controls to Reduce Lighting Time

For example, employ time clocks to automatically turn lights off, one hour after the end of each shift. Consider the use of photocell switches, at such locations as loading docks.

3. Plan to Replace All Lamps At The Same Time

Schedule bulk relamping at the best relamp time, using the same labour vs lamp cost tradeoff as will be examined in detail in the upcoming bulk relamp calculation.

4. Install Energy-Efficient Ballasts

It is not always cost effective to replace ballasts just for the sake of achieving increased energy efficiency. However, it may be advantageous to stock energy-efficient ballasts as replacement units. Before implementing such a program, the ballast to lamp compatibility should be verified with the lamp manufacturer.

5. Use Light Colours In The Interior Decoration Scheme

As was demonstrated in the Fundamentals section, the same lighting installation can provide substantially more light when surface reflectances are high. This consideration should be kept in mind when selecting colour schemes before decorating.

6. Consider The Use Of Low Pressure Sodium Lamps

In applications where it is permissible for everything to appear yellow or gray, the use of LPS lamps is recommended. Note that high-security guarded perimeters are not such an application. This is because visual difficulty increases appreciably with a monochromatic light source. When using LPS lamps in building interiors, occupant safety in the event of a utility power failure may not be compatible with the one minute time lapse before a LPS lamp delivers any appreciable lumen output. In this case, other lamps should be used to fill the emergency backup lighting requirement.

7. Apply The Task Lighting Concept Where Possible

Use spotlights on cranes and stackers, thereby permitting reduced general lighting levels in warehouses. Of course, safety and productivity factors must not be neglected and must immediately override possible energy savings.

Low-Cost Worked Examples

1. Install Energy Efficient Lamps

Since many lighting systems available for the past five or 10 years have been designed to deliver 70-150 decalux, relamping with inexpensive low-wattage lamps has offered a simple, effective way to reduce operating costs while still meeting or exceeding today's lower illumination standards.

Although lower-wattage lamps have a slightly higher retail price, in practice the wholesale prices, when buying in bulk, may be closer to standard lamp prices.

Yearly Cost Savings Calculation

Cost Saving = hours per year
x number of lamps

x (present lamp wattage - lower lamp wattage)
x electric rate

For instance, an office lit by 200 x 40 W fluorescent lamps 60 hours per week is relamped with 34 W lamps, since the 10 per cent reduction in illumination can easily be tolerated.

This can be demonstrated by comparing the results of the lighting survey Worksheet #1 with the recommended illumination value for general office. Calculate the yearly saving at $0.06/kWh.

Cost Saving = hours/yr x total watts saved x $/Wh
= 52 x 60 x 200 x (40 - 34) x $0.06 / 1,0000
= 624,000 x 6 x $0.00006
= $224.64

2. Install Lighting Controls To Reduce Lighting Time

There are three basic ways to achieve a reduction in lighting time:

1. Clock-timing
2. Occupancy-sensing
3. Manual shutoff

If the area has a known fixed schedule, then a clock-timing device to control the lights is appropriate. (For instance, the lights could be turned on one hour before the start of the regular shift and be turned off one hour after the end of the shift.) Otherwise, an occupancy sensor could be installed. Occupancy sensors use ultrasonic or infrared waves. Of course, if an occupancy sensor were inadvertently placed in a high traffic area, lamp life would be shortened due to the increased number of lamp starts per day.

The yearly cost saving is calculated as:

Cost Saving = (Existing Lighting Hours - Reduced Lighting Hours) x kW Lighting Load x Electricity Rate

For instance, a locker shower room has 40, 40 W fluorescent lamps. It is estimated that an occupancy sensor or timer could reduce lighting time by 50 per cent. Assuming an electricity rate of $0.06/kWh, the yearly savings would be:

Cost Saving = Hours x Watts x $/Wh
= 0.50 x 7 x 24 x 52 x 40 x 40 x $0.06 / 1,000
= $419.32/year

Assuming a shutoff device can be installed for $200.00,
payback = $200. ÷ $419.32/year
= 6 months

3. Plan To Replace All Lamps At The Same Time

In certain situations it is sometimes advantageous to trade off relatively high labour costs for marginal remaining lamp life.

Bulk relamping is a technique employed for improving lighting system reliability as well as reducing maintenance labour costs. Still-functioning lamps are removed and replaced with new lamps when 70 or 80 per cent of lamp life has expired. The time selected is referred to as the bulk replacement time interval. In return for shortening the service life of the more robust, long-lasting lamps, one can expect to realize an appreciable saving on the labour costs involved in relamping. This is because a single bulk relamping session is more efficient and less costly than multiple single lamp replacement sessions.

The following calculation is intended to highlight this reduced lamp life versus reduced labor costs tradeoff. Other benefits of bulk relamping, such as increased system reliability, should be weighed separately. (In the case of security lighting, where system reliability is of foremost importance, bulk relamping is the rule rather than the exception.)

When bulk-relamping, one can make use of either the used lamps which are still functioning or replace all the lamps with new ones. Used lamps can be used in this fashion for interior relamping because the design procedure allows for a certain number of burnouts (LBO) while still providing adequate illumination. This does not apply to exterior lighting installations because each light source is important to system performance. Most manufacturers have computer programs which will calculate optimum bulk-relamping strategies.

Bulk relamping is particularly effective when used with automatic energy control. In this case the group relamp interval is not 70 per cent rated life but rather 100 per cent, that is when the system, at full lumen output, can no longer deliver the design illuminance. The longer relamp interval means additional maintenance cost savings.

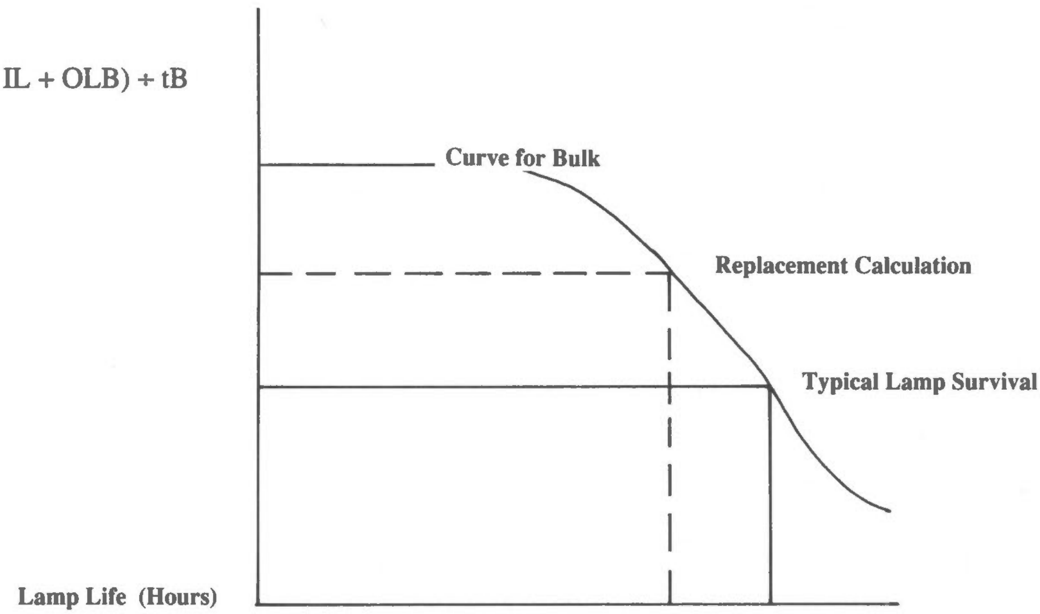
The following calculation can serve as a guide in evaluating some of the different component factors of a bulk-relamping strategy. Normally, a computer program would include a more complicated model and therefore produce a more precise result. Note that the calculation doesn't deal directly with energy although energy consumption will be reduced as is illustrated in the following case history.

The following equations quantify the tradeoff between labour and lamp costs.

Equation #1

The first equation establishes the cost (CB) of lamps, plus the cost of lamp replacement over time for bulk replacement:

$$CB = N \times (C + IL + OLB) \div tB$$



Typical Lamp Survival Curve

Figure 27

Where:
CB is the dollar cost of lamps and labour for bulk replacement
N is the number of lamps
C is the cost per lamp
IL is the incremental labour cost per lamp replaced
OLB is the fixed overhead labour cost per bulk maintenance session
tB is the bulk replacement time interval

In Figure 27, tB refers to the bulk relamp time interval, while tA refers to average lamp life. The approximation of tA equals the number of hours corresponding to the 50 per cent survival point.

Equation #2

With the second equation, the cost (CS) of lamps plus the cost of lamp replacement over time for spot replacement can be calculated as:

$$CS = N \times (C + IL + OLS) \div tA$$

Where:
CS is the dollar cost of lamps and labour for spot replacement
N is the number of lamps

C is the cost per lamp
IL is the incremental labour cost per lamp replaced
OLS is the fixed overhead labour cost per spot maintenance session
tA is the average lamp life

Applying these equations to a laboratory area fitted with 51 x 2-lamp fluorescent fixtures, results in the following comparative costs.

Lamps cost $4.00 each and labour is calculated at $16.00 per hour. A two-man team is assigned to the task. Manufacturer's data indicates that an average lamp life (tA) is 20,000 hours. It has been decided to replace all lamps at 75 per cent rated life, therefore, tB is 75 per cent of 20,000 hours. It is estimated that the team will take one hour to bring and remove tools and materials from the lab for bulk replacement and half of that time for spot replacement. On average, three minutes will be required to replace a lamp. Based on this scenario:

CB = N x (C + IL + OLB) ÷ tB
= 102 x ($4.00 + $1.60 + $32.00 x 3 ÷ 60) ÷ (0.75 x 20,000)
= $734.40 ÷ 15,000
= $0.04

CB is the cost per hour per lamp, excluding energy costs.

CS = N x (C + IL + OLS) ÷ tA
= 102 x ($4.00 + $1.60 + $16.00) ÷ 20,000
= $0.11

CS is the cost of lamp and labour per hour of lamp life. As the example illustrates, the high set-up cost makes spot replacement a costlier alternative than bulk replacement.

Bulk-Replacement Case History

A typical high-rise office building (33,200 m^2 of floor space, plus 1,860 m^2 for elevators and stairwells) experienced a 165,375 kWh reduction in annual lighting energy consumption due to a bulk-relamping program. This saving of $9,742 per annum (based on an electricity rate of $0.06/kWh) would not be expected in the above calculation, which only includes maintenance labor and lamp costs. The saving is due to avoiding the relative inefficiency of a circuit containing a burnt-out lamp, a situation which arises less frequently with bulk relamping.

The building's lighting energy use (41.8 per cent of total annual energy use) was reduced by 27 per cent using the following techniques:

1. task lighting, reduced illumination	10%
2. more efficient, air-handling luminaires	6%
3. group relamping	2%
4. better light switching	9%
Total saving	27%

Retrofit Opportunites

Retrofit opportunities are defined as energy management actions that are done once, and for which the cost is significant. Many of the opportunities in this category require detailed analysis by specialists and cannot be examined in detail in this module. Worked examples are provided for some of the listed energy management opportunities. The following are typical energy management opportunities in the Retrofit category.

1. Implement A Cost Efficient Lighting System

When renovating or adding new factory or office space, a new lighting system should be devised which uses less energy while at the same time satisfying illumination requirements. Such occasions permit the use of life-cycle costing methods to choose the lighting system that is most efficient when both initial and operating costs are taken into account.

2. Incorporate Lighting Into The Overall Building Architecture

This can be done at renovation time when lighting is often not sufficiently considered. Such measures include the installation of skylights for natural lighting, the redesign of areas so that tasks requiring high illumination are grouped together and the reorganization of facilities so that space requirements are next to windows. It is often possible to improve the heat balance of the building by directing return air to air-handling fixtures.

3. Modify The Lighting Control System

In cases where lamp life can be adversely affected by excessive on/off switching, it might be necessary to remove all wall-mounted light switches. All light switching would then emanate from a centralized building management system, working to a carefully-planned, energy conservation strategy.

Retrofit Worked Example

1. Implement A Cost-Effective Lighting System

A cost-effective lighting system incorporates lamp and fixture selection as well as giving attention to room surface reflectances. Surface reflectance should be kept as high as the environment will allow. Lamp and fixture selection can be facilitated through the use of life-cycle costing.

Applying life-cycle costing to lamp selection for a particular application involves assessing each of the following factors:

1. Luminous efficacy
2. Color rendition
3. Life
4. Cost (capital and operating)

A cost comparison based on equal task light can assist in the design of the most efficient lighting equipment for a given location. Over the years, efficient lighting can compensate an owner with greatly reduced energy and maintenance costs in return for the initial investment in a more expensive system.

Worksheet #2 itemizes the basic system parameters:

line 1	Location
line 2	Target illuminance in lux
line 3	Total area in square meters
line 4	Number of burn hours per year
line 5	Electricity rate

Worksheet #2 also includes the following manufacturer's data on the proposed options on a per fixture basis:

line 6	Initial lamp lumens
line 7	Rated lamp hours of life
line 8	Input watts per fixture
line 9	Fraction of effective lumens leaving the fixture (sometimes called the coefficient of utilization in data sheets)
line 10	Lamp Depreciation Factor
line 11	Dirt Depreciation Factor
line 12	Effective lumens 6 x 9 x 10 x 11
line 13	Number of fixtures 2 x (3 ÷ 12)
line 14	Total input watts 13 x 8
line 15	Cost of one fixture
line 16	Cost of wiring e.g. ($150.00 per kW) ÷ (13)
line 17	Labor cost for installing one fixture
line 18	Lamp cost per fixture
line 19	Total first cost 13 x (15+16+17+18)
line 20	Number of lamps per fixture

line 21	Number of lamp replacements per year 13 x 20 x (4 ÷ 7)
line 22	Labor cost per lamp replacement
line 23	Lamp cost per year (21 x 22) + (18 ÷ 20)
line 24	Energy cost per year 14 x 4 x 5
line 25	Total Operating Cost per year (23 + 24)

The completed Worksheet #3 illustrates the efficiency of high pressure sodium (HPS) lamps for lighting a 1,000 m^2 area to 500 lx, compared to similar illumination using mercury vapour (MV) lamps.

The installation of 26 x 1,000 W MV lamps costs $1,076, compared to $8,190 for 21 x 400 W HPS lamps. Nevertheless, when lamp replacements and energy costs are calculated, the total annual operating cost for the mercury vapour lighting system is $5,213, compared to $1,995 for the HPS system. On a premium cost basis, the higher initial investment in the HPS lighting system has a simple payback of:

$$\text{Payback} = \frac{(\$8{,}190 - \$1{,}076)}{(\$5{,}213 - \$1{,}995)}$$

$$= \frac{\$7{,}114}{\$3{,}218}$$

$$= 2.2 \text{ years}$$

Worksheet #4
Investigate Retrofit Possibilities

The lighting retrofit modifications Worksheets #4a and 4b summarize data relating to the possible replacement of an existing fluorescent lighting system with an HPS system. The cost of the fluorescent lighting system is presented in Worksheet #4a to show what the replacement cost of the existing lighting system would be. For the purpose of this example, it is assumed that the fluorescent lighting system has reached the end of its useful life.

Both systems supply 750 lx of average, horizontal illumination. Note that a new fluorescent lighting system would improve the existing layout by adding three new fixtures.

Worksheet #4a shows that the total initial cost of 54 fluorescent lighting fixtures amounts to $5,616, compared to $3,684 for 12 HPS lighting fixtures, shown in Worksheet #4b. The yearly operating cost of the fluorescent lighting system is estimated at $1,055. The operating cost of the HPS lighting system is estimated to be $763.

Based on this scenario, the initial cost of the HPS lighting system would save $1,932 ($5,616 fluorescent - $3,684 HPS). Further, the annual operating cost of the HPS lighting system would be $292 less per year ($1,055 fluorescent - $763 HPS). This example demonstrates that the condition of the existing system is an important consideration when evaluating retrofit opportunities and that more efficient lighting systems can often provide an attractive cost alternative.

APPENDIX

Glossary

Angle of Cut-Off — The angle, measured from the downward vertical, at which a light source within a luminaire ceases to be visible, when viewed from a point outside the luminaire. For practical purposes the angle may be measured to an agreed point within the light source.

Blackbody Radiator — A light source emitting radiation, the spectral distribution of which is dependent on the temperature only and not on the material and the nature of the source.

Candela — The unit of luminous intensity of a light source in a specified direction. The standard candela is derived from a blackbody radiator operating at a prescribed temperature and pressure.

Circuit Efficacy — The ratio of the luminous flux emitted by a lamp to the total power consumed by the lamp and its control gear. Measured in lumens per watt.

Colour Appearance — General expression for the colour appearance of a lamp as in warm or cool. Does not indicate colour rendering.

Colour Rendering — The effect of a lamp on the colour appearance of the objects in conscious or subconscious comparison with their colour appearance under white light.

Correlated Colour Temperature — The temperature of a full radiator which emits radiation having a colour nearest to that of the light source being considered. Measured in Kelvin.

Daylight Factor — At a given point inside a building: the ratio of the illumination measured on a horizontal plane at that point to that simultaneously existing on a horizontal plane under an unobstructed sky of uniform luminance. Light reflected from interior and exterior surface is included in the illumination at the point.

Directional Lighting — Lighting designed to illuminate predominantly from a preferred direction.

Equivalent Sphere Illumination — Illuminance of a sphere which gives task the same visibility that it has in the actual environment. Used in determining the effectiveness of a lighting system in controlling reflections from the task back to the observer (veiling reflections).

General Lighting — Lighting designed to illuminate an area.

Illumination — The luminous flux density at a surface, i.e. the luminous flux incident per unit area. Measured in lux.

Light Output Ratio — The ratio of the total flux emitted from the luminaire to that emitted from the light source. Can be regarded as the transmission ratio of the luminaire.

Lumen — SI unit of luminous flux, used in describing the quantity of light emitted by a source or received by a surface. A small source which has a uniform intensity of 1 candela emits a total of 4pi lumens in all directions and emits 1 lumen within unit solid angle (one steradian). Abbreviated lm.

Luminaire — A complete lighting fixture consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

Luminaire Efficiency — The ratio of luminous flux (lumens) emitted by a luminaire to that emitted by the lamp or lamps contained therein.

Luminance — At a point in a given direction: the luminous flux density leaving a surface in a particular direction. Measured in candelas per square meter.

Luminous Efficacy — The ratio of the luminous flux emitted by a lamp to the power consumed by it. Measured in lumens per watt.

Luminous Flux — The light emitted by a source, or received by a surface. The quantity is derived from radiant flux (power) by evaluating the radiation in accordance with the spectral sensitivity of the standard observer. Measured in lumens.

Luminous Intensity — The power of a source to emit light in a given direction. The luminous flux emitted in a cone containing the given direction divided by the solid angle of the cone. Measured in candelas.

Lux — The unit of illuminance. An illuminance of one lumen per square meter. Abbreviated lx.

Mean Spherical Candle-Power — The average value of the candlepower of a luminous source in all directions.

Reflectance — The ratio of the reflected luminous flux to the indicident luminous flux.

Solid Angle — A 3-dimensional angle whose magnitude corresponds to the area projected on the surface of a unit sphere. Measured in steradians.

Spacing/Height Ratio — The ratio of the distance between adjacent luminaires to their height above the illuminated plane.

Steradian — Unit of solid angle. There is 4pi steradians surrounding a point in space.

Task Lighting — Lighting designed to illuminate a workstation.

Uniform Diffuser — A surface having a reflection or transmission factor independent of the angle of illuminance and a luminance independent of the angle of view.

Uniformity Ratio — The ratio of the minimum illuminance to the average illuminance. Sometimes, the ratio of the minimum to the maximum illuminance. The ratio usually applies to values on the working plane and over the working area.

Uniform Light Source — A source of light, the luminous intensity of which is the same in all directions.

Work Plane — The plane on which illuminance measurements are made. Unless otherwise stated, the plane is assumed to be horizontal and 0.85 meters above the floor.

Zonal Cavity Method — A lighting design procedure used for predetermining the number and types of lamps or luminaires, based on the room characteristics, and the average illuminance required on the work-plane. It takes into account both direct and reflected flux.

Table 1

I.E.S. Recommended Levels of Illumination for Different Classes of Visual Task

Class of Visual Task	Examples	Illumination Category	Range (1x)
Public Areas with Dark Surroundings	Lobbies	A	20–30–50
Simple Orientations for Short Temporary Visits	Corridors; Storage Rooms	B	50–75–100
Working Spaces where Visual Tasks are only Occasionally Performed	Waiting Rooms;	C	100–150–200
Visual Tasks of High Contrast and Large Size	Conference Rooms Printed Material Typed Originals Ink Handwriting Rough Industrial Work	D	200–300–500
Visual Tasks of Medium Contrast or Small Size	Engineering Office Medium Pencil Handwriting Poorly Printed or Reproduced Material: Medium Industrial Work	E	500–750–1000
Visual Tasks of Low Contrast or Very Small Size Detail	Hard Pencil Handwriting on Poor Quality Paper; Faded Dittos; Difficult Industrial Work	F	1000–1500–2000
Visual Tasks of Low Contrast and Very Small Size over a Prolonged Period	Fine Industrial Work; Difficult Inspection	G	2000–3000–5000
Very Prolonged and Exacting Visual Tasks	Extra–fine Work;	G	5000–7500–10000
Very Special Visual Tasks of Extremely Low Contrast and Small Size	Surgical Procedures; Sewing	I	10000–15000–20000

Table 2
Cost Analysis — Lighting vs Productivity

Lx	Relative Time For Same Work	Labour Cost For Same Work ($/m²/Yr.)	Total Cost of Light ($/m²/Yr.)	Total Net Cost ($/m²/Yr.)	Net Loss ($/m²/Yr.)
1,500	1.000	$2,952.80	$34.40	$2,987.20	
500	1.136	$3,354.30	$11.50	$3,365.80	$378.60
		$401.50	$22.90		

Table 3
(page 1 of 4)
Base UPD Values

Task or Area	Base UPD: Watts per Square Meter	Base UPD: Watts per Square Foot	Note
Rough Easy Seeing	7.53	0.7	
Rough Difficult Seeing	13.99	1.3	
Glass Works			
Fine Grinding, Leveling, Polishing	34.44	3.2	
General Production	10.76	1.0	
Inspection, Etching and Decorating	67.81	6.3	
Glove Manufacturing			
General Production	26.91	2.5	
Pressing, Cutting, Sewing, and Inspection	59.20	5.5	
Hat Manufacturing			
Forming, Finishing Process, Sewing	59.20	5.5	
Preliminary Processing	26.91	2.5	
Inspection			
Difficult	30.14	2.8	
Fine	59.20	5.5	
Ordinary	15.07	1.4	
Iron and Steel Manufacturing			
Inspection			
Black Plate, Bloom and Billet Chipping	26.91	2.5	
Tin Plate and Other Bright Surfaces	67.81	6.3	
Motor Room	7.53	0.7	
Open Hearth Operations Area	6.46	0.6	
Rolling Mills Operations Area	10.76	1.0	
Tin Plate Mills	13.99	1.3	
Jewelry and Watch Manufacturing	67.81	6.3	
Leather Manufacturing and Working			
Cutting, Fleshing and Stuffing	13.99	1.3	
Finishing and Scarfing	30.14	2.8	
Grading, Matching, Cutting, Scarfing, Sewing	81.81	7.6	
Preparation Area	7.53	0.7	
Pressing, Winding, Glazing	44.13	4.1	
Machine Shops			
Medium Bench and Machine Work, Ordinary Automatic Machines, Rough Grinding, Medium Buffing and Polishing	26.91	2.5	
Rough Bench and Machine Work	13.99	1.3	
Meat Packing			
General Processing	26.91	2.5	
Slaughtering	7.53	0.7	
Metal Fabrication (Bulk)	6.46	0.6	
Paint Manufacturing	7.53	0.7	
Dipping, Simple Spraying, Firing	13.99	1.3	
Fine Hand Painting and Finishing	26.91	2.5	
Rubbing, Ordinary Hand Painting and Finishing Art, Stencil and Special Spraying	15.07	1.4	
Paper Box Manufacturing	13.99	1.3	
Paper Manufacturing			
General Production	10.76	1.0	
Inspection	26.91	2.5	
Rewinder	39.83	3.7	
Petroleum and Chemical Plants			
General Process Area	4.31	0.4	
Plating	7.53	0.7	
Polishing and Burnishing	30.14	2.8	
Poultry Industry			
Brooders and Hatcheries	7.53	0.7	
Egg Handling and Shipping	13.99	1.3	
Egg Processing	18.30	1.7	
Egg Production	6.46	0.6	
Fowl General Processing	22.60	2.1	
Fowl Unloading and Killing	6.46	0.6	
Printing			
Composing Room	30.14	2.8	
Electrotyping	20.45	1.9	
Photoengraving	20.45	1.9	
Printing Plants	54.90	5.1	
Type Foundries	20.45	1.9	
Rubber Goods Mechanical			
General Production	10.76	1.0	
Inspection	59.20	5.5	
Rubber Tire Manufacturing			
General Production	10.76	1.0	
Inspection, Cutting, Splicing	26.91	2.5	
Sawmills			
General Production	6.46	0.6	
Sorting Tables and Grading	26.91	2.5	
Sheet Metal Works			
General Production	13.99	1.3	
Inspection and Scribing	59.20	5.5	
Shoe Manufacturing, Leather	53.82	5.0	
Shoe Manufacturing, Rubber			
General Production	10.76	1.0	
Sole Rolling, lining, finishing	26.91	2.5	
Soap Manufacturing	10.76	1.0	
Stone Crushing and Screening	5.38	0.5	
Storage-Battery Manufacturing	13.99	1.3	
Structural Steel Fabrication	13.99	1.3	
Sugar Refining			
Color Inspection	81.81	7.6	
Grading	13.99	1.3	
Testing			
Extra-Fine Instruments, Scales, etc.	67.81	6.3	
General	18.30	1.7	
Textile Mills			
Drying and Finishing	40.90	3.8	
General Production	10.76	1.0	
Warping, Weaving, Grading	40.90	3.8	
Tobacco Products			
General Production	7.53	0.7	
Grading and Sorting	59.20	5.5	
Upholstering—Automobile, Coach, Furniture	26.91	2.5	
Welding			
General Illumination	13.99	1.3	
Woodworking—General	13.99	1.3	
Indoor Sports			
Seating Area All Sports	4.31	0.4	d
Badminton			
Club	6.46	0.6	c
Recreational	4.31	0.4	c
Tournament	8.61	0.8	c
Basketball			
College and Professional	15.07	1.4	c
College Intramural and High School	8.61	0.8	c
Bowling			
Approach Area	4.31	0.4	
Lanes	6.46	0.6	
Boxing or Wrestling (Ring)			
Amateur	26.91	2.5	c
Championship or Professional	53.82	5.0	c
Gymnasiums (Refer to Individual Sports Listed)			
Exhibitions, Matches	15.07	1.4	
General Exercising and Recreation	8.61	0.8	
Handball			
Club	8.61	0.8	
Recreational	6.46	0.6	
Tournament	15.07	1.4	
Hockey, Ice			
Amateur	15.07	1.4	c
College or Professional	30.14	2.8	c

Table 3
(page 2 of 4)
Base UPD Values

Task or Area	Base UPD: Watts per Square Meter	Base UPD: Watts per Square Foot	Note
Common Areas			
Boiler Room	7.53	0.7	d
Conference Room	13.99	1.3	a
Corridor	6.46	0.6	d
Electrical Equipment Room	6.46	0.6	d
Food Service Facilities			
Dining Areas	15.07	1.4	b
Kitchen	18.30	1.7	
Garage, Parking	2.15	0.2	d
General Assembly (Auditorium)	11.84	1.1	
Laboratories	34.44	3.2	
Library Room	23.68	2.2	
Lobby, Reception, Waiting	10.76	1.0	
Locker Room and Shower	6.46	0.6	d
Mail Room	30.14	2.8	
Material Handling (Bulk)	7.53	0.7	
Mechanical Equipment Room	6.46	0.6	d
Stairs	6.46	0.6	d
Storerooms or Warehouse			
Inactive	2.15	0.2	
Active Bulky	4.31	0.4	
Active Medium	6.46	0.6	
Switchboard and Control Room	18.30	1.7	
Toilet and Washroom	7.53	0.7	
Unlisted Spaces	2.15	0.2	d
Utility Room, General	4.31	0.4	
Office			
Accounting	34.44	3.2	f
Drafting	50.59	4.7	f
Filing (Active)	21.53	2.0	
Filing (Inactive)	8.61	0.8	
Graphic Arts	32.29	3.0	f
Office Machine Operation			
Computer Machinery	18.30	1.7	
Duplicating Machines	7.53	0.7	
EDP I/O Terminal (Internally Illuminated)	7.53	0.7	
EDP I/O Terminal (Room Illuminated)	18.30	1.7	
Typing and Reading	23.68	2.2	f
Residential			
Bath	46.28	4.3	d
Bedroom	15.07	1.4	a, d
Finished Living Spaces	23.68	2.2	d
Garage	5.38	0.5	d
Kitchen	43.06	4.0	d
Laundry	10.76	1.0	d
Unfinished Living Spaces	5.38	0.5	d
Commercial and Institutional			
Armories			
Drill	6.46	0.6	
Exhibitions	8.61	0.8	
Seating Area	4.31	0.4	
Art Galleries	17.22	1.6	a
Banks			
Lobby, General	24.76	2.3	
Posting and Keypunch	50.59	4.7	
Tellers' Stations	50.59	4.7	
Bar (Lounge)	11.84	1.1	b
Barber Shops and Beauty Parlors	40.90	3.8	
Church and Synagogues, Main Worship Area	24.76	2.3	a
Club and Lodge Rooms	11.84	1.1	
Courtrooms	9.69	0.9	
Depots, Air Terminals and Stations			
Baggage Checkroom	13.99	1.3	
Concourse (Main Thruway)	8.61	0.8	
Platforms	6.46	0.6	d
Ticket Counter	23.68	2.2	
Waiting and Lounge Area	8.61	0.8	
Hospitals			
Autopsy	34.44	3.2	
Central Sterile Supply	13.99	1.3	
Corridor, Special Areas			
Nursing Areas	6.46	0.6	d
Surgical & Lab Area	8.61	0.8	d
Critical Care Areas	40.90	3.8	
Cystoscopy Room	40.90	3.8	
Dental Suite	34.44	3.2	a
EKG and Specimen Room	8.61	0.8	
Emergency Outpatient	40.90	3.8	
Endoscopy Rooms (Non-Urologic)	30.14	2.8	
Examination and Treatment Rooms	21.53	2.0	
Fracture Room	21.53	2.0	
Inhalation Therapy Units	8.61	0.8	
Laboratories	34.44	3.2	
Linen Room	7.53	0.7	
Lobby (or Entrance Foyer)	21.53	2.0	
Medical Illustration Studio	59.20	5.5	
Medical Records Room	30.14	2.8	
Morgue	8.61	0.8	
Nurseries	40.90	3.8	
Nurses' Stations	15.07	1.4	a
Obstetric Delivery Suite			
Delivery Area	81.81	7.6	
Labor Rooms	9.69	0.9	
Postdelivery Recovery Area	11.84	1.1	
Occupational Therapy	13.99	1.3	
Patients' Rooms (includes bathrooms)	15.07	1.4	a, d
Pharmacy	32.29	3.0	
Physical Therapy	20.45	1.9	
Postanesthetic Recovery Room	40.90	3.8	
Pulmonary Function Lab	34.44	3.2	
Radiological Suite			
Preparation Area	26.91	2.5	
Special Procedures	53.82	5.0	
Treatment Room	5.38	0.5	
Solarium	6.46	0.6	
Surgical Induction and Hold Area	34.44	3.2	
Surgical Suite			
Operating Room, General	81.81	7.6	
Scrub and Cleanup Area	26.91	2.5	
Substerilizing and Instrument Area	7.53	0.7	
Utility Room, Work Area	13.99	1.3	
Waiting Area, General	6.46	0.6	
Hotels			
Bathrooms	13.99	1.3	a, d
Bedrooms	15.07	1.4	a, d
Entrance Foyer	11.84	1.1	
Lobby, General	11.84	1.1	a
Laundries			
Fine Hand Ironing	30.14	2.8	
Ironing, Weighing, Listing, Marking	13.99	1.3	
Machine and Press Finishing, Sorting	18.30	1.7	
Washing	7.53	0.7	
Library			
Audio Listening Areas, General	7.53	0.7	
Audiovisual Areas	18.30	1.7	
Book Stacks (Active)	9.69	0.9	
Book Stacks (Inactive)	4.31	0.4	
Book Repair and Binding	20.45	1.9	

See page 4-6 for footnotes.

Table 3
(page 3 of 4)
Base UPD Values

Task or Area	Base UPD Watts per Square Meter	Base UPD Watts per Square Foot	Note
Card Files	34.44	3.2	
Cataloging	23.68	2.2	
Microfilm Areas	23.68	2.2	
Reading Areas	23.68	2.2	
Municipal Building—Fire and Police			
Fire Engine Room	7.53	0.7	
Fireman's Dormitory	15.07	1.4	a
Identification Records	50.59	4.7	
Jail Cells	8.61	0.8	
Recreation Room	9.69	0.9	
Nursing Homes			
Administrative & Lobby Areas	15.07	1.4	
Chapel or Quiet Area, General	9.69	0.9	
Nurses' Station	15.07	1.4	a
Occupational Therapy	13.99	1.3	
Patient Care Unit (or Room), General	15.07	1.4	a, d
Pharmacy Area, General	17.22	1.6	a
Physical Therapy	20.45	1.9	
Recreation Area	15.07	1.4	
Post Offices			
Lobby	7.53	0.7	
Sorting, Mailing, etc.	30.14	2.8	
Restaurants-See Common Areas (Food Service)			
Schools			
Art	32.29	3.0	
Classrooms	23.68	2.2	
Dormitories	15.07	1.4	a
Drafting	34.44	3.2	
Home Economics	15.07	1.4	
Laboratories	30.14	2.8	
Lecture	23.68	2.2	
Music	18.30	1.7	
Sewing	45.21	4.1	
Shops	30.14	2.8	
Study Halls or Typing	23.68	2.2	
Service Stations, Auto	7.53	0.7	
Stores			
Alteration and Fitting	61.35	5.7	
Circulation	9.69	0.9	
Merchandise	40.90	3.8	
Sales Transaction	20.45	1.9	
Show Windows	93.65	8.7	
Stockrooms	7.53	0.7	
Wrapping and Packing	13.99	1.3	
Theaters and Motion Picture Houses	8.61	0.8	b
Industrial			
Aircraft Maintenance			
Docking and Maintenance	18.30	1.7	
Engine Overhaul	26.91	2.5	
Fabrication (Preparation for Assembly)	26.91	2.5	
First Manufacturing Operations (First Cut) Marking, Shearing, Sawing	13.99	1.3	
Aircraft Manufacturing			
Assembly—Sub and Final	26.91	2.5	
General Production	22.60	2.1	
Inspection Assembly	26.91	2.5	
Inspection Stock Parts	53.82	5.0	
Automobile Manufacturing			
Body Manufacturing			
Assembly	26.91	2.5	
Finishing and Inspecting	53.82	5.0	
Parts	18.30	1.7	
Chassis Assembly Line	26.91	2.5	
Final Assembly, Inspection Line	53.82	5.0	
Frame Assembly	13.99	1.3	
Bakeries			
General Production	'10.76	1.0	
Hand Decorating	36.60	3.4	
Mechanical Decorating	19.38	1.8	
Mixing and Filling	13.99	1.3	
Book Binding			
General Production	18.30	1.7	
Embossing and Inspection	81.81	7.6	
Brewing			
General Production	7.53	0.7	
Filling (Bottles, Cans, Kegs)	13.99	1.3	
Candy Making			
Die Cutting and Wrapping	26.91	2.5	
General Production	13.99	1.3	
Sorting and Decorating	36.60	3.4	
Canning and Preserving			
Can Unscrambler	18.30	1.7	
Color Grading	81.81	7.6	
Initial Grading	13.99	1.3	
Inspection—Container	59.20	5.5	
Inspection—Food	81.81	7.6	
Labelling and Cartoning	7.53	0.7	
Preparation and Canning	26.91	2.5	
Chemical Works (See Petroleum)	7.53	0.7	
Clay Products and Cements			
Enameling and Glazing, Rough	36.60	3.4	
Fine Glazing	73.19	6.8	
General Production	7.53	0.7	
Cleaning and Pressing			
General Processing	13.99	1.3	
Pressing	39.83	3.7	
Repair and Alteration, Inspection & Spotting	59.20	5.5	
Cloth Products	53.82	5.0	
Clothing Manufacturing			
General Production	15.07	1.4	
Inspection, Pressing, Sewing, Cutting	59.20	5.5	
Piling up and Marking, and Shops	36.60	3.4	
Cotton Gin Industry	10.76	1.0	
Coal Tipple and Cleaning Plants	4.31	0.4	
Dairy Products			
Bottle Sorting	13.99	1.3	
Filling and Inspection	26.91	2.5	
General Processing	7.53	0.7	
Milk Equipment Washing	26.91	2.5	
Electric Generating Stations—Interiors			
Controlled Access Areas	22.60	2.1	
General Operation Area	6.46	0.6	
Laboratories	25.83	2.4	
Electrical Equipment Manufacturing			
General Production and Testing	26.91	2.5	
Explosives Manufacturing	7.53	0.7	
Flour Mills			
General Production	13.99	1.3	
Packing, Cleaning, Checking	7.53	0.7	
Product Control	26.91	2.5	
Forge Shops	13.99	1.3	
Foundries			
Core Making and Inspection	26.91	2.5	
Cupola Area	6.46	0.6	
Fine Inspection	53.82	5.0	
General Production	10.76	1.0	
Molding and Grinding	26.91	2.5	
Garage—Service			
Repair Area	26.91	2.5	
Traffic Area	6.46	0.6	
General Assembly and Production Area			
Medium	26.91	2.5	

See page 4-6 for footnotes.

Table 3
(page 4 of 4)
Base UPD Values

Task or Area	Base UPD: Watts per Square Meter	Base UPD: Watts per Square Foot	Note	Task or Area	Base UPD: Watts per Square Meter	Base UPD: Watts per Square Foot	Note
Recreational	6.46	0.6	c	Professional	30.14	2.8	c
Skating Rinks	4.31	0.4		Recreational	15.07	1.4	c
Swimming				Tennis, Table			
Exhibitions	13.99	1.3	c	Club	8.61	0.8	c
Recreational	7.53	0.7	c	Recreational	6.46	0.6	c
Tennis				Tournament	15.07	1.4	c
Club	20.45	1.9	c	Volleyball	6.46	0.6	c

Areas and Functions	Power Allowance: Watts per Linear Meter	Power Allowance: Watts per Linear Foot	Note	Areas and Functions	Power Allowance: Watts per Linear Meter	Power Allowance: Watts per Linear Foot	Note
Exterior			e	Exits, With or Without Canopy	65.62	20.0	
Driveways				Loading Area	3.23	0.3	g
Private (based on 2-lane width)	6.56	2.0		Loading Doors	65.62	20.0	
Public (based on 2-lane width)	9.84	3.0		Outdoor Production and Processing	4.31	0.4	g
Entrances With Canopy				Outdoor Storage	2.15	0.2	g
Decorative (Retail, Hotel, Theater, etc)	107.64	10.0	g	Parking Lots (Open)			
Utilitarian (Hospital, Office, Ind., etc)	43.06	4.0	g	Private	20.0	20.0	h
Entrances Without Canopy	98.43	30.0		Public	30.0	30.0	h

[*] Values are not for design purpose, since they do not take room size or shape into consideration.
[a] Includes 5.4 watts per square meter (0.5 watts per square foot) for special tasks.
[b] Allows additional lighting for clean-up.
[c] Gross floor area to include up to 3 meters (10 feet) surrounding the activity or playing area.
[d] Use RF = 1 for these spaces when determining power limit.
[e] These areas and activities are associated with the building under consideration.
[f] It is important to determine task area within the space by the size and number of work locations.
[g] Watts per square meter or watts per square foot.
[h] Watts per space.

Determination of a Power Limit

The lighting power "limit" of a facility is determined by totaling for lighting power "budgets" of individual rooms or spaces and that allowed for exterior areas and activities directly associated with the building facility under consideration. Figs. 4-3 and 4-4 are to be used to determine the power budgets and limit. There are three basic steps:

1. Determine the lighting power budget for each individual room or space.
2. Determine the lighting power limit of the building interior.
3. Determine the lighting power limit of the facility.

Calculation Procedure. The lighting power budget of an individual room or space is determined by the formula:

$$P_r = A_r \times P_b \times \text{RF} \times \text{SUF}$$

where

P_r = power budget of the room or space in watts
A_r = area of the room in square meters (square feet)
P_b = base unit power density (UPD) in watts per square meter (watts per square foot)
RF = room factor
SUF = space utilization factor

Base UPD. Base UPD (P_b) is the UPD which will provide sufficient power to satisfy the lighting requirements of the listed visual tasks for the space, assuming the power is utilized effectively in a large and unobstructed space. Base UPD's of various Task/Areas are given in Fig. 4-2.

For rooms with multiple Task/Areas, the base UPD is the weighted average of the individual task UPD's, using the following formula:

$$\text{Weighted Average UDP} = \frac{(\text{UPD}_{t1}\, N_{t1}) + (\text{UPD}_{t2}\, N_{t2}) + (\text{UPD}_{t3}\, N_{t3}) + \ldots}{N_{t1} + N_{t2} + N_{t3} + \ldots}$$

Table 4
(page 1 of 2)
UPD Sample Worksheet

Project: Composite Bldg. By: DLD Date: 3 Nov 80
Units of Length Used: Meters ____ or Feet ✓ Page 1 of 2

A	B	C	D	E	F	G	I	J	K	L	M	N	O
Room Name or Number	Description of Visual Tasks (One Type per Line) or General Use of the Room	Work Stations: Number	Work Stations: Area A_t = C × 4.65 (50) m^2 (ft^2)	Room Dimensions m (ft): L × W / Ceiling Height	No Ident Rms	Room Area, A_r m^2 (ft^2) / H: Total Area of Identical Rms A_T = FxG m^2 (ft^2)	Room Factor RF	Space Utilization Factor ≥ 5 1.00; < 5 .85; < 4 .70; < 3 .55; < 2 .40: A_t/A_r	SUF	Base UPD (P_b) W/m^2 (W/ft^2): Individual Task	Base UPD (P_b) W/m^2 (W/ft^2): Weighted Average	Power Budget of Room Watts = G·I·K·M	Power Budget for Total of Identical Rooms Watts = F·N
1A	Lobby	—	—	50 x 50 16	1	2500	1.20				1.0		3000
1B	Vestibule and Lobby	—	—	22 x 30 8	1	660	1.15				1.0		759
2A	Library 30% Stack, 70% Read	—	—	50 x 50 9	1	2500	1.05			0.9 2.2	1.8		4725
2B 2C	Office Reading	2	100	10 x 14 8	2	140 280	1.45	0.71	1.0		2.2	447	893
3A 4A	Retail Store 50% Merch. 50% Cir.	—	—	45 x 20 9	2	900 1800	1.15			3.8 0.9	2.4	2484	4968
3B 4B	Show Window	—	—	5 x 20 8	2	100 200	1.70				8.7	1479	2958
3C 4C	Stockroom	—	—	10 x 20 8	2	200 400	1.40				0.7	196	392
5A	Computer Equip. Room	—	—	70 x 45 9	1	3150	1.0				1.7		5355
6A	Mechanical Room	—	—	50 x 50 10	1	2500	1.0				0.6		1500
6C	Electrical Equip. Room	—	—	18 x 10 8	1	180	1.0				0.6		108
6D	Woodworking Shop	—	—	20 x 50 10	1	1000	1.20				1.3		1560
7A	Food Service Dining Area	—	—	20 x 30 9	1	600	1.20				1.4		1008
7B	Kitchen	—	—	20 x 10 9	1	200	1.50				1.7		510
8 A-D	Toilet	—	—	10 x 18 8	4	180 720	1.40				0.7	176	706
9A	General Office	25	1250	40 x 50 9	1	2000	1.05	0.63	1.0		2.2		4620
9B	Accounting Office	10	500	25 x 30 9	1	750	1.15	0.67	1.0		3.2		2760
9C	Drafting	4	200	20 x 25 9	1	500	1.25	0.40	0.70		4.7		2056
9D	Filing Inactive	—	—	10 x 15 8	1	150	1.45				0.8		174
9 E-I	Office Reading	2	100	10 x 10 8	5	100 500	1.60	1.0	1.0		2.2	352	1760
Totals This Page						20590							39812

Table 4
(page 2 of 2)
UPD Sample Worksheet

Project: Composite Bldg. By: DLD Date: 3 Nov. 80
Units of Length Used: Meters ____ or Feet ✓ Page 2 of 2

A	B	C	D	E	F	G	I	J	K	L	M	N	O
Room Name or Number	Description of Visual Tasks (One Type per Line) or General Use of the Room	Work Stations Number	Work Stations Area A_t = C × 4.65 (50) m^2 (ft^2)	Room Dimensions m (ft) L × W Ceiling Height	No. Ident. Rms.	Room Area, A_r m^2 (ft^2) H Total Area of Identical Rms. A_T = FxG m^2 (ft^2)	Room Factor RF	Space Utilization Factor ≥ 5 < 5 < 4 < 3 < 2 A_t/A_r	1.00 .85 .70 .55 .40 SUF	Base UPD(P_b) W/m^2 (W/ft^2) Individual Task	Weighted Average	Power Budget of Room Watts = G·I·K·M	Power Budget for Total of Identical Rooms Watts = F·N
10A	Classroom	—	—	40 x 40 9	1	1600	1.05				2.2		3696
11A	Basketball College & Hi Sch.	—	—	100 x 60 25	1	6000	1.0				0.8		4800
11B	Basket ball Seating	—	—	15 x 100 25	1	1500	1.0				0.4		600
11C	Storage Active Bulky	—	—	10 x 20 8	1	200	1.40				0.4		112
12A	Surgical Suite Operating Rm.	—	—	20 x 15 8	1	300	1.25				7.6		2850
12B	Scrub Up Area	—	—	15 x 10 8	1	150	1.45				2.5		544
12C	Nurses Station	—	—	10 x 13 8	1	130	1.50				1.4		273
12 D-F	Laboratory	—	—	10 x 14 8	3	140 420	1.45				3.2	650	1949
12 G-J	Patients' Rooms	—	—	10 x 18 8	4	180 720	1.0				1.4	252	1008
12 K-L	Office Reading	3	150	10 x 20 8	2	200 400	1.40	0.75	1.0		2.2	616	1232
12M	Hospital Lobby	—	—	22 x 20 8	1	440	1.20				2.0		1056
12N	Corridor	—	—	42 x 10 8	1	420	1.0				0.6		252
13A	Tennis Club	—	—	60 x 120 35	1	7200	1.0				1.9		13680
14A	Hotel Lobby	—	—	24 x 36 8	1	864	1.10				1.1		1045
14 B-C	Guest Room	—	—	12 x 20 8	2	240 480	1.0				1.4	336	672
14D	Corridor	—	—	50 x 8 8	1	400	1.0				0.6		240
14E	Corridor	—	—	80 x 8 8	1	640	1.0				0.6		384
15A	Garage-Service 35% Traffic, 65% Repair			32 x 60 20	1	1920	1.45			0.6 2.5	1.8		5011
Totals This Page						23784							39404

Table 5
UPD Results from Sample Worksheet

Reference	Item		Area m^2 (n2)	Guide
Q	Gross Floor Area of Building			Exterior Building Dimension (Less Covered Exteriors)
R	Total Area Listed Interior Spaces			Total of All Columns H
S	Unlisted (Net) Building Area			Q – R
T	Power Limit – Unlisted Space			2.15 x Sum (0.2 x Sum)
U	Power Limit – Listed Space			Sum of Column 0 for All Pages
V	Power Limit – Building Interior			T + U
W	Basic Building Interior UPD			V + 0 watts / m^2 (n2)

Table 6
(page 1 of 2)
Room Factors (RF)

Dimensions* (feet)		Ceiling Height (feet)											
W	L	8	8.5	9	10	11	12	14	16	18	20+		
6	6											1.8	1.8
6	9											1.8	2.7
6	12	1.85										1.8	3.7
6	15	1.75	1.90									1.8	4.6
6	18	1.70	1.80	1.95								1.8	5.5
6	24	1.65	1.75	1.85								1.8	7.3
6	30	1.60	1.70	1.80								1.8	9.1
6	36	1.60	1.65	1.75	1.95							1.8	11.0
6	60	1.55	1.60	1.70	1.85							1.8	18.3
6	60+	1.45	1.50	1.60	1.75	1.90						1.8	18.3+
8	8	1.85										2.4	2.4
8	12	1.65	1.75	1.85								2.4	3.7
8	16	1.55	1.65	1.70	1.90							2.4	4.9
8	20	1.50	1.55	1.65	1.80	1.95						2.4	6.1
8	24	1.45	1.50	1.60	1.75	1.90						2.4	7.3
8	32	1.40	1.45	1.55	1.65	1.80	1.95					2.4	9.8
8	40	1.40	1.45	1.50	1.65	1.75	1.90					2.4	12.2
8	48	1.35	1.45	1.50	1.60	1.75	1.85					2.4	14.6
8	80	1.35	1.40	1.45	1.55	1.65	1.80					2.4	24.4
8	80+	1.30	1.35	1.40	1.50	1.60	1.70	1.90				2.4	24.4+
10	10	1.60	1.70	1.80								3.0	3.0
10	15	1.45	1.50	1.60	1.75	1.90						3.0	4.6
10	20	1.40	1.45	1.50	1.65	1.75	1.90					3.0	6.1
10	25	1.35	1.40	1.45	1.55	1.70	1.80					3.0	7.6
10	30	1.30	1.35	1.40	1.50	1.65	1.75					3.0	9.1
10	40	1.30	1.35	1.40	1.45	1.60	1.70	1.90				3.0	12.2
10	50	1.25	1.30	1.35	1.45	1.55	1.65	1.85				3.0	15.2
10	60	1.25	1.30	1.35	1.45	1.50	1.60	1.80				3.0	18.3
10	100	1.25	1.25	1.30	1.40	1.45	1.55	1.75	1.95			3.0	30.5
10	100+	1.20	1.25	1.25	1.35	1.40	1.50	1.65	1.85			3.0	30.5+
12	12	1.45	1.50	1.60	1.75	1.90						3.7	3.7
12	18	1.35	1.40	1.45	1.55	1.70	1.80					3.7	5.5
12	24	1.30	1.35	1.40	1.45	1.60	1.70	1.90				3.7	7.3
12	30	1.25	1.30	1.35	1.45	1.50	1.60	1.80				3.7	9.1
12	36	1.25	1.30	1.30	1.40	1.50	1.55	1.75				3.7	11.0
12	48	1.20	1.25	1.30	1.35	1.45	1.50	1.70	1.90			3.7	14.6
12	60	1.20	1.25	1.25	1.35	1.40	1.50	1.65	1.85			3.7	18.3
12	72	1.20	1.20	1.25	1.30	1.40	1.45	1.60	1.80			3.7	21.9
12	120	1.15	1.20	1.25	1.30	1.35	1.40	1.55	1.75	1.90		3.7	36.6
12	120+	1.15	1.15	1.20	1.25	1.30	1.35	1.50	1.65	1.80	1.95	3.7	36.6+
16	16	1.30	1.35	1.40	1.45	1.60	1.70	1.90				4.9	4.9
16	24	1.20	1.25	1.30	1.35	1.45	1.50	1.70	1.90			4.9	7.3
16	32	1.20	1.20	1.25	1.30	1.35	1.45	1.60	1.75	1.95		4.9	9.8
16	40	1.15	1.20	1.20	1.25	1.35	1.40	1.55	1.70	1.85		4.9	12.2
16	48	1.15	1.15	1.20	1.25	1.30	1.35	1.50	1.65	1.80	1.95	4.9	14.6
16	64	1.15	1.15	1.20	1.25	1.30	1.35	1.45	1.55	1.70	1.85	4.9	19.5
16	80	1.10	1.15	1.15	1.20	1.25	1.30	1.40	1.55	1.65	1.80	4.9	24.4
16	96	1.10	1.15	1.15	1.20	1.25	1.30	1.40	1.50	1.65	1.75	4.9	29.3
16	160	1.10	1.10	1.15	1.20	1.20	1.25	1.35	1.45	1.60	1.70	4.9	48.8
16	160+	1.10	1.10	1.10	1.15	1.20	1.25	1.30	1.40	1.50	1.60	4.9	48.8+
20	20	1.20	1.25	1.25	1.35	1.40	1.50	1.65	1.85	2.00	2.00	6.1	6.1
20	30	1.15	1.15	1.20	1.25	1.30	1.35	1.50	1.65	1.80	1.95	6.1	9.1
20	40	1.10	1.15	1.15	1.20	1.25	1.30	1.40	1.55	1.65	1.80	6.1	12.2
20	50	1.10	1.10	1.15	1.20	1.25	1.30	1.40	1.50	1.60	1.70	6.1	15.2
20	60	1.10	1.10	1.15	1.15	1.20	1.25	1.35	1.45	1.55	1.65	6.1	18.3
20	80	1.10	1.10	1.10	1.15	1.20	1.25	1.30	1.40	1.50	1.60	6.1	24.4
20	100	1.05	1.10	1.10	1.15	1.20	1.20	1.30	1.40	1.45	1.55	6.1	30.5
20	120	1.05	1.10	1.10	1.15	1.15	1.20	1.30	1.35	1.45	1.55	6.1	36.6
20	200	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.35	1.40	1.50	6.1	61.0
20	200+	1.05	1.05	1.05	1.10	1.15	1.15	1.20	1.30	1.35	1.45	6.1	61.0+
		2.4	2.6	2.7	3.0	3.4	3.7	4.3	4.9	5.5	6.1+	W	L
		Ceiling Height (meters)										Dimensions (meters)	

Table 6
(page 2 of 2)
Room Factors (RF)

Dimensions* (feet)		Ceiling Height (feet)											
W	L	8	8.5	9	10	11	12	14	16	18	20+		
24	24	1.15	1.15	1.20	1.25	1.30	1.35	1.50	1.65	1.80	1.95	7.3	7.3
24	36	1.10	1.10	1.15	1.20	1.25	1.25	1.35	1.45	1.60	1.70	7.3	11.0
24	48	1.10	1.10	1.10	1.15	1.20	1.25	1.30	1.40	1.50	1.60	7.3	14.6
24	60	1.05	1.10	1.10	1.15	1.15	1.20	1.30	1.35	1.45	1.55	7.3	18.3
24	72	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.35	1.40	1.50	7.3	21.9
24	96	1.05	1.05	1.10	1.10	1.15	1.15	1.25	1.30	1.40	1.45	7.3	29.3
24	120	1.05	1.05	1.05	1.10	1.15	1.15	1.20	1.30	1.35	1.45	7.3	36.6
24	144	1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.35	1.40	7.3	43.9
24	240	1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	1.35	7.3	73.2
24	240+		1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	7.3	73.2+
30	30	1.10	1.10	1.15	1.15	1.20	1.25	1.35	1.45	1.55	1.65	9.1	9.1
30	45	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.35	1.40	1.50	9.1	13.7
30	60	1.05	1.05	1.05	1.10	1.15	1.15	1.20	1.30	1.35	1.45	9.1	18.3
30	75	1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	1.40	9.1	22.9
30	90		1.05	1.05	1.05	1.10	1.10	1.20	1.25	1.30	1.35	9.1	27.4
30	120		1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	9.1	36.6
30	150			1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	9.1	45.7
30	180			1.05	1.05	1.05	1.10	1.15	1.20	1.25	1.30	9.1	54.9
30	300				1.05	1.05	1.10	1.10	1.15	1.20	1.25	9.1	91.4
30	300+				1.05	1.05	1.05	1.10	1.15	1.20	1.20	9.1	91.4+
40	40	1.05	1.05	1.05	1.10	1.15	1.15	1.20	1.30	1.35	1.45	12.2	12.2
40	60		1.05	1.05	1.05	1.10	1.10	1.15	1.20	1.25	1.30	12.2	18.3
40	80				1.05	1.05	1.10	1.15	1.20	1.20	1.25	12.2	24.4
40	100				1.05	1.05	1.05	1.10	1.15	1.20	1.25	12.2	30.5
40	120				1.05	1.05	1.05	1.10	1.15	1.20	1.20	12.2	36.6
40	160					1.05	1.05	1.10	1.10	1.15	1.20	12.2	48.8
40	200					1.05	1.05	1.10	1.10	1.15	1.20	12.2	61.0
40	240					1.05	1.05	1.05	1.10	1.15	1.20	12.2	73.2
40	400						1.05	1.05	1.10	1.15	1.15	12.2	122.0
40	400+							1.05	1.10	1.10	1.15	12.2	122+
60	60				1.05	1.05	1.05	1.10	1.15	1.20	1.20	18.3	18.3
60	90						1.05	1.05	1.10	1.15	1.15	18.3	27.4
60	120							1.05	1.10	1.10	1.15	18.3	36.6
60	150							1.05	1.05	1.10	1.10	18.3	45.7
60	180							1.05	1.05	1.10	1.10	18.3	54.9
60	240								1.05	1.05	1.10	18.3	73.2
60	300								1.05	1.05	1.10	18.3	91.4
60	360								1.05	1.05	1.10	18.3	110.0
60	600								1.05	1.05	1.05	18.3	183.0
60+	600+									1.05	1.05	18.3	183+
		2.4	2.6	2.7	3.0	3.4	3.7	4.3	4.9	5.5	6.1+	W	L
		Ceiling Height (meters)										Dimensions (feet)	

* W = width, L = length.
† Where no value is listed on page 4-12, RF = 2.00. Where none appears on page 4-13, RF = 1.00.

Table 7

Currently Recommended Illuminance Categories

Area Activity	Illuminance Category	Veiling Reflection
Accounting		
(see individual tasks)		
Copied Tasks		
Ditto Copy[5]	E	•
Micro–Fiche Reader[1]	B	••
Mimeograph	D	
Photographs, Mod. Detail	E	••
Thermal Copy, Poor Copy	F	•
Xerograph, 3rd Generation[5] and greater	E	
Xerograph		
Drafting Tasks		
Drafting: Mylar		
High Contrast Media; Soft Graphite Leads	E	•
Low Contrast Media; Hard Graphite Leads	F	•
Vellum: High Contrast	F	•
Low Contrast	E	
Tracing Paper:High Contrast	F	
Low Contrast	E	•
Overlays[2]	C	
Light Table	E	
Prints: Blue Line	E	
Blue Prints	E	
Sepia Prints	F	
EDP Tasks		
CRT Screens[1] B	••	
Impact Printer : Good Ribbon	D	
Impact Printer : Poor Ribbon	E	
2nd Carbon and Greater[5]	E	
Ink Jet Printer	D	
Keyboard Reading	D	
Machine Rooms: Active Operations	D	
Tape Storage D		
Machine Area D		
Equipment Service[3]	E	
Thermal Print	E	•
Filing (See Individual Tasks)		

Table 7
Categories

Area Activity	Illuminance Category	Veiling Reflection
General and Public Areas	D	
Conference Rooms	D	
(critical seeing, refer to individual tasks)		
Display Areas	C	
Duplicating and off–set printing area	D	
Elevators	C	
Escalators	E	
First Aid Areas	E	
Food Service		
Hallways	B	
Janitorial Spaces	C	
Libraries	C	
Lobbies and lounges		C
Model Making	E	
Mail Sorting	B	
Mechanical Rooms: Operations	B	
Equipment Service[3]	E	
Reception Area	C	
Rest Rooms		C
Stairs	B	
Utility Rooms	B	
Graphic Design and Material		
Color Selection	F	
Charting and Mapping		F
Graphs		E
Keylining	F	
Layout and Artwork		F
Photographs, Mod. Detail		E
Handwritten Tasks		
#2 Pencil and Softer Leads	D	•
#3 Pencil	E	•
#4 Pencil and Harder Leads[5]	F	
Ball–Point Pen	D	
Felt–Tip Pen	D	
Handwritten Carbon Copies[5]	E	
Non Photographically Reproducible colors	F	
Printed Tasks		
6 pt 5	E	•
8 & 10 pt	D	•
Glossy Magazines	D	••
Maps	E	
Newsprint	D	
Typed Originals	D	

Table 7

Foot Notes

1 Veiling reflections may be produced on glass surfaces. It may be necessary to treat plus weighting factors as minus in order to obtain proper light balance.

2 Degradation factors: Overlays — add 1 weighting factor for each overlay
Used Material — estimate additional factors.

3 Only when actual equipment service is in progress. May be achieved by a general lighting system or by localized lighting or by portable equipment.

4 For color matching, the quality of the color of the light source may be important.

5 Designing to higher light levels to accommodate poor quality tasks should be undertaken only after it is determining that task quality cannot be improved. If a poor quality task cannot be eliminated, its "time–and–importance" factor should be carefully considered before allowing it to govern the illuminance level selection.

• Task subject to veiling reflections. Illuminance listed is not an ESI value. Currently, insufficient experience in the use of ESI target values precludes the direct use of Equivalent Sphere Illumination in the present consensus approach to recommend illuminance values. Equivalent Sphere Illumination may be used as a tool in determining the effectiveness of controlling veiling reflections and as a part of the evaluation of lighting systems.

•• Especially subject to veiling reflections. It may be necessary to shield the task or to reorient it.

Source: IES Lighting Handbook, 1981

Table 8
Lower Specific Variance Within Ranges of Values

a. For Illuminance Categories A through C

Room and Occupant Characteristics	Weighting Factor -1	Weighting Factor 0	Weighting Factor +1
Occupants Ages	Under 40	40 – 55	Over 55
Room Surface Reflectances *	Greater than 70 Percent	30 to 70 Percent	Less than 30 Percent

a. For Illuminance Categories A through C

Task and Worker Characteristics	Weighting Factor -1	Weighting Factor 0	Weighting Factor +1
Workers Ages	Under 40	40 – 55	Over 55
Speed and / or Accuracy **	Not Important	Important	Critical
Reflectance of task background	Greater than 70 Percent	30 to 70	Less than 30 Percent

• Average weighted surface reflectances, including wall, floor and ceiling reflectances. If they encompass a large portion of the task area or visual surround. For instance, in an elevator lobby, where the ceiling height is 7.6 meters (25 feet), neither the task nor the visual surround encompass the ceiling, so only the floor and wall reflectances would be considered.

•• In determining whether speed and/or accuracy is not important, important critical, the following questions need to be answered: What are the time limitations? How important is it to perform the task rapidly? Will errors produce an unsafe condition or product? Will errors reduce productivity and be costly? For example, in reading for leisure there are no time limitations and it is not important to read rapidly. Errors will not be costly and will not be related to safety. Thus, speed and/or accuracy is not important. If however, prescription notes are to be read by the pharmacist, accuracy is critical because errors could produce an unsafe condition and time is important for customer relations.

••• The task background is that portion of the task upon which the meaningful visual display is exhibited. For example, on this page the meaningful visual display includes each letter which combines with other letters to form words and phrases.

Table 9
Lamp Types

Lamp Type	Luminous Efficacy (Lumens/Watt)	Life (Hours)	% Lumen Depreciation
Incandescent	9-22	750-3,500	4-22
Fluorescent	45-95	7,500-20,000	11-28
LPS	62-150	12,000-18,000	6-7
Mercury Vapour	34-61	16,000-24,000	12-22
Metal Halide	80-115	7,500-15,000	13-22
HPS	80-140	12,000-24,000	8-10

Table 10
Fixture Shields

Type of fixture light shield	VCP*	% Efficiency
Dark metal louver	70-90	25-40
White metal louver	65-85	35-45
Plastic louver	50-70	45-55
Parabolic louver	99	35-45
Toned lens	65-95	30-65
Clear lens	50-85	45-70
Diffuser	40-50	40-60
Polarizer	60-70	55-80

Table 11
Percent Effective Ceiling or Floor Cavity Reflectances

Percent base† reflectance	90									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
Cavity ratio										
0.2	89	88	88	87	86	85	85	84	84	82
0.4	88	87	86	85	84	83	81	80	79	76
0.6	87	86	84	82	80	79	77	76	74	73
0.8	87	85	82	80	77	75	73	71	69	67
1.0	86	83	80	77	75	72	69	66	64	62
1.2	85	82	78	75	72	69	66	63	60	57
1.4	85	80	77	73	69	65	62	59	57	52
1.6	84	79	75	71	67	63	59	56	53	50
1.8	83	78	73	69	64	60	56	53	50	48
2.0	83	77	72	67	62	56	53	50	47	43
2.2	82	76	70	65	59	54	50	47	44	40
2.4	82	75	69	64	58	53	48	45	41	37
2.6	81	74	67	62	56	51	46	42	38	35
2.8	81	73	66	60	54	49	44	40	36	34
3.0	80	72	64	58	52	47	42	38	34	30
3.2	79	71	63	56	50	45	40	36	32	28
3.4	79	70	62	54	48	43	38	34	30	27
3.6	78	69	61	53	47	42	36	32	28	25
3.8	78	69	60	51	45	40	35	31	27	23
4.0	77	69	58	51	44	39	33	29	25	22
4.2	77	62	57	50	43	37	32	28	24	21
4.4	76	61	56	49	42	36	31	27	23	20
4.6	76	60	55	47	40	35	30	26	22	19
4.8	75	59	54	46	39	34	28	25	21	18
5.0	75	59	53	45	38	33	28	24	20	16
6.0	73	61	49	41	34	29	24	20	16	11
7.0	70	58	45	38	30	27	21	18	14	08
8.0	68	55	42	35	27	23	18	15	12	06
9.0	66	52	38	31	25	21	16	14	11	05
10.0	65	51	36	29	22	19	15	11	09	04

Percent base† reflectance	80									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
Cavity ratio										
0.2	79	78	78	77	77	76	76	75	74	72
0.4	79	77	76	75	74	73	72	71	70	68
0.6	78	76	75	73	71	70	68	66	65	63
0.8	78	75	73	71	69	67	65	63	61	57
1.0	77	74	72	69	67	65	62	60	57	55
1.2	76	73	70	67	64	61	58	55	53	51
1.4	76	72	68	65	62	59	55	53	50	48
1.6	75	71	67	63	60	57	53	50	47	44
1.8	75	70	66	62	58	54	50	47	44	41
2.0	74	69	64	60	56	52	48	45	41	38
2.2	74	68	63	58	54	49	45	42	38	35
2.4	73	67	61	56	52	47	43	40	36	33
2.6	73	66	60	55	50	45	41	38	34	31
2.8	73	65	59	53	48	43	39	36	32	29
3.0	72	65	58	52	47	42	37	34	30	27
3.2	72	65	57	51	45	40	35	33	28	25
3.4	71	64	56	49	44	39	34	32	27	24
3.6	71	63	54	48	43	38	32	30	25	23
3.8	70	62	53	47	41	36	31	28	24	22
4.0	70	61	53	46	40	35	30	26	22	20
4.2	69	60	52	45	39	34	29	25	21	18
4.4	69	60	51	44	38	33	28	24	20	17
4.6	69	59	50	43	37	32	27	23	19	15
4.8	68	58	49	42	36	31	26	22	18	14
5.0	68	58	48	41	35	30	25	21	18	14
6.0	66	55	44	38	31	27	22	19	15	10
7.0	64	53	41	35	28	24	19	16	12	07
8.0	62	50	38	32	25	21	17	14	11	05
9.0	61	49	36	30	23	19	15	13	10	04
10.0	59	46	33	27	21	18	14	11	08	03

Percent base† reflectance	70									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
Cavity ratio										
0.2	70	69	68	68	67	67	66	66	65	64
0.4	69	68	67	66	65	64	63	62	61	58
0.6	69	67	65	64	63	61	59	58	57	54
0.8	68	66	64	62	60	58	56	55	53	50
1.0	68	65	62	60	58	55	53	52	50	47
1.2	67	64	61	59	57	54	50	48	46	44
1.4	67	63	60	58	55	51	47	45	44	41
1.6	67	62	59	56	53	47	45	43	41	38
1.8	66	61	58	54	51	46	42	40	38	35
2.0	66	60	56	52	49	45	40	38	36	33
2.2	66	60	55	51	48	43	38	36	34	32
2.4	65	60	54	50	46	41	37	35	32	30
2.6	65	59	54	49	45	40	35	33	30	28
2.8	65	59	53	48	43	38	33	30	28	26
3.0	64	58	52	47	42	37	32	29	27	24
3.2	64	58	51	46	40	36	31	28	25	23
3.4	64	57	50	45	39	35	29	27	24	22
3.6	63	56	49	44	38	33	28	25	22	20
3.8	63	56	49	43	37	32	27	24	21	19
4.0	63	55	48	42	36	31	26	23	20	17
4.2	62	55	47	41	35	30	25	22	19	16
4.4	62	54	46	40	34	29	24	21	18	15
4.6	62	53	45	39	33	28	24	21	17	14
4.8	62	53	45	38	32	27	23	20	16	13
5.0	61	52	44	36	31	26	22	19	16	12
6.0	60	51	41	35	28	24	19	16	13	09
7.0	58	48	38	32	26	22	17	14	11	06
8.0	57	46	35	29	23	19	15	13	10	05
9.0	56	45	33	27	21	18	14	12	09	04
10.0	55	43	31	25	19	16	12	10	08	03

Percent base† reflectance	60									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
Cavity ratio										
0.2	60	59	59	59	58	57	56	56	55	53
0.4	60	59	59	58	57	55	54	53	52	50
0.6	60	58	57	56	55	53	51	51	50	46
0.8	59	57	56	55	54	51	48	47	46	43
1.0	59	57	55	53	51	48	45	44	43	41
1.2	59	56	54	51	49	46	44	42	40	38
1.4	59	56	53	49	47	44	41	39	38	36
1.6	59	55	52	48	45	42	39	37	35	33
1.8	58	55	51	47	44	40	37	35	33	31
2.0	58	54	50	46	43	39	35	33	31	29
2.2	58	53	49	45	42	37	34	31	29	28
2.4	58	53	48	44	41	36	32	30	27	26
2.6	58	53	48	43	39	35	31	28	26	24
2.8	58	53	47	43	38	34	29	27	24	22
3.0	57	52	46	42	37	32	28	25	23	20
3.2	57	51	45	41	36	31	27	23	22	18
3.4	57	51	45	40	35	30	26	23	20	17
3.6	57	50	44	39	34	29	25	22	19	16
3.8	57	50	43	38	33	29	24	21	19	15
4.0	57	49	42	37	32	28	23	20	18	14
4.2	56	49	42	37	32	27	22	19	17	14
4.4	56	49	42	36	31	27	22	19	16	13
4.6	56	49	41	35	30	26	21	18	16	13
4.8	56	48	41	34	29	25	21	18	15	12
5.0	56	48	40	34	28	24	20	17	14	11
6.0	55	45	37	31	25	21	17	14	11	07
7.0	54	43	35	30	24	20	15	12	09	05
8.0	53	42	33	28	22	18	14	11	08	04
9.0	52	40	31	26	20	16	12	10	07	03
10.0	51	39	29	24	18	15	11	09	07	02

Percent base† reflectance	50									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
Cavity ratio										
0.2	50	50	49	49	48	48	47	46	46	44
0.4	50	49	48	48	47	46	45	45	44	42
0.6	50	48	47	46	45	44	43	42	41	38
0.8	50	48	47	45	44	42	40	39	38	36
1.0	50	48	46	44	43	41	38	37	36	34
1.2	50	47	45	43	41	39	36	35	34	29
1.4	50	47	45	42	40	38	35	34	32	27
1.6	50	47	44	41	39	36	33	32	30	26
1.8	50	46	43	40	38	35	31	30	28	25
2.0	50	46	43	40	37	34	30	28	26	24
2.2	50	46	42	38	36	33	29	27	24	22
2.4	50	46	42	37	35	31	27	25	23	21
2.6	50	46	41	37	34	30	26	23	21	20
2.8	50	46	41	36	33	29	25	22	20	19
3.0	50	45	40	36	32	28	24	21	19	17
3.2	50	44	39	35	31	27	23	20	18	16
3.4	50	44	39	35	30	26	22	19	17	15
3.6	50	44	39	34	29	25	21	18	16	14
3.8	50	44	38	34	29	25	21	17	15	13
4.0	50	44	38	33	28	24	20	17	15	12
4.2	50	43	37	32	28	24	20	17	14	12
4.4	50	43	37	32	27	23	19	16	13	11
4.6	50	43	36	31	26	22	18	15	13	10
4.8	50	43	36	31	26	22	18	15	12	09
5.0	50	42	35	30	25	21	17	14	12	09
6.0	50	42	34	29	23	19	15	13	10	06
7.0	49	41	32	27	21	18	14	11	08	05
8.0	49	40	30	25	19	16	12	10	07	03
9.0	48	39	29	24	18	15	11	09	07	03
10.0	47	37	27	22	17	14	10	08	06	02

Percent base† reflectance	40									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
0.2	40	40	39	39	39	38	38	37	36	36
0.4	41	40	39	39	38	37	36	35	34	34
0.6	41	40	39	38	37	36	34	33	32	31
0.8	41	40	38	37	36	35	33	32	31	29
1.0	42	40	38	37	35	33	32	31	29	27
1.2	42	40	38	36	34	32	30	29	27	25
1.4	42	39	37	35	33	31	29	27	25	23
1.6	42	39	37	35	32	30	27	25	23	22
1.8	42	39	36	34	31	29	26	24	22	21
2.0	42	39	36	34	31	28	25	23	21	19
2.2	42	39	36	33	30	27	24	22	19	18
2.4	43	39	35	33	29	27	24	21	18	17
2.6	43	39	35	32	29	26	23	20	17	15
2.8	43	39	35	32	28	25	22	19	16	14
3.0	43	39	35	31	27	24	21	18	16	13
3.2	43	39	35	31	27	23	20	71	15	13
3.4	43	39	34	30	26	23	20	17	14	12
3.6	44	39	34	30	26	22	19	16	14	11
3.8	44	38	33	29	25	22	18	16	13	10
4.0	44	38	33	29	25	21	18	15	12	10
4.2	44	38	33	29	24	21	17	15	12	10
4.4	44	38	33	28	24	20	17	14	11	09
4.6	44	38	32	28	23	19	16	14	11	08
4.8	44	38	32	27	22	19	16	13	10	08
5.0	45	38	31	27	22	19	15	13	10	07
6.0	44	37	30	25	20	17	13	11	08	05
7.0	44	36	29	24	19	16	12	10	07	04
8.0	44	35	28	23	18	15	11	09	06	03
9.0	44	35	26	21	16	13	10	08	05	02
10.0	43	34	25	20	15	12	08	07	05	02

Percent base† reflectance	30									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
0.2	31	31	30	30	29	29	29	28	28	27
0.4	31	31	30	30	29	28	28	27	26	25
0.6	32	31	30	29	28	27	26	26	25	23
0.8	32	31	30	29	28	26	25	25	23	22
1.0	33	32	30	29	27	25	24	23	22	20
1.2	33	32	30	28	27	25	23	22	21	19
1.4	34	32	30	28	26	24	22	21	19	18
1.6	34	33	29	27	25	23	22	20	18	17
1.8	35	33	29	27	25	23	21	19	17	16
2.0	35	33	29	26	24	22	20	18	16	14
2.2	36	32	29	26	24	22	19	17	15	13
2.4	36	32	29	26	24	22	19	16	14	12
2.6	36	32	29	25	23	21	18	16	14	12
2.8	37	33	29	25	23	21	17	15	13	11
3.0	37	33	29	25	22	20	17	15	12	10
3.2	37	33	29	25	22	19	16	14	12	10
3.4	37	33	29	25	22	19	16	14	11	09
3.6	38	33	29	24	21	18	15	13	10	09
3.8	38	33	28	24	21	18	15	13	10	08
4.0	38	33	28	24	21	18	14	12	09	07
4.2	38	33	28	24	20	17	14	12	09	07
4.4	39	33	28	24	20	17	14	11	09	06
4.6	39	33	28	24	20	17	13	10	08	06
4.8	39	33	28	24	20	17	13	10	08	05
5.0	39	33	28	24	19	16	13	10	08	05
6.0	39	33	27	23	18	15	11	09	06	04
7.0	40	33	26	22	17	14	10	08	05	03
8.0	40	33	26	21	16	13	09	07	04	02
9.0	40	33	25	20	15	12	09	07	04	02
10.0	40	32	24	19	14	11	08	06	03	01

Percent base† reflectance	20									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
0.2	21	20	20	20	20	20	19	19	19	17
0.4	22	21	20	20	20	19	19	18	18	16
0.6	23	21	21	20	19	19	18	18	17	15
0.8	24	22	21	20	19	19	18	17	16	14
1.0	25	23	22	20	19	18	17	16	15	13
1.2	25	23	22	20	19	17	17	16	14	12
1.4	26	24	22	20	18	17	16	15	13	12
1.6	26	24	22	20	18	17	16	15	13	11
1.8	27	25	23	20	18	17	15	14	12	10
2.0	28	25	23	20	18	16	15	13	11	09
2.2	28	25	23	20	18	16	14	12	10	09
2.4	29	26	23	20	18	16	14	12	10	08
2.6	29	26	23	20	18	16	14	11	09	08
2.8	30	27	23	20	18	15	13	11	09	07
3.0	30	27	23	20	17	15	13	11	09	07
3.2	31	27	23	20	17	15	12	11	09	06
3.4	31	27	23	20	17	15	12	10	08	06
3.6	32	27	23	20	17	15	12	10	08	05
3.8	32	28	23	20	17	15	12	10	07	05
4.0	33	28	23	20	17	14	11	09	07	05
4.2	33	28	23	20	17	14	11	09	07	04
4.4	34	28	24	20	17	14	11	09	07	04
4.6	34	29	24	20	17	14	11	09	07	04
4.8	35	29	24	20	17	13	10	08	06	04
5.0	35	29	24	20	16	13	10	08	06	04
6.0	36	30	24	20	16	13	10	08	05	02
7.0	36	30	24	20	15	12	09	07	04	02
8.0	37	30	23	19	15	12	08	06	03	01
9.0	37	29	23	19	14	11	08	06	03	01
10.0	37	29	22	18	13	10	07	05	03	01

Percent base† reflectance	10									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
0.2	11	11	11	10	10	10	10	09	09	09
0.4	12	11	11	11	11	10	10	09	09	08
0.6	13	13	12	11	11	10	10	09	08	08
0.8	15	14	13	12	11	10	10	09	08	07
1.0	16	14	13	12	12	11	10	09	08	07
1.2	17	15	14	13	12	11	10	09	07	06
1.4	18	16	14	13	12	11	10	09	07	06
1.6	19	17	15	14	12	11	09	08	07	06
1.8	19	17	15	14	13	11	09	08	06	05
2.0	20	18	16	14	13	11	09	08	06	05
2.2	21	19	16	14	13	11	09	07	06	05
2.4	22	19	17	15	13	11	09	07	06	05
2.6	23	20	17	15	13	11	09	07	06	04
2.8	23	20	18	16	13	11	09	07	05	03
3.0	24	21	18	16	13	11	09	07	05	03
3.2	25	21	18	16	13	11	09	07	05	03
3.4	26	22	18	16	13	11	09	07	05	03
3.6	26	22	19	16	13	11	09	06	04	03
3.8	27	23	19	17	14	11	09	06	04	02
4.0	27	23	20	17	14	11	09	06	04	02
4.2	28	24	20	17	14	11	09	06	04	02
4.4	28	24	20	17	14	11	08	06	04	02
4.6	29	25	20	17	14	11	08	06	04	02
4.8	29	25	20	17	14	11	08	06	04	02
5.0	30	25	20	17	14	11	08	06	04	02
6.0	31	26	21	18	14	11	08	06	03	01
7.0	32	27	21	17	13	11	08	06	03	01
8.0	33	27	21	17	13	10	07	05	03	01
9.0	34	28	21	17	13	10	07	05	02	01
10.0	34	28	21	17	12	10	07	05	02	01

Percent base† reflectance	0									
Percent wall reflectance	90	80	70	60	50	40	30	20	10	0
0.2	02	02	02	01	01	01	01	00	00	0
0.4	04	03	03	02	02	02	01	01	00	0
0.6	05	05	04	03	03	02	02	01	01	0
0.8	07	06	05	04	04	03	02	02	01	0
1.0	08	07	06	05	04	03	02	02	01	0
1.2	10	08	07	06	05	04	03	02	01	0
1.4	11	09	08	07	06	04	03	02	01	0
1.6	12	10	09	07	06	05	03	02	01	0
1.8	13	11	09	08	07	05	04	03	01	0
2.0	14	12	10	09	07	05	04	03	01	0
2.2	15	13	11	09	07	06	04	03	01	0
2.4	16	13	11	09	08	06	04	03	01	0
2.6	17	14	12	10	08	06	05	03	02	0
2.8	17	15	13	10	08	07	05	03	02	0
3.0	18	16	13	11	09	07	05	03	02	0
3.2	19	16	14	11	09	07	05	03	02	0
3.4	20	17	14	12	09	07	05	03	02	0
3.6	20	17	15	12	10	08	05	04	02	0
3.8	21	18	15	12	10	08	05	04	02	0
4.0	22	18	15	15	13	10	08	04	02	0
4.2	22	19	16	13	10	08	06	04	02	0
4.4	23	19	16	13	10	08	06	04	02	0
4.6	23	20	17	13	11	08	06	04	02	0
4.8	24	20	17	14	11	08	06	04	02	0
5.0	25	21	17	14	11	08	06	04	02	0
6.0	27	23	18	15	12	09	06	04	02	0
7.0	28	24	19	15	12	09	06	04	02	0
8.0	30	25	20	15	12	09	06	04	02	0
9.0	31	25	20	15	12	09	06	04	02	0
10.0	31	25	20	15	12	09	06	04	02	0

[illegible]iling, floor, or floor of cavity.

Source: J. E. Kaufman (ed.), *IES Lighting Handbook*, Reference volume, 1981 ed., IES, New York, 1981, fig. 9-11, with permission.

Table 12
Flourescent Lamp Data

Type	Lamp no.	Watts	Length (in)	Life (at 3 h per start)	Initial lumens	Lamp current (mA)	Initial lamp lumens per watt	Lumens at 70% life
Preheat	F14T8CW	14	15	7,500	650	420	46	520
	F14T12CW	14	15	7,500	675	390	48	555
	F15T8CW	15	18	7,500	870	300	58	690
	F15T12CW	15	18	9,000	800	330	53	650
	F20T12CW	20	24	9,000	1,250	380	63	1,060
Rapid start and preheat	F40CW	40	48	20,000	3,150	425	79	2,650
	F40WW	40	48	20,000	3,200	425	80	2,690
	F40CWX	40	48	20,000	2,200	425	55	1,670
	F40WWX	40	48	20,000	2,150	425	54	1,635
	F40ES	34	48	20,000	2,750	450	81	2,310
Instant start	F48T12CW	39	48	9,000	3,000	425	77	2,490
	F72T12CW	55	72	12,000	4,600	425	84	4,090
	F96T12CW	75	96	12,000	6,300	425	84	5,610
	F64T6CW	40	64	7,500	2,800	200	70	2,160
	F72T8CW	35	72	7,500	3,000	200	86	2,490
	F96T8CW	50	96	7,500	4,200	200	84	3,740
	F96T12ES	60	96	12,000	5,600	440	93	4,985
High output rapid start	F48T12CWHO	60	48	12,000	4,300	800	72	3,525
	F72T12CWHO	85	72	12,000	6,650	800	78	5,455
	F96T12CWHO	110	96	12,000	9,200	800	84	7,545
	F96T12ESHO	95	96	12,000	8,300	810	87	6,805
Very high output rapid start	F48T12CW1500	115	48	10,000	6,800	1,500	59	4,690
	F72T12CW1500	160	72	10,000	10,900	1,500	68	7,850
	F96T12CW1500	215	96	10,000	15,000	1,500	70	12,300
	F96T12ES1500	195	96	10,000	14,000	1,580	72	10,100

COMMON CONVERSIONS

1 barrel (35 Imp gal) (42 US gal)	=	159.1 litres
1 gallon (Imp)	=	1.20094 gallon (US)
1 horsepower (boiler)	=	9809.6 watts
1 horsepower	=	2545 Btu/hour
1 horsepower	=	0.746 kilowatts
1 joule	=	1 N-m
Kelvin	=	(°C + 273.15)
1 kilowatt · hour	=	3600 kilojoules
1 Newton	=	1 kg-m/s^2
1 therm	=	10^5 Btu
1 ton (refrigerant)	=	12002.84 Btu/hour
1 ton (refrigerant)	=	3516.8 watts
1 watt	=	1 joule/second
Rankine	=	(°F + 459.67)

Cubes

1 yd^3	=	27 ft^3
1 ft^3	=	1728 in^3
1 cm^3	=	1000 mm^3
1 m^3	=	10^6 cm^3
1 m^3	=	1000 L

Squares

1 yd^2	=	9 ft^2
1 ft^2	=	144 in^2
1 cm^2	=	100 mm^2
1 m^2	=	10000 cm^2

SI PREFIXES

Prefix	Symbol	Magnitude	Factor
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^9
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deca	da	10	10^1
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pica	p	0.000 000 000 001	10^{-12}

4138T/T33(-6)

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
amperes/square centimetre	A/cm^2	amperes/square inch	A/in^2	6.452
Celsius	°C	Fahrenheit	°F	(°C × 9/5) + 32
centimetres	cm	inches	in	0.3937
cubic centimetres	cm^3	cubic inches	in^3	0.06102
cubic metres	m^3	cubic foot	ft^3	35.314
grams	g	ounces	oz	0.03527
grams	g	pounds	lb	0.0022
grams/litre	g/L	pounds/cubic foot	lb/ft^3	0.06243
joules	J	Btu	Btu	9.480×10^{-4}
joules	J	foot-pounds	ft-lb	0.7376
joules	J	horsepower-hours	hp-h	3.73×10^{-7}
joules/metre, (Newtons)	J/m, N	pounds	lb	0.2248
kilograms	kg	pounds	lb	2.205
kilograms	kg	tons (long)	ton	9.842×10^{-4}
kilograms	kg	tons (short)	tn	1.102×10^{-3}
kilometres	km	miles (statute)	mi	0.6214
kilopascals	kPa	atmospheres	atm	9.87×10^{-3}
kilopascals	kPa	inches of mercury (@ 32°F)	in Hg	0.2953
kilopascals	kPa	inches of water (@ 4°C)	in H_2O	4.0147
kilopascals	kPa	pounds/square inch	psi	0.1450
kilowatts	kW	foot-pounds/second	ft-lb/s	737.6
kilowatts	kW	horsepower	hp	1.341
kilowatt-hours	kWh	Btu	Btu	3413
litres	L	cubic foot	ft^3	0.03531
litres	L	gallons (Imp)	gal (Imp)	0.21998
litres	L	gallons (US)	gal (US)	0.2642
litres/second	L/s	cubic foot/minute	cfm	2.1186
lumen/square metre	lm/m^2	lumen/square foot	lm/ft^2	0.09290
lux, lumen/square metre	lx, lm/m^2	footcandles	fc	0.09290
metres	m	foot	ft	3.281
metres	m	yard	yd	1.09361
parts per million	ppm	grains/gallon (Imp)	gr/gal (Imp)	0.07
parts per million	ppm	grains/gallon (US)	gr/gal (US)	0.05842
permeance (metric)	PERM	permeance (Imp)	perm	0.01748
square centimetres	cm^2	square inches	in^2	0.1550
square metres	m^2	square foot	ft^2	10.764
square metres	m^2	square yards	yd^2	1.196
tonne (metric)	t	pounds	lb	2204.6
watt	W	Btu/hour	Btu/h	3.413
watt	W	lumen	lm	668.45

4138T/T33(-4)

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in^2	A/in^2	ampere/cm^2	A/cm^2	0.1550
atmospheres	atm	kilopascals	kPa	101.325
British Thermal Unit	Btu	joules	J	1054.8
Btu	Btu	kilogram-metre	kg-m	107.56
Btu	Btu	kilowatt-hour	kWh	2.928×10^{-4}
Btu/hour	Btu/h	watt	W	0.2931
calorie, gram	cal or g-cal	joules	J	4.186
chain	chain	metre	m	20.11684
cubic foot	ft^3	cubic metre	m^3	0.02832
cubic foot	ft^3	litre	L	28.32
cubic foot/minute	cfm	litre/second	L/s	0.47195
cycle/second	c/s	Hertz	Hz	1.00
Fahrenheit	°F	Celsius	°C	(°F-32)/1.8
foot	ft	metre	m	0.3048
footcandle	fc	lux, lumen/ square metre	lx, lm/m^2	10.764
footlambert	fL	candela/square metre	cd/m^2	3.42626
foot-pounds	ft-lb	joule	J	1.356
foot-pounds	ft-lb	kilogram-metres	kg-m	0.1383
foot-pounds/second	ft-lb/s	kilowatt	kW	1.356×10^{-3}
gallons (Imp)	gal (Imp)	litres	L	4.546
gallons (US)	gal (US)	litres	L	3.785
grains/gallon (Imp)	gr/gal (Imp)	parts per million	ppm	14.286
grains/gallon (US)	gr/gal (US)	parts per million	ppm	17.118
horsepower	hp	watts	W	745.7
horsepower-hours	hp-h	joules	J	2.684×10^6
inches	in	centimetres	cm	2.540
inches of Mercury (@ 32°F)	in Hg	kilopascals	kPa	3.386
inches of water (@ 4°C)	in H_2O	kilopascals	kPa	0.2491

UNIT CONVERSION TABLES
IMPERIAL TO METRIC (cont'd)

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
lamberts	* L	candela/square metre	cd/m^2	3.183
lumen/square foot	lm/ft^2	lumen/square metre	lm/m^2	10.76
lumen	lm	watt	W	0.001496
miles (statute)	mi	kilometres	km	1.6093
ounces	oz	grams	g	28.35
perm (at 0°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.721×10^{-11}
perm (at 23°C)	perm	kilogram per pascal-second-square metre	$kg/Pa\text{-}s\text{-}m^2$ (PERM)	5.745×10^{-11}
perm-inch (at 0°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4532×10^{-12}
perm-inch (at 23°C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4593×10^{-12}
pint (Imp)	pt	litre	L	0.56826
pounds	lb	grams	g	453.5924
pounds	lb	joules/metre, (Newtons)	J/m, N	4.448
pounds	lb	kilograms	kg	0.4536
pounds	lb	tonne (metric)	t	4.536×10^{-4}
pounds/cubic foot	lb/ft^3	grams/litre	g/L	16.02
pounds/square inch	psi	kilopascals	kPa	6.89476
quarts	qt	litres	L	1.1365
slug	slug	kilograms	kg	14.5939
square foot	ft^2	square metre	m^2	0.09290
square inches	in^2	square centimetres	cm^2	6.452
square yards	yd^2	square metres	m^2	0.83613
tons (long)	ton	kilograms	kg	1016
tons (short)	tn	kilograms	kg	907.185
yards	yd	metres	m	0.9144

* "L" as used in Lighting

4138T/T33(-2)

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

ENERGY TYPE	METRIC	IMPERIAL
COAL		
— metallurgical	29 000 megajoules/tonne	25.0 × 10^6 Btu/ton
— anthracite	30 000 megajoules/tonne	25.8 × 10^6 Btu/ton
— bituminous	32 100 megajoules/tonne	27.6 × 10^6 Btu/ton
— sub-bituminous	22 100 megajoules/tonne	19.0 × 10^6 Btu/ton
— lignite	16 700 megajoules/tonne	14.4 × 10^6 Btu/ton
COKE		
— metallurgical	30 200 megajoules/tonne	26.0 × 10^6 Btu/ton
— petroleum		
— raw	23 300 megajoules/tonne	20.0 × 10^6 Btu/ton
— calcined	32 600 megajoules/tonne	28.0 × 10^6 Btu/ton
PITCH	37 200 megajoules/tonne	32.0 × 10^6 Btu/ton
CRUDE OIL	38.5 megajoules/litre	5.8 × 10^6 Btu/bbl
No. 2 OIL	38.68 megajoules/litre	5.88 × 10^6 Btu/bbl .168 × 10^6 Btu/IG
No. 4 OIL	40.1 megajoules/litre	6.04 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
No. 6 OIL (RESID. BUNKER C)		
@ 2.5% sulphur	42.3 megajoules/litre	6.38 × 10^6 Btu/bbl .182 × 10^6 Btu/IG
@ 1.0% sulphur	40.5 megajoules/litre	6.11 × 10^6 Btu/bbl .174 × 10^6 Btu/IG
@ .5% sulphur	40.2 megajoules/litre	6.05 × 10^6 Btu/bbl .173 × 10^6 Btu/IG
KEROSENE	37.68 megajoules/litre	.167 × 10^6 Btu/IG
DIESEL FUEL	38.68 megajoules/litre	.172 × 10^6 Btu/IG
GASOLINE	36.2 megajoules/litre	.156 × 10^6 Btu/IG
NATURAL GAS	37.2 megajoules/m^3	1.00 × 10^6 Btu/MCF
PROPANE	50.3 megajoules/kg 26.6 megajoules/litre	.02165 × 10^6 Btu/lb .1145 × 10^6 Btu/IG
ELECTRICITY	3.6 megajoules/kWh	.003413 × 10^6 Btu/kWh

Lighting System Survey
Section : Low-Cost Opportunities
Worksheet #1
(Page 1 of 2)

Company : ______________________ Date : ____________

Location : ______________________ By : ____________

1. General Information

Work Performed in Area: ______________________

Space Size: A Length ________ m; width ________ m; Height ________ m;

B ________ ________ ________

C ________ ________ ________

Light Source Identification: Incandescent ☐ HID ☐

Fluorescent ☐ Other ☐

2. Lighting System Conditions

Approximate Age of System ______________________ Years

Date of Last Luminaire Maintenance ______________________

Date of Last Lamp Replacement ______________________

Type of Lighting Control: Manual ☐

Automatic– Timer ☐

Microprocessor ☐

Photocell ☐

3. Operating Schedules

Facility ____________ h/d ____________ d/w ____________ w/y

Lighting ____________ h/d ____________ d/w ____________ w/y

Cleaning ____________ h/d ____________ d/w ____________ w/y

Lighting System Survey
Section : Low-Cost Opportunities
Worksheet #1

4. Average Level of Illumination

Measured ______________________ Recommended ______________

Lightmeter: Make ____________ Model ____________________
Calibrations Date:

5. Power Density

Measured A | Recommended Limit A ____________
B | B ____________
C | C ____________

Luminaire Identification ______________________________________

Manufacturer's Name ______________ Type ________ Model ________

Luminaire Description ____

Total Wattage per Luminaire Including Ballast ____________________

Total Number of Luminaires A ________
B ________
C ________

Condition __________________

6. Reflectances – Transmittance

Room Reflectances
Measured: Ceiling ____________ Recommended: Ceiling ____________
Walls ____________ Ref. Attached Walls ____________
Floor ____________ Floor ____________

Luminaire Lense Transmittance ______________________

Measured __________________ Recommended ____________________

Life Cycle Costs Analysis
Section : Retrofit
Worksheet # 2
(Page 1 of 1)

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

2. ______________ Target Illuminance in Lux
3. ______________ Total Area in Square Meters
4. ______________ Number of Burn Hours per Year
5. ______________ Electric Rate

Lamp

6. ______________ Initial Lamp Lumens
7. ______________ Rated Lamp Hours of Life
8. ______________ Input Watts per Fixture
9. ______________ Fraction of Effective Lumens Leaving the Fixture (CU)
10. ______________ Lamp Depreciation Factor
11. ______________ Dirt Depreciation Factor
12. ______________ Effective Lumens (6) (99) (10) (11)
13. ______________ Number of Fixtures (2) (3) / (12)
14. ______________ Total Input Watts (8) (13)
15. ______________ Cost of 1 Fixture
16. ______________ Cost of Wiring e.g. ($150.00 per kW) / (13)
17. ______________ Labor Cost for Installing 1 Fixture
18. ______________ Lamp Cost per Fixture
19. ______________ Total First Cost (13) (15 + 16 + 17 + 18)
20. ______________ Number of Lamps per Fixture
21. ______________ Number of Lamp Replacements per Year (13) (20) (4) / (7)
22. ______________ Labor Cost per Lamp Replacement
23. ______________ Lamp Cost per Year (21) ((22) + (18) / (20))
24. ______________ Energy Cost per Year
25. ______________ Total Operating Cost per Year (23) + (24)

Life Cycle Costs Analysis
Section : Retrofit
Worksheet # 3
(Page 1 of 1)

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

2. ______________ Target Illuminance in Lux
3. ______________ Total Area in Square Meters
4. ______________ Number of Burn Hours per Year
5. ______________ Electric Rate

Lamp

6. ______________ Initial Lamp Lumens
7. ______________ Rated Lamp Hours of Life
8. ______________ Input Watts per Fixture
9. ______________ Fraction of Effective Lumens Leaving the Fixture (CU)
10. ______________ Lamp Depreciation Factor
11. ______________ Dirt Depreciation Factor
12. ______________ Effective Lumens (6) (99) (10) (11)
13. ______________ Number of Fixtures (2) (3) / (12)
14. ______________ Total Input Watts (8) (13)
15. ______________ Cost of 1 Fixture
16. ______________ Cost of Wiring e.g. ($150.00 per kW) / (13)
17. ______________ Labor Cost for Installing 1 Fixture
18. ______________ Lamp Cost per Fixture
19. ______________ Total First Cost (13) (15 + 16 + 17 + 18)
20. ______________ Number of Lamps per Fixture
21. ______________ Number of Lamp Replacements per Year (13) (20) (4) / (7)
22. ______________ Labor Cost per Lamp Replacement
23. ______________ Lamp Cost per Year (21) ((22) + (18) / (20))
24. ______________ Energy Cost per Year
25. ______________ Total Operating Cost per Year (23) + (24)

Life Cycle Costs Analysis
Section : Retrofit
Worksheet # 4a
(Page 1 of 1)

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

2. ______________ Target Illuminance in Lux
3. ______________ Total Area in Square Meters
4. ______________ Number of Burn Hours per Year
5. ______________ Electric Rate

Lamp

6. ______________ Initial Lamp Lumens
7. ______________ Rated Lamp Hours of Life
8. ______________ Input Watts per Fixture
9. ______________ Fraction of Effective Lumens Leaving the Fixture (CU)
10. ______________ Lamp Depreciation Factor
11. ______________ Dirt Depreciation Factor
12. ______________ Effective Lumens (6) (99) (10) (11)
13. ______________ Number of Fixtures (2) (3) / (12)
14. ______________ Total Input Watts (8) (13)
15. ______________ Cost of 1 Fixture
16. ______________ Cost of Wiring e.g. ($150.00 per kW) / (13)
17. ______________ Labor Cost for Installing 1 Fixture
18. ______________ Lamp Cost per Fixture
19. ______________ Total First Cost (13) (15 + 16 + 17 + 18)
20. ______________ Number of Lamps per Fixture
21. ______________ Number of Lamp Replacements per Year (13) (20) (4) / (7)
22. ______________ Labor Cost per Lamp Replacement
23. ______________ Lamp Cost per Year (21) ((22) + (18) / (20))
24. ______________ Energy Cost per Year
25. ______________ Total Operating Cost per Year (23) + (24)

Life Cycle Costs Analysis
Section : Retrofit
Worksheet # 4b
(Page 1 of 1)

Company : ______________________ Date : ______________

Location : ______________________ By : ______________

2. ______________ Target Illuminance in Lux
3. ______________ Total Area in Square Meters
4. ______________ Number of Burn Hours per Year
5. ______________ Electric Rate

Lamp

6. ______________ Initial Lamp Lumens
7. ______________ Rated Lamp Hours of Life
8. ______________ Input Watts per Fixture
9. ______________ Fraction of Effective Lumens Leaving the Fixture (CU)
10. ______________ Lamp Depreciation Factor
11. ______________ Dirt Depreciation Factor
12. ______________ Effective Lumens (6) (99) (10) (11)
13. ______________ Number of Fixtures (2) (3) / (12)
14. ______________ Total Input Watts (8) (13)
15. ______________ Cost of 1 Fixture
16. ______________ Cost of Wiring e.g. ($150.00 per kW) / (13)
17. ______________ Labor Cost for Installing 1 Fixture
18. ______________ Lamp Cost per Fixture
19. ______________ Total First Cost (13) (15 + 16 + 17 + 18)
20. ______________ Number of Lamps per Fixture
21. ______________ Number of Lamp Replacements per Year (13) (20) (4) / (7)
22. ______________ Labor Cost per Lamp Replacement
23. ______________ Lamp Cost per Year (21) ((22) + (18) / (20))
24. ______________ Energy Cost per Year
25. ______________ Total Operating Cost per Year (23) + (24)