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Introduction to Lighting and Illumination

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Course No.:

LDG101

Publication Source:

US Corp of Engineers

"Lighting Design"

Pub. # TI 811-16

Release Date:

Aug. 1998

1265 San Juan Dr. - Merritt Island, FL 32952
Phone: 321-501-5601

US Army Corps of Engineers®

TI 811-16
3 August 1998

Technical Instructions

Lighting Design

Headquarters
U.S. Army Corps of Engineers
Engineering and Construction Division
Directorate of Military Programs
Washington, DC 20314-1000

TECHNICAL INSTRUCTIONS

Lighting Design

Approved for public release; distribution is unlimited

Record of Changes (changes indicated \1\... /1/)

No. Date Location

This Technical Instruction supersedes EI 16E500, dated 01 September 1997.

(EI 16E500 text is included in this Technical Instruction and may carry EI 16E500 identification.)

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FOR THE DIRECTOR OF MILITARY PROGRAMS.

KISUK CHEUNG, P.E.
Chief, Engineering and Construction Division
Directorate of Military Programs

Lighting Design Guide

prepared by

HEADQUARTERS
US ARMY CORPS OF ENGINEERS

February 20, 1997

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Lighting Design Guide

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Introduction

This document is to be used as a design tool for lighting layouts. The rules of thumb provided are general guidelines; specific manufacturers' data should always be consulted. In addition to easily measured quantities such as light levels, the more qualitative aspects of lighting are covered and should be given consideration. The Illuminating Engineering Society of North America (IESNA) Handbook is a very good reference and is the source for many of the recommendations. Additional guidance is contained in the Corps' **Architect-Engineer Instructions**, *Chapter 12.*

I. Review of Background Information

A. Terminology

Candlepower Distribution Curve: Graphic representation of light distribution from a lighting fixture.

Coefficient of Utilization (CU): Used during calculations. Based on the size and shape of the room, it correlates how much usable light gets to the work surface.

Color temperature: Rating of light sources according to apparent color of light produced. Measured in degrees Kelvin. Lower numbers indicate yellower light, higher numbers indicate bluer light. High intensity discharge lamps can slowly change color temperature over their lifespans. This phenomenon is referred to as color shift. The color shift may be either warmer or cooler.

Color Rendering Index (CRI): A measurement of how accurately colors can be determined under different light sources. Rated 1 to 100, with 100 being best.

Footcandle (FC): Measure of light falling on a surface. 1 footcandle = 1 lumen/square foot.

Illuminance: Light striking a surface, measured in FC.

Luminance: Also referred to as **Exitance.** Light reflected from a surface. Measured in candelas/ square meter. May also be listed as footlamberts, which is an old designation.

Lux: Metric equivalent to the footcandle. 1 FC = approximately 10 lux.

Luminance Intensity: Light produced in a specific direction. Measured in candlepower.

Lumen: Total amount of light produced by a source, regardless of its direction.

SPACING RATIO: The maximum recommended distance between fixtures based on the ceiling height. Provided by fixture manufacturers. For example, if the ceiling height is 9 feet and the spacing ratio is 1.2, the maximum distance between fixtures is 10.8 feet. Always round down to the smaller number.

B. LAMPS

All lamps are identified by a letter and a number, for example: A19. The letter identifies the shape of the lamp, while the number identifies the size. The size is measured at the largest diameter of the lamp, in eighths of an inch. Therefore, an A19 lamp is 19/8″ or 2.375″ in diameter. Additional information is available from lamp manufacturers' catalogues.

INCANDESCENT

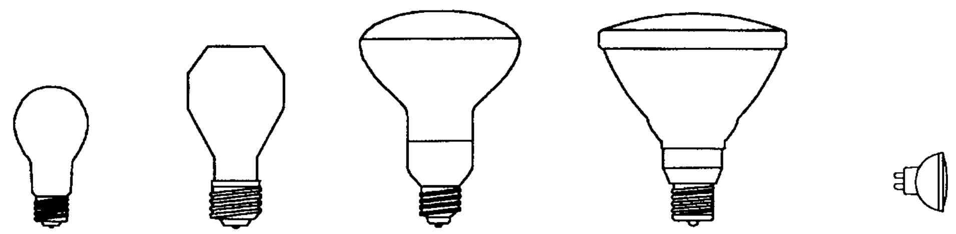


FIG. 1

Incandescent lamps (figure 1) are the most common type and are available in a variety of shapes and sizes. The most common is the A lamp which is made of soft glass, so it shatters very easily. These lamps are used in downlights, wallwashers, table lamps, chandeliers, and wall sconces. The color temperature is 2200K and the CRI is 95. A lamps have a short life, the average being 750 hours. Lamps are specified as 100w A19/IF, designating wattage, lamp shape & size, and inside frosted. IF lamps should be used because they have a higher light output and better diffusion than standard A lamps.

The next most common types are the R (reflector) and PAR (parabolic aluminized reflector) lamps. R lamps are also made from soft glass. They have a smoother beam pattern than their cousin the PAR lamp. The PAR lamp is a hard glass lamp. The hard glass allows the bare lamp to be exposed to the elements in outdoor fixtures like floodlights. Unlike A lamps, the light from reflector lamps is directed out the front of the lamp, so they are available in different beam patterns ranging from spot to wide flood. Reflector lamps are generally used in downlights, lensed wallwashers, adjustable accent fixtures, track fixtures and exterior floodlights. Color temperature is 2600K with a CRI of 95. Lamp life is approximately 2000 hours. Lamps are specified as 150w PAR38/NFL, designating wattage, lamp shape and size, and beam pattern (narrow flood).

Halogen is a sub-category of the incandescent lamp family. Halogen lamps come in the same shapes and sizes as standard incandescent lamps, but the gas which fills the glass envelope is halogen rather than nitrogen and argon. The halogen gas provides whiter light along with energy savings and longer life. For example, a 60 watt (16,000 CBCP @ 10 degree) or 90 watt (17,000 CBCP @ 11 degree) halogen PAR can replace a standard 150 watt (18,000 CBCP @ 12 degree) PAR (CBCP stands for Center Beam Candle Power) because the light output is equivalent in intensity and beam pattern. The TB shape replaces the standard A lamp. The color temperature is 2900K and CRI is 95. Lamp life ranges from 2500 to 4000 hours.

MR (mirrored reflector) lamps are low voltage halogen lamps. They require a transformer to reduce the voltage to 12 volts. They are often used in accents and downlights due to their small size. Color temperature is 3000K and CRI is 95. Lamp life is 4000 hours. MR lamps are specified and used in the same manner as "PAR" lamps, for example: 50w MR16/NFL.

Fluorescent

Tubular fluorescent lamps, commonly called linear lamps, are available in two shapes, straight and U-bent. They are used in troffers, pendants, and wall mounted units. The T8 lamp is currently the most energy efficient fluorescent lamp available. Because of its efficiency and low replacement cost, it is typically the most life-cycle cost-effective fluorescent lamp. T5 lamps and fixtures are under development and promise even greater efficiency in the future.

Common available color temperatures are 3000, 3500, and 4100K. The 3500K lamp is the Corps of Engineers standard lamp color. The CRI is 75 for standard lamps and 85 for deluxe lamps. The 75 CRI lamps are acceptable for all but the most color-sensitive areas. Fluorescent lamps have a much longer life than incandescent. They typically last 20,000 hours at an average of three hours of burning time per start; more frequent starting will shorten their life. Lamps are specified as F32T8/SP35, which designates fluorescent, wattage, lamp size, CRI and color temperature.

Compact Fluorescent

Compact fluorescent lamps (figure 2) were developed as replacements for incandescent lamps and are available in a number of shapes and sizes. The common shapes are single twin tube (TT), double twin tube (DTT) and triple twin tube (TTT). Lamps are available for new construction with snap-in bases and for retrofit applications with self-ballasted, medium screw bases. In either application, the length of the lamp is critical because it is undesirable for the lamp to protrude from the fixture. These lamps are used in downlights, wallwashers, pendants, and wall sconces.

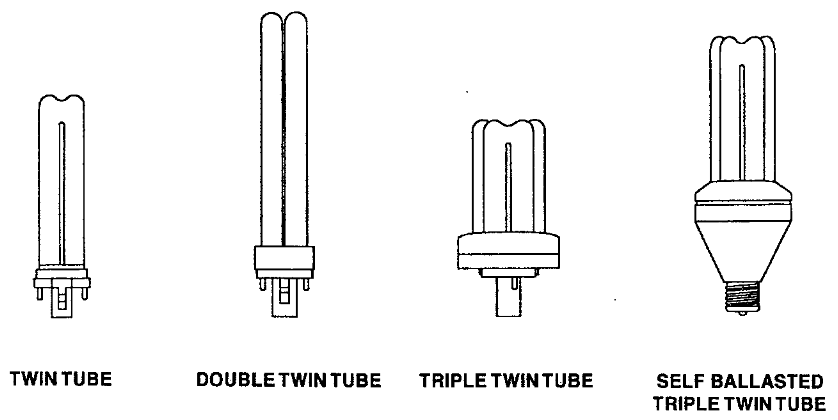


FIG. 2.

Available color temperatures are 2700, 3000, 3500, and 4100 K. Similar to the tubular lamps, the 3500K lamp is the Corps standard. The color temperatures of fluorescent and compact fluorescent lamps in the same space should match. The CRI for compact fluorescent lamps is approximately 85. Compact fluorescent lamp life ranges from 10,000 to 20,000 hours; frequent starting will shorten lamp life.

Light output is influenced by lamp wall temperature; if the lamp wall runs cooler or warmer than the design range, light output is reduced. This characteristic limits the use of compact fluorescent lamps as replacements for incandescents in enclosed fixtures and outdoor fixtures. Temperature also affects starting characteristics as follows:

- Twin tube lamps and double/triple tube lamps with no internal starter (typically four-pin lamps) will start down to 0°C (32°F).
- Double and triple tube lamps with an internal starter (typically two-pin lamps) will start down to -9°C (15°F).
- For other lamps, manufacturers' literature should be consulted.

Compact fluorescent lamps are specified as F18DTT/SP35, which designates fluorescent, wattage, lamp shape (double twin tube), CRI and color temperature. The length varies according to the manufacturer and should be verified.

METAL HALIDE

Metal halide (MH) lamps (figure 3) have improved tremendously in recent years. Manufacturers reduced the wattage and size in order to take advantage of their white light and long life for indoor applications. The most recent development is PAR-shaped MH lamps which come in a variety of beam spreads and sizes similar to incandescent PAR lamps. These lamps have a very strong center beam which can reach great distances and are often used in atria and stairwells. Metal halide lamps are used in higher ceiling areas (10 feet or more) in downlights, wallwashers, pendants, outdoor floodlights, high and low bay industrial fixtures, roadway fixtures, and wall sconces.

Available color temperatures have been improved through the recent introduction of 3200K lamps for indoor use, to complement the standard 4000K lamp used in industrial, warehouse, roadway and floodlighting. The color temperature can shift by as much as 300K in either direction over the life of the lamp. This shift is gradual and is not consistent, even among lamps of the same size and type. The light from some lamps will remain white; others may gradually become bluish or pinkish with age. Developments in ceramic arc tube technology are reducing the color shift to a point where it is no longer noticeable. Depending on the lamp, the CRI ranges from 65 to 70 and lamp life ranges from 10,000 to 20,000 hours. Lamps are available in clear and coated varieties. Performance fixtures, such as floodlights and high bays, require clear lamps. Lamps are specified as 150w MH/ 3200K.

Like all High Intensity Discharge (HID) lamps, once a metal halide lamp is extinguished it must cool completely before it will re-strike. If light is required immediately upon power restoration after an accidental outage, some of the fixtures in the space should be specified with the quartz restrike option, which provides light until the HID lamp can come up to full output.

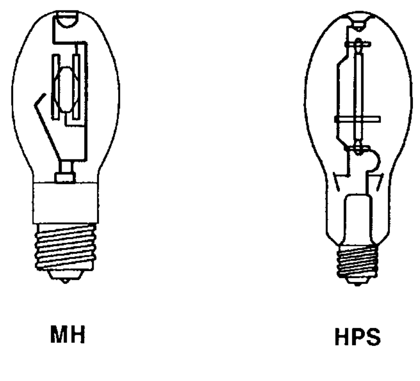


FIG. 3.

HIGH PRESSURE SODIUM

High pressure sodium (HPS) lamps (figure 3) are the most energy efficient lamp type, but have the worst color rendering properties. The light is very yellow in color. White sodium lamps have been developed, but the color shift is unacceptable and for most applications, the lamp is unreasonably expensive. Sodium lamps are used in high ceilings (15 feet or higher) in downlights, wallwashers, outdoor floodlights, high and low bay fixtures, and roadway lighting. Color temperature is 1900 K, with a CRI of 22. Lamp life is 24,000 hours or more. Lamps are available in clear and coated varieties. Clear lamps should be used in performance fixtures, such as floodlights and high bays. Lamps are specified as 150w HPS.

MERCURY VAPOR

Mercury vapor lamps were the first high intensity discharge lamps to be invented. The light is very blue in color. Mercury lamps are being phased out by lamp manufacturers and have no current interior applications. They may still be seen in existing downlights, landscape lighting and roadway lighting. The color temperature is 3900K, while the CRI is 15. Lamp life is 24,000 hours or more. The major problem with mercury lamps is that they never "burn out". At the very end of the lamp life there is still a slight glow from the bulb. Therefore, maintenance personnel tend not to change the lamp even when it has little usable light output.

C. FIXTURES

Light fixtures, also called luminaires, should be designed for a specific lamp type in order to provide the highest efficiency. The three main fixture categories are:

- DIRECT in which the light is directed downward;
- INDIRECT in which the light is directed upward;
- DIRECT/INDIRECT, which combines the two.

While most of the Corps standard fixture types are generic and available from several sources, the differences between various manufacturers' versions of these fixtures are often sufficient to affect the lighting layout. Some fixture data used in design, like spacing criteria, are available only from manufacturers' catalogs. Since project specifications must usually be generic, the designer should look at data from several manufacturers to establish the range of characteristics available in standard fixtures, and design accordingly.

DIRECT LUMINAIRES

Direct fixtures add shadow and texture to the environment. Downlights, wallwashers, adjustable accents, and fluorescent troffers fall into this category. The rules of thumb for fixture layout described below will apply for most situations; however, fixture spacing should be verified using manufacturer's data.

DOWNLIGHTS AND WALLWASHERS

Downlights and wallwashers (figure 4) are made for almost every lamp type. Trims are available in many colors such as clear, gold, white, wheat, bronze, pewter, umber, and black. Colored cones may be used to change the color of the light. For example, wheat or bronze cones are often used with 4100K metal halide lamps to provide warmer light.

As a rule of thumb, downlights are spaced on center at a distance equal to the ceiling height, i.e. 8 feet on center in an 8 foot ceiling. Wallwashers should typically be the same distance on center as they are from the wall; for example, wallwashers mounted 3 feet from the wall should be 3 feet on center.

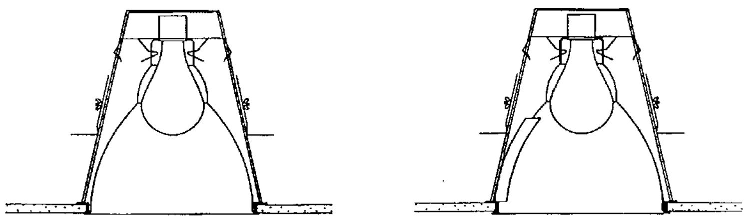


FIG. 4.

ADJUSTABLE ACCENTS

Adjustable accents (figure 5) are available in the same color options as downlights and are commonly used to highlight displayed objects, such as artwork. An adjustable fixture should never be aimed at an angle higher than 45 degrees to avoid glare. Objects should typically be lighted from at least two sides, possibly three, depending on the size and shape of the piece.

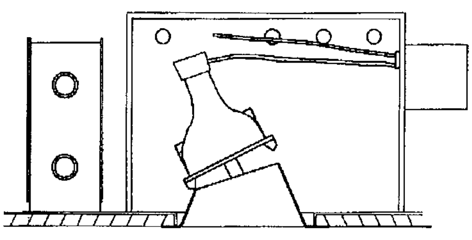


FIG. 5.

FLUORESCENT TROFFERS

Troffers (figure 6) are available in a variety of sizes and shielding materials. Shielding materials include the standard lens, the paracube, and the deep cell parabolic louver. Paracube louvers are useful to reduce glare in computer areas or similar spaces, but they should be used with caution because they have low efficiency and create a very shadowy, dark environment. Parabolic louvers are available in 3 and 4 inch depths. The deeper louvers reduce glare more than shallow louvers. The 3 inch depth is acceptable for most applications. The number of cells will vary depending on the size of the fixture and number of lamps. Available finishes include white (painted), specular or semi-specular in either clear or gold. Iridescence is a rainbow effect produced on the surface of the louver by the phosphors in the lamp. Low iridescent finishes are available and are recommended. White louvers help to disperse light at higher angles, reducing the darkness at the top of the wall created by parabolic troffers. For example, troffers are typically spaced 10′ x 12′ in an 8 to 10 foot ceiling height to provide 50 FC. The wider the spacing, the lower the ambient light level.

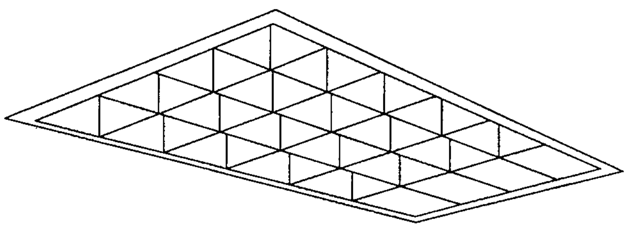


FIG. 6.

INDIRECT LUMINAIRES

Indirect fixtures (figure 7) produce shadowless soft light which creates a glare-free environment conducive to higher productivity. Lamps are usually fluorescent but may be metal halide. Metal halide indirect fixtures should be used with caution, because the color shift of the lamp is very apparent against a white ceiling. With indirect fixtures, the most critical distance is that from the ceiling to the fixture. If the fixture is too close to the ceiling, the light cannot spread and will create a hot spot. A proper installation of indirect fixtures creates a uniform light pattern on the ceiling. Typically, the suspension distance should be 18″ or more, and the fixtures should be approximately 10 to 12 feet on center. However, spacing is application-dependent and should be verified using manufacturer's data.

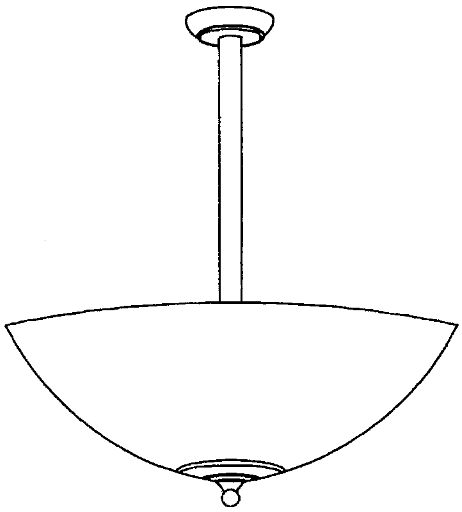


FIG. 7.

DIRECT/ INDIRECT LUMINAIRES

The direct component of a direct/indirect luminaire (figure 8) adds depth by creating slight shadows. These fixtures typically have fluorescent lamps, but metal halide fixtures are also available. The spacing criteria are the same as for indirect fixtures and should be verified using manufacturer's data.

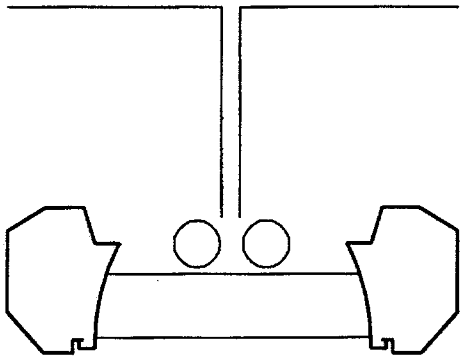


FIG. 8.

D. BALLASTS / TRANSFORMERS

All arc discharge-type lamps, including fluorescent and HID lamps, require a ballast to create the proper electrical conditions to drive the lamp and to limit the current flow. The most energy efficient type is the electronic ballast, which is the Corps standard. Electronic ballasts produce no sound and virtually no lamp flicker. The next best energy efficient ballast is the high power factor magnetic, but these are subject to the inherent magnetic ballast problems of noise and flicker. Ballasts are lamp-specific; each lamp type and size requires a particular ballast.

Radio frequency interference (RFI) is produced by fluorescent lamps and ballasts. Ballasts must meet 47 CFR, Part 18, for RFI emissions. RFI is not a problem for most areas; it may cause difficulties in rooms housing extremely sensitive electronic equipment, such as scientific instruments and specialized equipment serving communications or weapons systems. RFI in such cases may be controlled by a silver grid on the lens of the fixture.

Power line harmonics are another issue when electronic ballasts are used. These ballasts use switch mode power electronics, like desktop computers do, which may create harmonic currents that are difficult to measure with conventional equipment and can cause overheating of transformers and neutral conductors unless precautions are taken during electrical system design. Harmonics are produced in third multiples of the electrical frequency, i.e. the third, sixth, ninth, etc. The third harmonic causes the most damage. Ballast harmonics can be reduced through design changes, but ballasts designed for low total harmonic distortion (THD) typically have very high inrush (starting) currents. Ballasts with <20% THD are the optimal selection. They reduce harmonics without large inrush currents. By contrast, ballasts with <10% THD have inrush currents five times greater than <20% ballasts. This large inrush has been known to cause welding of electrical contacts. Any ballast should have a ballast factor of 0.85 or higher.

Transformers change higher voltages to lower voltages. They are required for MR lamps and other low voltage lamps. The standard low voltages are 6, 12 and 24 volts and must be matched to the lamp. Transformers may be either integral or remote. If remote, a location for the transformer must be shown. Closets, cabinets, or above accessible ceilings are good locations. Voltage drop along the length of the power feed is important when utilizing remote transformers. The wattage consumed and the distance to the last fixture or lamp relate directly to the size of the wire used for the power feed. Manufacturers are willing to assist with the layout of the transformers and the wire size.

E. DAYLIGHTING

Natural daylight can contribute a great deal of light to the work environment. Windows, skylights and clerestories are the usual methods used to collect daylight. To incorporate skylights and clerestories into the architecture, the lighting designer must work closely with the architect in the early stages of design. Direct sunlight may cause unwanted glare due to extreme brightness. Daylight from windows will only penetrate 15 feet into the room. Clerestories can be designed to provide ambient light without the direct sun component. Skylights permit direct daylight penetration.

When designing for daylight, a dimming system should be used to reduce the electric light levels automatically and gradually as the daylight increases. A gradual change is important because worker productivity is reduced when the light level drops instantaneously, causing the new light level to appear darker. A life cycle cost analysis must be performed for each application to truly evaluate the cost depending on the number of "black boxes" required for the system. The "black box" is the device that controls the dimmer based on light levels sensed by a photocell. The photocell should be mounted on the ceiling in the center of the space to evaluate the average light level. Due to the limit of daylight penetration through windows, the row of fixtures closest to the window wall should be circuited separately for individual dimming control. Additional air conditioning may be required in daylighted spaces due to the heat gain from direct sunlight. This must also be factored into the life cycle cost analysis.

II. DESIGN GUIDELINES

A. SPATIAL ORGANIZATION AND SUBJECTIVE IMPRESSIONS

Good lighting design not only provides the proper amount of light for the task at hand, but also gives directional and social behavioral cues. In a lobby, for example, if visitors are expected to check in with the receptionist, the reception desk should be the most brightly lighted area in the space. The light levels for other elements should be lower.

Behavioral cues are set up by the subjective impression developed. An impression of relaxation is important in the design of casual spaces like waiting rooms, lounges and food service areas. This is reinforced by non-uniform wall lighting and warm colored light. An impression of privacy is also important in these areas and is reinforced by non-uniform lighting and lower ambient light levels with higher brightness remote from the user.

An impression of perceptual clarity is important to help people negotiate through spaces. This is used extensively for administrative areas and is reinforced by high light levels on work surfaces, uniform wall lighting and cool colored light.

An impression of spaciousness is important in the design of circulation areas, corridors, lobbies and assembly halls. This is reinforced by uniform wall lighting and evenly distributed brightness throughout the space. Light color does not appear to be a factor.

B. ENERGY CONSERVATION AND LIGHTING POWER ALLOWANCE

Two key factors in energy conservation are the power consumed and the duration of its consumption. The most effective energy conservation measure is to turn off the lighting fixtures! However, that is usually not possible so every design needs to consider using energy efficient light sources. For example, using high intensity discharge lamps in high ceiling areas and compact or standard fluorescent lamps in lower ceiling areas, rather than incandescent lamps, is recommended. T8 lamps with electronic ballasts are the most efficient linear fluorescent equipment competitively available today. T5 lamps, fixtures, and ballasts will soon become available and promise to offer even better efficiency. Providing the appropriate level of light, i.e. not over-lighting spaces and using task/ambient lighting whenever possible, helps reduce energy consumption. The ultimate energy conservation tactic is automatic shutoff using occupancy sensors or utility monitoring and control systems. These controls reduce wasted energy by turning off the lights when spaces are unoccupied.

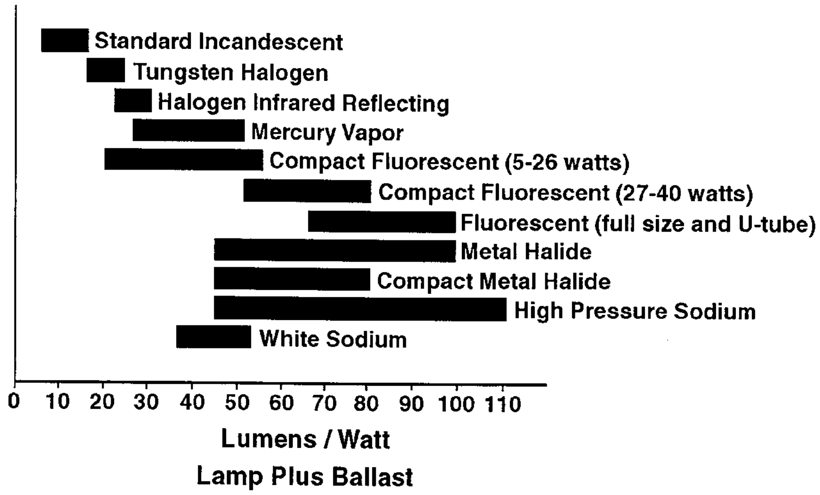


FIG. 9. Light source efficacies

Energy conservation performance standards for new buildings are described in **10 CFR 435.** This document provides recommendations for energy conservation as well as the building types which are exempt from the guidelines. The Building Lighting Power Allowance provides allowances of watts per square foot based on the tasks performed. The allowance consists of the Exterior Lighting Power Allowance (ELPA) in accordance with section 3.3, plus the Interior Lighting Power Allowance (ILPA) in accordance with section 3.4 or 3.5. This lighting power allowance is the upper limit to which the lighting system can be designed, based on the criteria of the compliance alternative chosen.

C. LIFE CYCLE COST ANALYSIS

Life cycle cost analysis is used to compare the cost effectiveness of different systems. It can be used to compare an existing system to a retrofit system or several options for a new installation. The analysis considers construction, energy and maintenance costs over the life of the lighting system, and can account for the time value of money to provide a uniform basis for comparison. All aspects of the system should be considered, including ballasts, transformers, lamp life, relamping and other maintenance costs, and changes in air conditioning loads if applicable. The analysis will vary for each project location due to such factors as operating hours and utility rates. It is performed using the methods and procedures described in **10 CFR 436, Subpart A.**

There are several types of life cycle cost calculations. The methods described in 10 CFR 436 are used to perform a full LCCA, which accounts for the time value of money. The first costs (design and construction), annual operating costs (energy and maintenance), and salvage value (if any) at the end of the system life are discounted using formulas or tables according to a specific interest rate (the *discount rate*) and the year in which they occur. The annual operating costs are adjusted using tables for the estimated future rates of change in the prices of energy and non-energy costs. Finally, a net present worth figure is calculated which represents the value, at the time of construction, of the total cost stream over the life of the project:

NPW = Σ (construction and design costs)
+ (NPW of annual energy and maintenance costs over system life)
- (SPW of equipment salvage value at end of system life, if any)

Where: NPW = Net Present Worth of annual cost stream over time
SPW = Single Present Worth of a non-recurring cost in a given year

The savings to investment ratio can also be calculated to evaluate investments in greater efficiency:

$$\text{SIR} = \frac{\text{NPW of annual savings over life of more efficient system}}{\text{Extra first cost of more efficient system}}$$

Full LCCA is the most accurate way to compare alternatives involving costs occurring at different times, but the calculations can be complicated. **NIST Handbook 135** contains guidance on LCCA methods; its annual supplement, **Energy Price Indices and Discount Factors for Life Cycle Cost Analysis,** contains updated discount rates and tables. Several personal computer-based LCCA programs have been developed by the government, including *Building Life Cycle Costs (BLCC)* and *Life Cycle Costs In Design (LCCID).* These programs are updated annually to reflect changes in discount rates and price forecasts.

A faster and easier way to evaluate project costs is the simple payback calculation, or SPB. This is used to decide quickly between two alternatives. Typically, one alternative has a higher first cost (design and construction) but lower annual costs over its life (for energy, maintenance, etc.). The SPB is simply the extra first cost divided by the annual savings, which tells the designer how many years are required to recover the extra investment:

$$\text{SPB} = \frac{\text{Extra first cost of more efficient system}}{\text{Annual cost savings}}$$

For Corps projects, a simple payback of ten years or less generally indicates a cost-effective alternative. The SPB calculation does not account for the time value of money or for the different future inflation rates of various costs, but it can be performed very quickly and is often used as a quick check on whether a more costly or complex design is worth pursuing from an economic standpoint.

When establishing the cost of electricity, the designer must determine whether the installation pays separate charges for electric energy (kWH) and demand (kW). Demand charges can account for up to half of the electric bill. Since reductions in connected lighting load (kW) almost always represent direct reductions in peak demand, the demand charge savings should be calculated separately from the energy consumption cost savings. A common error is the use of a combined average cost per kWH to account for both demand and energy costs on installations where they are charged separately, which will typically understate the cost savings from a more efficient lighting system. Since different utility companies charge for demand in different ways, the actual electric bills and rate schedule should always be obtained to verify the method used.

The following is a simplified example which uses a computer spreadsheet to compare a four-lamp lensed troffer layout against a two-lamp indirect pendant layout over a 20′ x 20′ space.

Assumptions:
Operating hours 5 days x 9 hours/day = 45 hours/week
Energy cost $0.10/kWH; no separate demand charge
Maintenance staff labor rate $25/hour

EXAMPLE: SIMPLE PAYBACK ANALYSIS

DESCRIPTION	TROFFERS	PENDANTS
INITIAL FIXTURE COST	$75	$180
NUMBER OF FIXTURES	4	6
TOTAL INITIAL COST (B2XB3)	**$300.00**	**$1,080.00**
ANNUAL BURNING HOURS	2340	2340
ENERGY RATE	$0.10	$0.10
LAMP QUANTITY	16	12
LAMP COST	$2.00	$2.00
TOTAL LAMP COST (B8X B9)	$32.00	$24.00
LAMP LIFE	20,000	20,000
SPOT RE-LAMPING INTERVAL (B6/B11)	0.117	0.117
ANNUALIZED SPOT RE-LAMPING COST(B10X B12)	3.744	2.808
ANNUALIZED SPOT RE-LAMPING MAINTENENCE COST (B13 X 0.5 HRS X $/HR)	$46.80	$35.10
GROUP RE-LAMPING INTERVAL (B6/B11 X .75)	0.08775	0.08775
ANNUALIZED GROUP RE-LAMPING COST (B10 X B15)	$2.81	$2.11
ANNUALIZED GROUP RE-LAMPING MAINTENENCE COST (B16 X 0.25 HRS X $/HR)	$17.55	$13.16
BALLAST QUANTITY	8	3
BALLAST COST	$35.00	$35.00
TOTAL BALLAST COST (B18X B19)	$280.00	$105.00
BALLAST LIFE, HOURS	65,000	65,000
ANNUALIZE BALLAST COST (B6/B21 X B20)	$10.08	$3.78
WATTS PER FIXTURE	120	60
ANNUAL KILOWATT HOURS(B23 X B3 X B6/1000)	1123.2	842.4
ANNUAL SYSTEM OPERATING COST (B13 + B14 + B16 + B17 + B22 + B24)	$1,204.18	$899.36
ANNUAL SAVINGS (B25- C25)		**$304.83**
SIMPLE PAYBACK in YEARS (C4- B4)/C28		**2.56**

D. CONTROLS

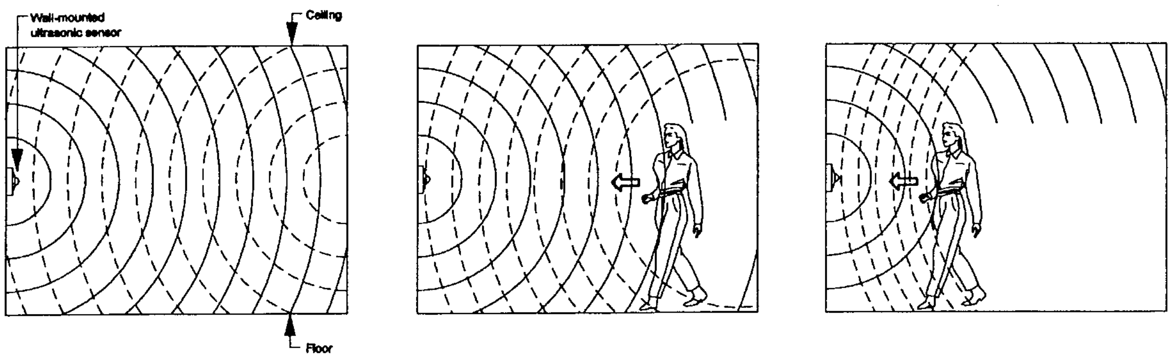
Controls are used for a number of reasons: changing lighting levels as required, reducing energy consumption, and extending lamp life to reduce maintenance costs.

Lighting levels may need to be reduced during video/slide projection in conference rooms or for dining. It is usually necessary to reduce light levels in order to properly view slide or video materials. Dimming reduces the energy consumption. This is accomplished by using wall box dimmers or large dimming systems.

Controlling the duration of energy use is the foremost way to conserve energy. Manual switching is frequently ineffective because it depends on occupant action. Occupancy sensors are very effective if applied with care. Occupancy sensors alone work only in enclosed rooms with few obstructions. Sensors in conjunction with utility monitoring and control systems can work well in open plan areas.

OCCUPANCY SENSORS

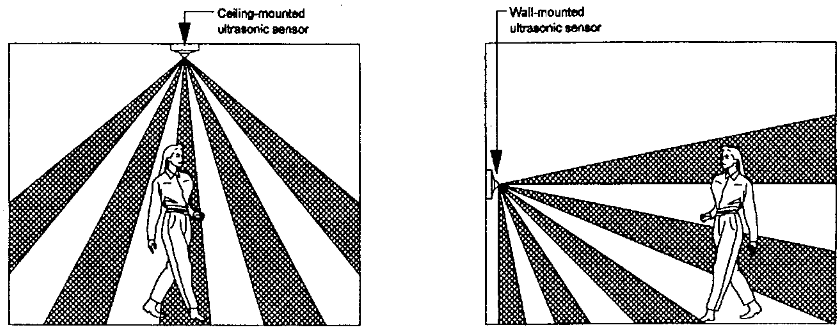
Occupancy sensors use two basic technologies: infrared and ultrasonic. Infrared sensors (figure 11) detect heat that is in motion. They are usually used in administrative areas. Normal office tasks are easily detected; however, stationary tasks like typing are hard to detect. Ultrasonic sensors detect motion using reflected high frequency sound waves, so they work best in hard surface areas like restrooms and kitchens. Ultrasonic sensors (figure 10) should not be subjected to vibration.



This figure shows a simplified wave pattern in an empty room. Ultrasonic waves (solid) are emitted by the sensor and reflect off the back wall. The reflected waves (dashed) then return to the sensor.

A person, or any other object in the room, reflects waves emitted by the sensor. As a person moves in the space, the frequency of the waves reflected off the person changes. The sensor detects this change in frequency and the luminaires are turned on.

FIG. 10. Example of Motion Detection with Ultrasonic Sensors.



Ceiling-Mounted Sensor: Section view with vertical fan patterns

Wall-Mounted Sensor: Section view with vertical fan patterns

FIG. 11. Example of Motion Detection with Infared Sensors. The motion of a person through the pattern of receiver areas is detected as a change, and the luminaires are turned on.

Either type must have a direct line of sight to all occupants in order to work properly. False tripping may occur when the sensor is not properly located and can see into a corridor; infrared sensors may be tripped by warm air from heating systems. Therefore, sensors should not be located facing doors or near heat sources. Sensitivity and time delay are set manually in the field.

Integral wall switch/sensor units are easily retrofitted and can cover up to 300 square feet. Ceiling mounted sensors can cover 2,000 square feet. Multiple ceiling sensors can be used to cover larger areas. The typical sensor is automatic on and off; however, they are available with manual on/auto off and manual override for conference or similar rooms where audiovisual equipment may be used. Occupancy sensors should not be used to control all lighting in machine or mechanical rooms because the machinery prevents a direct line of sight to all areas. A hazardous condition would be created if a sensor turned off all the lights while a technician was working.

PHOTOCELLS

Photocells detect light levels and are used in conjunction with outdoor fixtures. Typically they are dusk to dawn types, meaning they will turn on and off at a preset light level. Timeclocks can be used in conjunction with photocells. The photocell will turn the fixture on and the timeclock will turn the fixture off. This works when the fixtures needs to be turned on at dusk and shut off at a particular time in applications like landscape or facade lighting. It further reduces energy consumption by reducing the burning time.

E. ENERGY POLICY ACT OF 1992

The Energy Policy Act of 1992 eliminated many common lamp types based on efficiency, measured in lumens per watt. The standard incandescent A lamp was exempted. The following chart lists the common lamp types which were outlawed and their recommended energy-efficient substitutes:

April 1994	Recommended substitute	Acceptable substitute
F96T12		
CW	F96T12SP41/WM	F96T12CW/RS/WM
WW/SW/WWX	F96T12SP30/WM	F96T12WW/RS/WM
F96T12/HO		
CW/LW	F96T12SP41/HO/WM	F96T12CW/HO/WM
WW/W	F96T12SP30/HO/WM	F96T12WW/HO/WM
October 1995		
F40		
CW	F40SP41/RS/WM	F40/CW/RS/WM
WW/SW/WWX	F40SP30/RS/WM	F40WW/RS/WM
F40/U/6		
CW	F40SP41/U/6	F40CW/6/WM
WW/WWX/W	F40SP30/U/6	F40WW/U/6/WM
F40/U/3		
CW/D	F40SP41/U/3	F40CW/U/3/WM
WW/WWX	F40SP30/U/3	F40WW/U/3/WM
R30		
50R30	40R30/K	45R30/WM
75R30	60R30/K	65R30/WM
100R30	75PAR30L/H	75ER30
R40		
75R40	50PAR/HIR	45PAR/H/PLUS
100R40	60PAR/HIR	75PAR/H/PLUS
150R40	60PAR/HIR	90PAR/H/PLUS
PAR38		
75PAR & 65PAR	50PAR/HIR	50PAR/H
100PAR & 85PAR	60 PAR/HIR	100PAR/H
150PAR & 120PAR	60PAR/HIR	90PAR/H/PLUS

F. LUMEN METHOD CALCULATION

The lumen method is used to calculate illumination levels for square or rectangular rooms with flat ceilings. This method assumes the fixtures are uniformly spaced to provide general ambient light. If the two preceding assumptions do not apply, see Point Calculation below. The lumen method calculation yields an average light level, which means that various points in the space will be higher or lower than the average. The quantity of light calculated will not be exact; a +/- 10 percent variance is expected. *Chapter 9* of the **IESNA Handbook** describes the lumen method in detail.

The worksheet shown (figure 12) is meant to be used a guideline. The designer begins by completing the information at the top of the sheet, including the fixture and lamp data. The number of lumens per lamp is found in the lamp manufacturer's data or occasionally in the fixture manufacturer's data. One of the most common mistakes occurs on the line "Total lumens per luminaire," which is the number of lamps in one fixture multiplied by the lumens per lamp. Designers sometimes forget to multiply by the correct number of lamps.

STEP 1: Fill in the sketch. The room is broken into different cavities; the ceiling cavity, the room cavity, and the floor cavity. The work plane height which creates the floor cavity, (H_{fc}) is assumed to be typical desk height or thirty inches. The height from the work plane to the light fixtures (H_{rc}) is the portion of the wall which is usable to reflect light onto the work plane. is the symbol for reflectance. The reflectances are assumed to be 80 percent for the ceiling, 50 percent for the walls and 20 percent for the floor unless known otherwise. These reflectances are typically written 80/50/20.

STEP 2: Determine Cavity Ratios. The room cavity ratio (RCR) will be used for this example.

$$RCR = \frac{5H(W + L)}{W \times L}$$

WHERE: H is the height from the work plane to the fixtures
W is the width of the room
L is the length of the room

STEP 3: Obtain Coefficient of Utilization (CU). The CU charts are printed in manufacturer's fixture data. The CU is determined according to the RCR. If the RCR is not a whole number, the CU values can be extrapolated. For example if the RCR is 2.5, the CU for 2 is 70 and the CU for 3 is 60, the correct CU would be 65. The CU is always a percentage so it would be plugged into the equation as 0.65. Incorrect percentage conversion is the second most common mistake.

STEP 4: Select Light Loss Factor (LLF). The light loss factor accounts for various effects which reduce the light output over the life of the lamp and fixture. It is generally recognized that applications are divided by category and environment as listed on the guideline. For example, an office with troffers would be a direct fixture in a clean environment, LLF = 0.75.

FIG. 12. Lumen Method Calculation

GENERAL INFORMATION

Project identification: ____

(Give name of area and/or building and room number)

Average maintained illuminance for design: ____ lux or
: ____ footcandles

Luminaire data:

Manufacturer: ______________________

Catalog number: ______________________

Lamp data:

Type and color: ______________________

Number per luminaire: ______________________

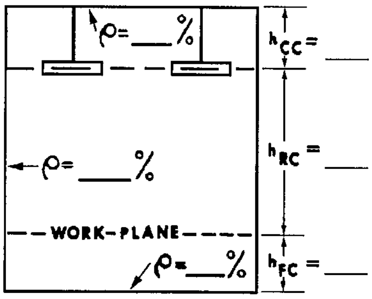
Total lumens per luminaire: ______________________

SELECTION OF COEFFICIENT OF UTILIZATION

Step 1: Fill in sketch at right

Step 2: Determine Cavity Ratios

Room Cavity Ratio, RCR = __________



L = ___

W = ___

Step 3: Obtain Coefficient of Utilization (CU) from Manufacturer's Data CU = ________

SELECTION OF LIGHT LOSS FACTORS

Direct Fixtures:	**0.75**	**Clean Environment**
	0.65	**Dirty Environment**
Indirect Fixtures:	**0.65**	**Clean Environment**
	0.50	**Dirty Environment**

Step 4: Select Light Loss Factor (LLF) LLF = ________

CALCULATIONS

(Average Maintained Illuminance)

$$\text{Number of Luminaires} = \frac{(\text{Illuminance}) \times (\text{Area})}{(\text{Lumens per Luminaire}) \times (\text{CU}) \times (\text{LLF})}$$

= ______________________________ =

$$\text{Illuminance} = \frac{(\text{Number of Luminaires}) \times (\text{Lumens per Luminaire}) \times (\text{CU}) \times (\text{LLF})}{(\text{Area})}$$

= ____ =

Calculated by: ______________________________________ Date: ______________________

Most often the designer will start with the top equation, in order to determine the number of fixtures required to provide a predetermined light level. All of the parts have been determined from the previous steps and can be plugged into the following formula:

$$\text{Number of Luminaires} = \frac{(\text{Illuminance}) \times (\text{area})}{(\text{lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}$$

To verify the light level of an existing layout, the designer would use the second equation:

$$\text{Illuminance} = \frac{(\text{Number of luminaires}) \times (\text{lumens per luminaire}) \times (\text{CU}) \times (\text{LLF})}{(\text{area})}$$

For example: An administrative area measuring 25′ x 30′ x 10′ ceiling, will be lighted using three lamp, parabolic troffers. Each lamp produces 2900 lumens, so each luminaire produces:

2900 lumens x 3 lamps = 8700 total lumens per luminaire

Assumed reflectances are 80/50/20. The design illumination level for administrative areas with general ambient lighting systems is 50 footcandles (see below, Design Applications: Administrative Areas). The RCR is:

RCR= 5(7.5)(25+30)/(25 x 30) = 2.75

From the fixture manufacturer's data, the CU = .66. For clean environments with direct fixtures, the LLF = 0.75. Plugging these items into the equation yields:

Number of fixtures = 50 (25 x 30)/(8700)(0.66)(0.75)= 8.7 fixtures

Since a fraction of a fixture cannot be provided, the designer rounds up to the next whole number, which provides a slightly higher light level. 9 fixtures would be used.

G. POINT CALCULATION

If a space is not square or rectangular, as in a circular or domed area, or if the fixtures are not uniformly spaced, point calculations can be performed to determine the illumination levels at various points within the space. This method calculates the illumination level at a given point due to one source of light. If more than one source is involved, the individual point calculations are added to yield the total illumination. The point method can also be used to determine the illumination on vertical surfaces. The equations are:

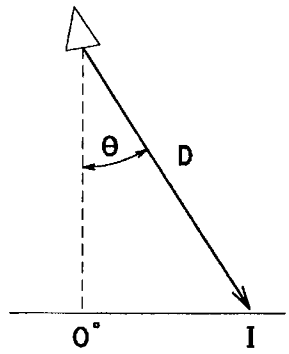
Horizontal Surface

$$E = \frac{I \cos\Theta}{D^2}$$

Vertical Surface

$$E = \frac{I \sin\Theta}{D^2}$$

Where: E=illumination intensity at a point
I=candela value from fixture manufacturer's data
D=distance from fixture to calculation plane
Θ=angle between light striking surface and surface



This calculation is based on initial footcandle levels. The result must be multiplied by the appropriate Light Loss Factor (LLF) as described above under Lumen Method Calculation to obtain the maintained illumination level, which accounts for the depreciation of the lamp output and dirt accumulation on the fixture over time.

H. Lighting Fixture Schedule

The lighting fixture schedule conveys the designer's fixture, lamp and option selections to the contractor. Even when using the Corps standard fixture types, the schedule is usually needed to describe variations in fixture options, lamp count and wattage, etc. Variations on the same fixture type are indicated by different symbols on the drawings and described in the fixture schedule.

As an example, if Corps standard type RF7 is to be specified, the first column would contain the drawing symbol which represents this fixture. The lamps would be designated by quantity (2) and type (F32T8). The maximum wattage should include ballast losses for all but incandescent fixtures, which do not have ballasts. Ballast loss information can be found in manufacturers' catalogs. A single F32T8 lamp will consume 30 watts when matched with a standard electronic ballast, so for this example the maximum fixture wattage would be 60. The supply voltage is filled in next.The description should be concise but complete, mentioning any options to be included. For this example, the designer might specify a 300 x 1200 mm lensed troffer, pattern 19 lens, and electronic dimming ballast with dimming to 20%. The notes column is used for specific instructions to the contractor, such as verification of mounting conditions or recess depth.

LIGHTING FIXTURE SCHEDULE

CONTRACT DRAWING FIXTURE SYMBOL	CORPS STANDARD TYPE	LAMP		FIXTURE			NOTE NO.
		QTY.	TYPE	MAX WATT	VOLT	DESCRIPTION (INCLUDING OPTIONS)	
NOTES:							

III. Design Applications

A. Administrative areas

Most administrative areas incorporate both computers and paper-based tasks. In such cases the light levels are selected for the more critical task, which is the paper-based task. Paper-based tasks typically require light levels of 50 FC. The general ambient system and the task ambient system are two options for lighting administrative areas. A general ambient system provides a uniform light level (50 FC in this case) over the entire area. A task ambient system provides a lower ambient light level, typically 35 FC for administrative areas, and task lighting on the work surface to supplement the ambient light. The task light may be either the under-cabinet variety which is mounted to overhead book bins (used in conjunction with modular furniture), or a swing arm task light. Using task lighting, the higher light levels are restricted to the actual task area, reducing energy consumption. Task ambient systems, as a rule of thumb, have higher first costs and lower energy consumption and costs than the general ambient system. A life cycle cost analysis is usually necessary to choose the most cost-effective system.

Modular furniture adds complexity for lighting designers. The furniture is available in varying partition heights, either with or without book bins. The partition height is a critical design issue which becomes more critical as the height increases. High partitions prevent light from adjacent luminaires from traveling into the work space. A furniture plan indicating the various partition heights is required. A section should be drawn through the area showing the partitions to ensure that each work station has an adequate amount of light. Under-cabinet task lighting can be used beneath the book bins to provide additional task illumination and reduce the shadows created by the bins. The task ambient approach is most appropriate for use with modular furniture and book bins in small cubicles.

Parabolic troffers and indirect pendants are the most commonly used fixtures for administrative areas. Selecting the type of fixture to be used is a tradeoff between critical elements. The parabolic troffer is the workhorse of the industry. It provides a large amount of light with some glare at reasonable cost. A 3 lamp, 24 cell parabolic troffer, Corps standard type RF12, is recommended in most applications. While an indirect or combination direct/indirect pendant provides a virtually glare free environment, it is very costly. Therefore, pendant use is typically limited to specialty areas, such as concentrated monitor viewing in security offices or command centers where glare is a serious concern and the budget allows for the higher cost of the pendant system. Indirect fluorescent pendants, such as Corps standard type PF2, need adequate ceiling height ranging from 9-12′ for proper light distribution, and a minimum suspension length of 18 inches (figure 13). When using indirect pendants, the ceiling reflectance should be high—about 70-80%. Standard acoustical ceiling tiles typically provide the required reflectance. If pendant layouts are not designed properly they can create as much glare as a lensed troffer.

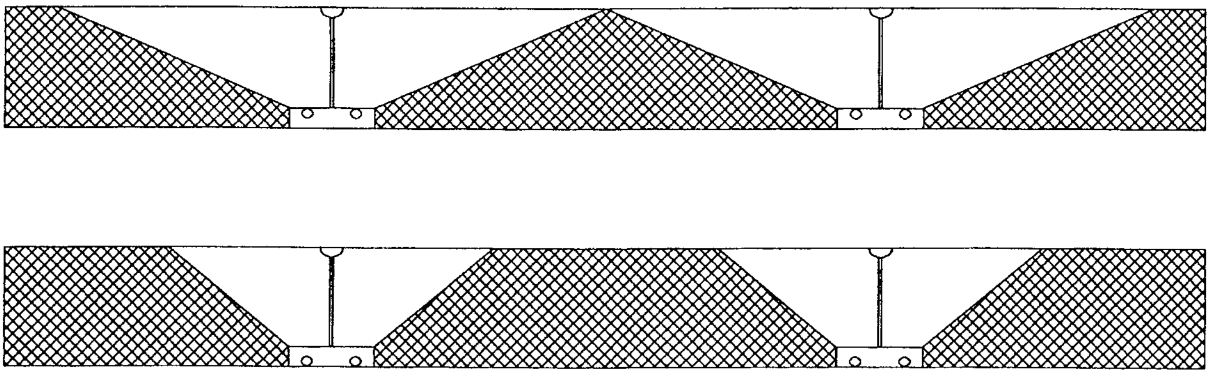


FIG. 13. Indirect luminaires should have a widespread light distribution as shown in the upper image. A narrow light distribution as shown in the lower image may cause patches of brightness.

The relationship between task and ambient illumination should be considered. The IES recommends that the task to work surface (desk top) brightness ratio should not exceed 2 to 1. Simply put, the desk top should have a light finish in order to reduce the contrast. The color of the surfaces plays a large role in the apparent brightness of the surfaces. For example, a tan wall will have more brightness than a chocolate brown wall. The task to near surround (partition wall) brightness ratio should not exceed 3 to 1; the partition wall can be lighted by under-cabinet task lighting. The task to far surround (wall across the room) brightness ratio should not exceed 10 to 1. Wall surfaces can be lighted in the traditional manner by using wall washer fixtures to project light onto the surface. However, this requires additional fixtures which increases the budget. Positioning the ceiling fixtures to allow adequate light to strike the upper wall surface can produce a similar effect at lower cost. For example, a fluorescent troffer with a 45° cut-off characteristic placed two feet from a wall will throw light on the wall starting two feet down from the ceiling. This is an inexpensive alternative to wall washer fixtures, but the light provided will be less uniform.

The brightness ratio recommendations imply that the vertical surfaces should be lighted in order to provide a work environment with minimal eye fatigue. Vertical illumination is especially important in enclosed offices to increase the sense of brightness.

EXAMPLE 1: See figure 14. An administrative area measuring 25′ x 30′ x 10′ ceiling, with modular furniture in 10′ x 10′ cubicles, 5.5′ partition height. Assumed reflectances are 80/50/20. Because of the size of the cubicles and partition height, the task ambient system will be used, with a target ambient light level of 35 footcandles as described in **AEI** *Chapter 12,* General and Task Illumination. Since the space is not computer-intensive and pendant fixtures are more costly than troffers, the three lamp parabolic troffer, Corps standard type RF12, will be selected. By the lumen method calculation this area requires 6 fixtures to provide the target ambient light level. A clamp mounted task light, Corps standard type FF2, will also be provided for each work surface. The energy consumption for each RF12 fixture is 90 watts including ballast loss, and energy consumption for the FF2 is 25 watts including ballast loss, totaling 690 watts for the area, giving an interior lighting power consumption of 0.92 watts per square foot. This figure is less than the UPD of 1.3 required by 10 CFR 435. A ceiling mounted infrared occupancy sensor, Corps standard type C2, will facilitate a direct "line of sight" over the tops of the partitions in addition to the square footage to be covered.

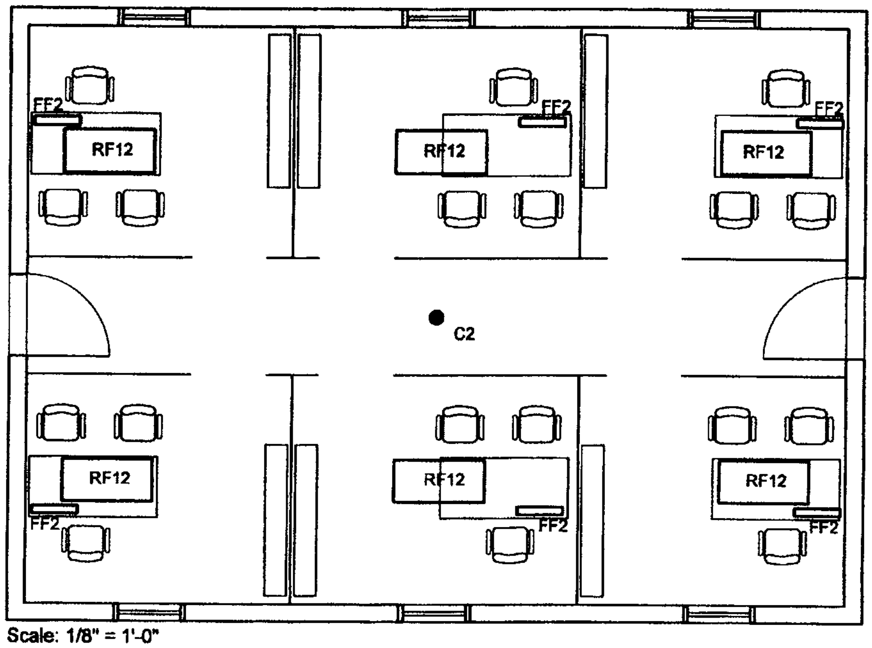


FIG. 14. Administrative area Example 1.

EXAMPLE 2: See figure 15. An open plan administrative area measuring 25′ x 30′ x 10′ ceiling, with standard (not modular) furniture. Assumed reflectances are 80/50/20. Because of the densely spaced work surfaces without binder bins, the general ambient system will be used, which requires a target light level of 50 footcandles as described in **AEI** *Chapter 12* for illumination levels in general office spaces. For cost reasons, the three lamp parabolic troffer, Corps standard type RF12, will be selected. By the lumen method calculation, this area requires 9 fixtures. An 8′ x 12′ spacing (which does not exceed the manufacturer's recommended spacing ratio) will be selected to allow light from the troffers to strike the walls, creating vertical brightness. The energy consumption for the RF12 fixture is 90 watts including ballast loss, totaling 810 watts for the area, giving an interior lighting power consumption of 1.08 watts per square foot. This figure is less than the UPD of 1.3 required by 10 CFR 435. A ceiling mounted infrared occupancy sensor, Corps standard type C2, will be selected due to the square footage to be covered.

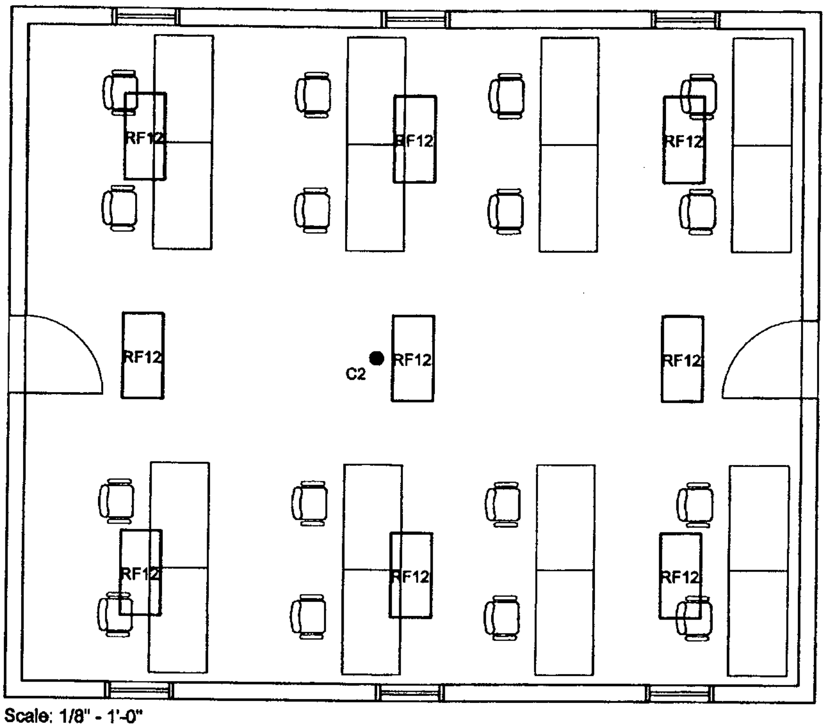


FIG. 15 Administrative area Example 2.

B. WAREHOUSE AREAS

Warehouses consist mostly of vertical shelving units. Lighting the lowest shelf is the challenge. From the **IESNA Handbook,** *Chapter 11,* the target illuminance level is 30 FC. Low bay metal halide fixtures, Corps standard type PH8, are used for 10 to 18 foot ceilings, while high bay warehouse aisle fixtures, type PH6, are used for 15 to 40 foot ceilings with high shelving, and standard high bay metal halide industrial fixtures, type PH7, are used for high ceiling spaces without high shelving. Refer to fixture manufacturer's data for spacing criteria depending on the lamp wattage selected. Shelving layouts should be developed before the lighting design is done in order to place the fixtures over the aisles, not over the shelves. Having the fixtures over the aisles helps light reach the bottom shelf. Hi- low ballasts with occupancy sensors are recommended in this application to conserve energy. When the occupancy sensor does not detect motion, the ballast reduces light output to 60%, which saves electricity. Since the lamp is not extinguished, it can provide immediate full light output when the occupancy sensor detects motion.

Industrial fluorescent pendants, Corps standard type PF6, are often used in lower height ceilings of 12 feet and less, and are also placed over the aisles.

EXAMPLE 3: See figure 16. Warehouse, 30′ x 60′ x 25′ ceiling with 20′ high shelves and 6′ wide aisles. As stated above, the target illuminance level is 30 FC. Due to the height of the space and shelving, a high bay warehouse aisle fixture, Corps standard type PH6, will be selected. Metal halide lamps will be used instead of high pressure sodium, due to their better color rendition. According to the fixture manufacturer's data, 400 watt metal halide lamps will provide 25 FC. This is slightly low, but 1000 watt lamps will provide 62 FC, which is excessive. The spacing ratio is 1.7:1, so the fixtures could be spaced as far as 43 feet on center. They will be laid out on 40 foot centers to center them in the available space, which will increase the average illumination level slightly above 25 FC. Each fixture will be specified with a hi-low ballast to reduce energy consumption. The power consumption at full output will be 1800 watts, or 1.0 watt per square foot, which equals the maximum UPD of 1.0 required by 10 CFR 435. Due to the hard surfaces, Corps standard type C1 ultrasonic occupancy sensors will be used. One sensor will be located in each aisle to control the fixtures in that aisle.

EXAMPLE 4: See figure 17. Warehouse, 29′ x 30′ x 10′ ceiling with 9′ high shelves and 3′ wide aisles. Because of the low ceiling height, Corps standard type PF6 fluorescent fixtures will be selected. The task ambient approach will be used, placing the fixtures between the shelves and out of the aisles. The fixtures will be spaced 6′ on center, which will provide a slightly high illumination level of 38 FC. Spacing the fixtures further apart would reduce the illumination, but the 6′ spacing works well with the shelving layout. The power consumption is 960 watts, or 1.0 watt per square foot, which meets the maximum UPD of 1.0 required by 10 CFR 435. Due to the height of the shelves in relationship to the ceiling, one Corps standard type C1 ultrasonic occupancy sensor with corridor option will be used for each aisle. Each sensor will be circuited separately to control the fixtures for its aisle, so the lights in each aisle will operate only when necessary.

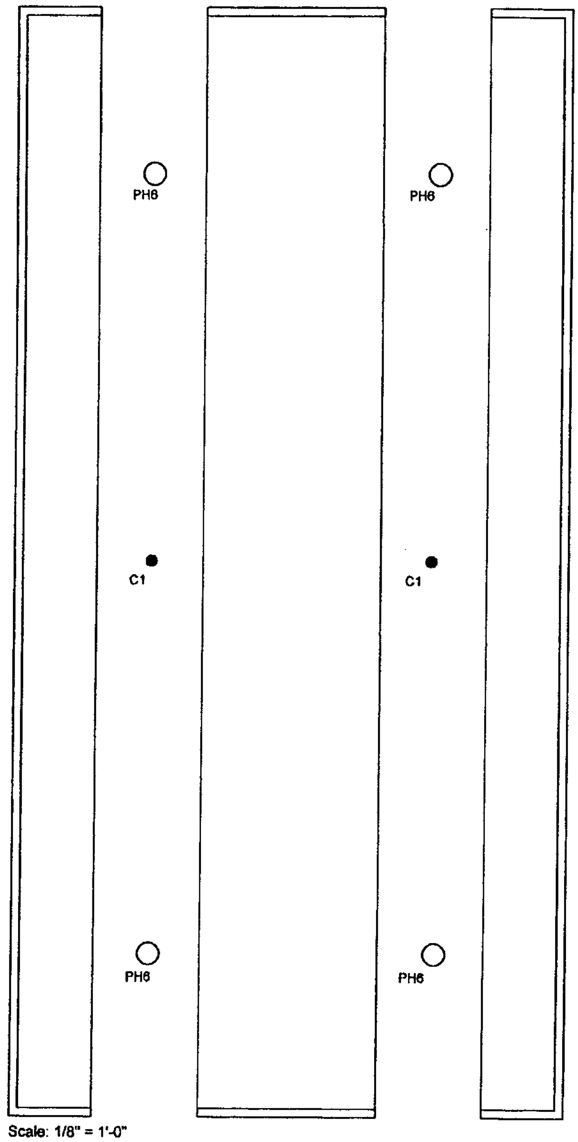


FIG. 16. Warehouse Example 3.

C. Unaccompanied Personnel Housing

The new motel style UPH design in which two rooms share a bath is very similar to a college dormitory room. The most critical tasks are typically reading or writing at the desk. Lower light levels are generally acceptable in residential applications, so an ambient level of 20 FC with a task light at the desk is appropriate. Some users may require a flexible, general light level. In that case, downlights should be spaced evenly to provide 35 footcandles. A recessed or surface mounted compact fluorescent downlight, Corps standard type RF3 or SF1, could be used.

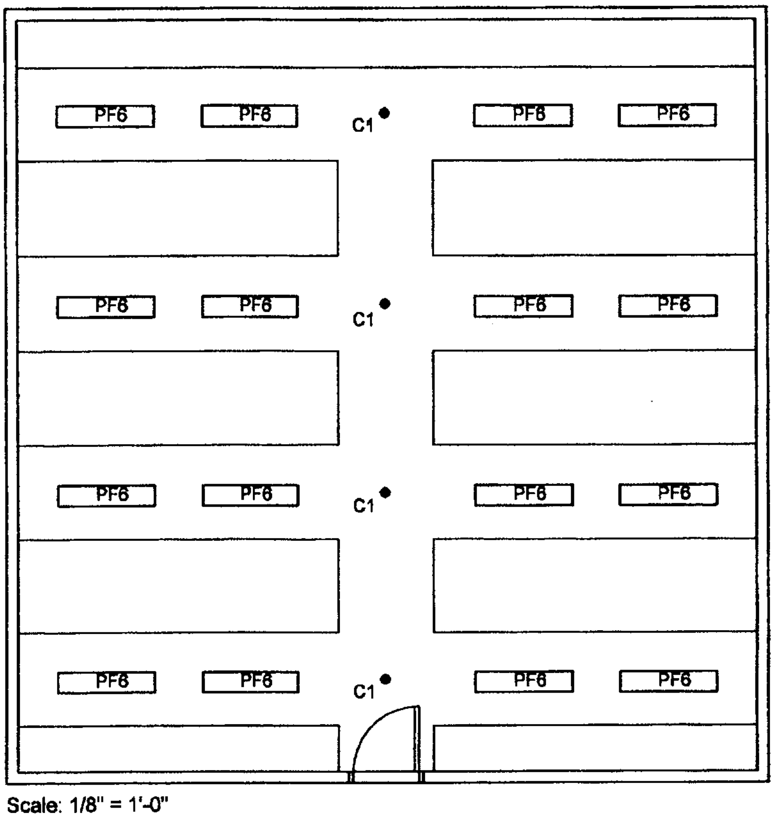


FIG. 17. Warehouse Example 4.

Example 5: See figure 18. Unaccompanied Personnel Housing measuring 20′ x 15′ x 9′ ceiling. The general ambient approach will be used, spacing fixtures evenly throughout the room. Corps standard type RF3 fixtures will be selected, spaced 8′ on center with an additional fixture for the kitchen. The power consumption will be 200 watts, or 0.67 watts per square foot, which is less than the maximum UPD of 1.3 required by 10 CFR 435. In the bathroom, Corps standard type RF1 will be used over the shower stall and Corps standard type WF3 over the mirror. The arrangement of the space will allow the use of a wall switch/ occupancy sensor, Corps standard type C3, in both the living space and the bathroom. The sensor will be equipped with a manual over-ride in order to keep the lights off during sleeping hours.

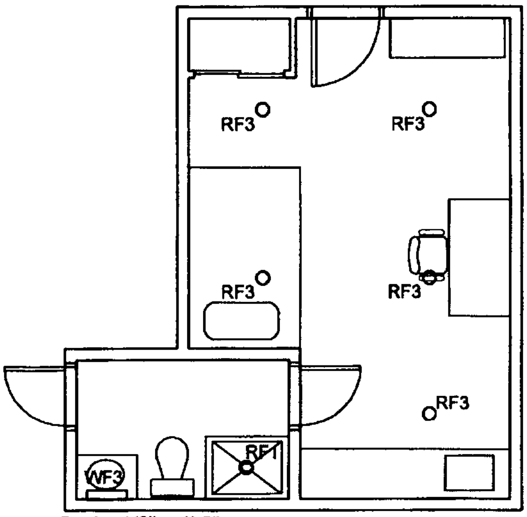


FIG. 18. Unaccompanied Personnel Housing Example 5.

D. EXTERIOR

LIGHT SOURCES

A growing number of lighting specifiers now recommend metal halide (MH) lamps for applications in which high pressure sodium (HPS) lamps were formerly used. The benefits of metal halide lamps include improved color rendition (good for surveillance cameras), better visibility, and the smaller arc tube, which permits the use of smaller reflectors and fixtures with better glare control. The primary drawback is the slightly lower efficiency of MH lamps, which use more energy to produce a given illumination level than HPS lamps require.

The usage of parking areas should be considered in selecting light sources. In exterior areas used by the public or where there is much pedestrian traffic, MH lamps are preferred due to their superior color rendering properties. In areas having little or no pedestrian traffic or where color rendering is not critical, such as tank hardstands, HPS lamps are recommended due to their lower energy cost.

PARKING FACILITIES

Parking facilities utilize fixtures of varying distribution (see figure 19). Type II distribution produces a long narrow light pattern. Type III produces a pattern very similar to type II but slightly wider. Type IV is forward throw. Type V is a square pattern. Fixtures are located based on the coverage provided by the pattern. For example, types I and II are used on roadways, while type V is used in the center of parking lots and type IV on the edges of parking lots or on wide roadways. Typically 175W, 250W, and 400W lamps are used on poles of up to 35 feet. 40 foot and higher poles use 1000W lamps. Cut-off luminaires, Corps standard type EH1, are preferred because they reduce glare and light trespass.

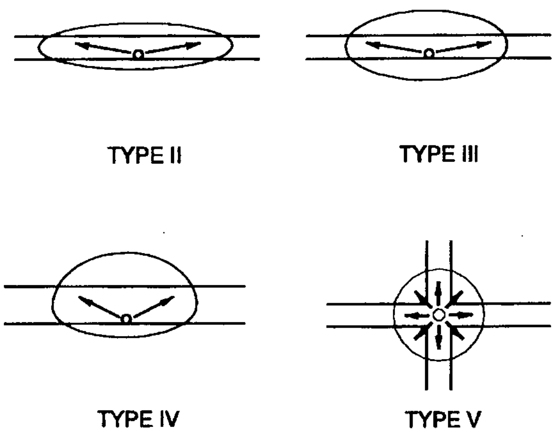


FIG. 19. Plan view of roadway coverage for different types of luminaires.

Recommended lighting levels and uniformity ratios for parking facilities are shown in figure 20. The recommended levels depend upon the amount of activity expected. Poles are typically located on islands so the number of parking spaces is not reduced. Trees should be held 15 feet back from the pole location and trimmed as they grow in order to prevent interference with the light distribution.

FIG. 20. Recommended Maintained Horizontal Illuminances for Parking Facilities

Open Parking Facilities	General Parking and Pedestrian Areas			Vehicle Use Areas (only)		
Level of Activity	Lux (Minimum on Pavement)	Footcandles (Minimum on Pavement)	Uniformity Ratio (Average Minimum)	Lux (Minimum on Pavement)	Footcandles (Minimum on Pavement)	Uniformity Ratio (Average Minimum)
High	10	0.9	4:1	22	2	3:1
Medium	6	0.6	4:1	11	1	3:1
Low	2	0.2	4:1	5	0.5	4:1

EXAMPLE 6: See figure 21. Surface parking lot, high activity level, 200′ x 100′ with perimeter and center parking stalls. Corps standard type EH1 will be selected to minimize glare. Manufacturer's data indicates that a 250 watt metal halide lamp is required to achieve the recommended minimum of approximately 1 FC. Manufacturers' data show that twin heads using Type III distribution on 30′ poles will cover the width of the lot and can be spaced at 150′, therefore two poles will be needed. Placing the fixtures 150 feet on center would put one pole in the drive aisle, therefore they will be placed 140 feet on center. This layout would provide an average of 2 FC, with a minimum of 0.82 and a uniformity ratio of 2.4:1. These levels meet or exceed the levels recommended in figure 20. Due to the twin heads, there is too much light at the base of each pole, which is driving up the average illumination level beyond the minimum requirement. One alternative is to place the poles around the perimeter. This would require four poles with single Type II heads and would provide an average of 1.25 FC with a uniformity ratio of 2.5:1. Either layout would provide the required light, but the two pole solution is less costly to install.

Duration of operation is important in minimizing energy use. If the lot need be lighted only from dusk until a specific time, such as midnight, control could be provided using a photocell to turn on the lights and a time clock to turn them off. If the lot must be illuminated from dusk until dawn, a photocell alone should be used. It is typically less expensive to provide one photocell to control all the fixtures rather than having an integral photocell in each fixture.

SITE AND FACADE

Site lighting refers primarily to pedestrian walkways. To promote a feeling of security, low height (12 to 16 foot) poles are used. By having the light source above head height, light is cast onto the faces of persons walking towards each other, helping to identify whether the approaching person is friendly or a potential assailant. Metal halide lamps have better color rendering properties than sodium or mercury lamps, which increases the feeling of security because colors appear to be natural and would-be assailants can more easily be identified. Recommended light levels are given in figure 22. The uniformity is the most critical issue. People feel safer when walkways are evenly illuminated.

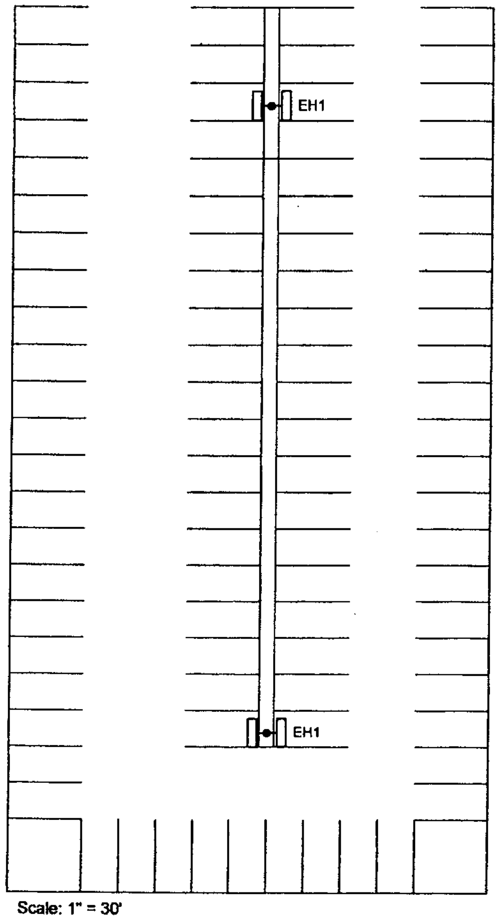


FIG. 21. Surface parking lot Example 6.

Example 7: See figure 22. Pedestrian walkways 5 feet wide. Corps standard type EH1 will be used to minimize glare. Manufacturer's data indicates that a 100 watt metal halide lamp is required and can be spaced 100 feet on center using single head, type III distribution on a 16 foot pole. This layout would provide an average of 0.63 footcandles, with a minimum of 0.36 and an excellent uniformity ratio of 1.75:1. The fixtures may be controlled like parking lot fixtures, using either a photocell alone or in combination with a time clock.

Walkway and Bikeway Classification	Minimum Average Horizontal Levels ($E_{avg.}$)	Average Vertical Levels for Special Pedestrian Security ($E_{avg.}$)‡
Sidewalks (roadside) and Type A bikeways:		
Commercial areas	10	22
Intermediate areas	6	11
Residential areas	2	5
Walkways distant from roadways and Type B bikeways:		
Walkways, bikeways, and stairways	5	5
Pedestrian tunnels	43	54

* Crosswalks traversing roadways in the middle of long blocks and at street intersections should be provided with additional illumination.

† For approximate values in footcandles, multiply by 0.1.

‡ For pedestrian identification at a distance. Values at 1.8 meters (6 feet) above walkway.

FIG. 22. Recommended Average Maintained Illuminance Level for Pedestrian Ways* in Lux†

Facade lighting is typically provided on Corps projects for security purposes. Exterior building lighting at ground level reduces dark areas where assailants can hide. Typically, Corps standard type EH5 is used adjacent to doors. Corps standard type EF1, a recessed compact fluorescent step light, can be used to light exterior stairs. Ground mounted flood-lights, Corps standard type EH7 with a low wattage metal halide lamp, can be aimed at the building to provide security lighting. It is not possible to light glass windows, therefore the floodlights should be aimed at the solid portions of the structure when possible.

Any ground mounted fixture may become a maintenance problem. In grassy areas, fixtures are often damaged by grass cutting equipment. In areas with heavy snow fall, snow will cover the fixtures, which may also be damaged by snow removal equipment. Depending on the depth of snow cover, the heat from the fixture may melt the snow. Falling leaves may prevent the fixtures from working. Plantings or other shields around the fixtures can help protect them from being run over. Maintenance personnel should remove debris from fixtures when relamping.

E. SPECIALTY SPACES

CORRIDORS

The task in a corridor is walking, which does not require high light levels. The typical light level is 10 FC. Providing brightly lighted terminal views (lighted end walls) helps people negotiate corridors. Lensed or parabolic fluorescent troffers, Corps standard type RF7, RF8, RF9, RF10, RF11, or RF12 could be used. Wall slots, Corps standard type RF14, could be used on either one or both sides of the corridor, depending on its width.

Lighting can be used to break long corridors visually into smaller sections. Decorative pendants, Corps standard type PF1, at periodic intervals with fluorescent troffers or compact fluorescent downlights, Corps standard type RF3, RF4, RF7, RF8 or RF9 in between, will develop a rhythm, making the corridor appear as a series of shorter corridors.

STAIRS

The most important steps on a flight of stairs are the first and the last. Having taken the first step, the brain memorizes the height and can continue without thinking. Therefore, the bottom, intermediate and top landings should be lighted to a level of 20 FC. Maintenance is simplified by not having fixtures over the sloping sections of the stairs because it is very difficult to set up a ladder on a flight of stairs. Recessed compact fluorescent downlights, Corps standard type RF2, could be used.

TRAINING ROOMS

Training rooms have the same requirements for light levels as administrative areas: 50 FC. Fixtures are typically run parallel to the blackboard or writing surface. If the room requires slide, video, or overhead projection, dimming or separate switching of the fixtures should be considered in order to lower the light levels. Depending on the sophistication of video equipment, turning off the row of fixtures closest to the screen may be adequate. In most cases, however, the row closest to the screen must be turned off and the remaining fixtures dimmed. Recessed parabolic troffers or indirect pendants, Corps standard types RF10, RF11, RF12, or PF2, could be used. They have the same limitations as discussed for administrative areas.

CONFERENCE ROOMS

Conference rooms have the same concerns for video as training rooms mentioned above. An additional concern is the use of wall surfaces as display areas for presentations. At least one wall of a conference room should be lighted for this purpose and to provide visual comfort. Recessed compact fluorescent lensed wallwashers, Corps standard type RF6, would be a good choice.

TOILET ROOMS

Depending on the level of finishes in the space, the fixture selection and placement can vary greatly. Typical concepts are to provide general lighting in the area of the stalls and to provide illumination on the faces of persons looking into the mirror.

General illumination can be as simple as a lensed troffer, Corps standard type RF7, RF8, or RF9. In higher scale rest rooms, either compact fluorescent downlights or wall slots over the stalls, Corps standard type RF3 or RF14, could be used.

At the mirror, lensed 1′ x 4′ troffers, Corps standard type RF7; wall mounted fluorescent fixtures, Corps standard type WF6 or WF8; or compact fluorescent sconces, Corps standard type WF1, WF2, or WF3, could be used to provide facial illumination.

MACHINE ROOMS

The fixture should be selected based on ceiling height. Metal halide fixtures, Corps standard type PH7, are used in higher ceiling areas (10-18 feet), while fluorescent fixtures, Corps standard type PF6 or PF7, are used for lower ceiling heights. The fixtures should be located in relationship to the equipment in the room. The most usable light should get to the work area. An average of 70 FC should be provided. Occupancy sensors should not be used to switch all lights in machine rooms, due to the danger of all lights going out while a technician is working on machinery out of view of the sensor.

FAMILY HOUSING

Light levels of 20 FC are adequate in the living areas and 50 FC in the kitchen. Typically in the living areas, switched receptacles are provided. Decorative pendants such as Corps standard type PF1 could be used in the dining area. Surface mounted wraparound fixtures, Corps standard type SF5, might be used in the kitchen. Surface mounted decorative compact fluorescent fixtures, Corps standard type SF1, could be used in the bedrooms, or a switched receptacle could be provided. The bathrooms would typically have surface mounted decorative sconces, Corps standard type WF1, WF2, or WF3 on either side of the mirror.

KITCHEN/CAFETERIA

Industrial kitchens required enclosed and gasketed lensed fixtures such as Corps standard type RF7, RF8, or RF9 with gasketed option, located in relation to the kitchen equipment. These fixtures are often specified for kitchens with the lens flipped upside down with the smooth side out, for ease of maintenance. Corps standard type RI1 or PF1, incandescent downlights and compact fluorescent pendants, could be used in the seating area either separately or in combination to add decoration.

List of Abbreviations

AEI	Architect-Engineer Instructions
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
CBCP	Center Beam Candle Power
CFR	Code of Federal Regulations
CRI	Color Rendering Index
CU	Coefficient of Utilization
DTT	Double Twin Tube
ELPA	Exterior Lighting Power Allowance
FC	Footcandle
HID	High Intensity Discharge
HPS	High Pressure Sodium
IF	Inside Frosted
ILPA	Interior Lighting Power Allowance
K	Kelvin
kW	kilowatt
kWH	kilowatt hour
LCCA	Life Cycle Cost Analysis
LLF	Light Loss Factor
MH	Metal Halide
MR	Mirrored Reflector
NPW	Net Present Worth
PAR	Parabolic Aluminized Reflector
R	Reflector
RCR	Room Cavity Ratio
RFI	Radio Frequency Interference
SIR	Savings to Investment Ratio
SPB	Simple Payback
SPW	Single Present Worth
THD	Total Harmonic Distortion
TT	Twin Tube
TTT	Triple Twin Tube
UPH	Unaccompanied Personnel Housing