LIGHTING FUNDAMENTALS

LIGHTING UPGRADE MANUAL
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U.S. EPA Green Lights Program

CONTENTS

A basic understanding of lighting fundamentals is essential for specifiers and decision-makers who are evaluating lighting upgrades. This document provides a brief overview of design parameters, technologies, and terminology used in the lighting industry. For more detailed information about specific energy-efficient lighting technologies, refer to the Lighting Upgrade Technologies document.

ILLUMINATION

Quantity of Illumination

Light Output

The most common measure of light output (or luminous flux) is the lumen. Light sources are labeled with an output rating in lumens. For example, a T12 40-watt fluorescent lamp may have a rating of 3050 lumens. Similarly, a light fixture's output can be expressed in lumens. As lamps and fixtures age and become dirty, their lumen output decreases (i.e., lumen depreciation occurs). Most lamp ratings are based on initial lumens (i.e., when the lamp is new).

Light Level

Light intensity measured on a plane at a specific location is called ***illuminance***. Illuminance is measured in ***footcandles,*** which are workplane lumens per square foot. You can measure illuminance using a light meter located on the work surface where tasks are performed. Using simple arithmetic and manufacturers' photometric data, you can predict illuminance for a defined space. (Lux is the metric unit for illuminance, measured in lumens per square meter. To convert footcandles to lux, multiply footcandles by 10.76.)

Brightness

Another measurement of light is ***luminance***, sometimes called brightness. This measures light "leaving" a surface in a particular direction, and considers the illuminance on the surface and the reflectance of the surface.

The human eye does not see illuminance; it sees luminance. Therefore, the amount of light delivered into the space and the reflectance of the surfaces in the space affects your ability to see.

Refer to the GLOSSARY at the end of this document for more detailed definitions.

Quantity Measures

- Luminous flux is commonly called light output and is measured in lumens (lm).
- Illuminance is called light level and is measured in footcandles (fc).
- Luminance is referred to as brightness and is measured in footlamberts (fL) or candelas/m2 (cd/m2).

Determining Target Light Levels

The Illuminating Engineering Society of North America has developed a procedure for determining the appropriate average light level for a particular space. This procedure (used extensively by designers and engineers (recommends a target light level by considering the following:

- the task(s) being performed (contrast, size, etc.)
- the ages of the occupants
- the importance of speed and accuracy

Then, the appropriate type and quantity of lamps and light fixtures may be selected based on the following:

- fixture efficiency
- lamp lumen output
- the reflectance of surrounding surfaces
- the effects of light losses from lamp lumen depreciation and dirt accumulation
- room size and shape
- availability of natural light (daylight)

When designing a new or upgraded lighting system, one must be careful to avoid overlighting a space. In the past, spaces were designed for as much as 200 footcandles in places where 50 footcandles may not only be adequate, but superior. This was partly due to the misconception that the more light in a space, the higher the quality. Not only does overlighting waste energy, but it can also reduce lighting quality. Refer to Exhibit 2 for light levels recommended by the Illuminating Engineering Society of North America. Within a listed range of illuminance, three factors dictate the proper level: age of the occupant(s), speed and accuracy requirements, and background contrast.

For example, to light a space that uses computers, the overhead light fixtures should provide up to 30 fc of ambient lighting. The task lights should provide the additional footcandles needed to achieve a total illuminance of up to 50 fc for reading and writing. For illuminance recommendations for specific visual tasks, refer to the IES Lighting Handbook, 1993, or to the IES Recommended Practice No. 24 (for VDT lighting).

Quality Measures

- Visual comfort probability (VCP) indicates the percent of people who are comfortable with the glare from a fixture.
- Spacing criteria (SC) refers to the maximum recommended distance between fixtures to ensure uniformity.
- Color rendering index (CRI) indicates the color appearance of an object under a source as compared to a reference source.

Quality of Illumination

Improvements in lighting quality can yield high dividends for US businesses. Gains in worker productivity may result by providing corrected light levels with reduced glare. Although the cost of energy for lighting is substantial, it is small compared with the cost of labor. Therefore, these gains in productivity may be even more valuable than the energy savings associated with new lighting technologies. In retail spaces, attractive and comfortable lighting designs can attract clientele and enhance sales.

Three quality issues are addressed in this section.

- **glare**
- **uniformity of illuminance**
- **color rendition**

Glare

Perhaps the most important factor with respect to lighting quality is glare. Glare is a sensation caused by luminances in the visual field that are too bright. Discomfort, annoyance, or reduced productivity can result.

A bright object alone does not necessarily cause glare, but a bright object in front of a dark background, however, usually will cause glare. ***Contrast*** is the relationship between the luminance of an object and its background. Although the visual task generally becomes easier with increased contrast, too much contrast causes glare and makes the visual task much more difficult.

You can reduce glare or luminance ratios by not exceeding suggested light levels and by using lighting equipment designed to reduce glare. A louver or lens is commonly used to block direct viewing of a light source. Indirect lighting, or uplighting, can create a low glare environment by uniformly lighting the ceiling. Also, proper fixture placement can reduce **reflected glare** on work surfaces or computer screens. Standard data now provided with luminaire specifications include tables of its **visual comfort probability (VCP**) ratings for various room geometries. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. A minimum VCP of 70 is recommended for commercial interiors, while luminaires with VCPs exceeding 80 are recommended in computer areas.

Uniformity of Illuminance on Tasks

The uniformity of illuminance is a quality issue that addresses how evenly light spreads over a task area. Although a room's average illuminance may be appropriate, two factors may compromise uniformity.

- improper fixture placement based on the luminaire's ***spacing criteria*** (ratio of maxim recommended fixture spacing distance to mounting height above task height)
- fixtures that are retrofit with reflectors that narrow the light distribution

Non-uniform illuminance causes several problems:

- inadequate light levels in some areas
- visual discomfort when tasks require frequent shifting of view from underlit to overlit areas
- bright spots and patches of light on floors and walls that cause distraction and generate a low quality appearance

Color Rendition

The ability to see colors properly is another aspect of lighting quality. Light sources vary in their ability to accurately reflect the true colors of people and objects. The color rendering index (CRI) scale is used to compare the effect of a light source on the color appearance of its surroundings.

A scale of 0 to 100 defines the CRI. A higher CRI means better color rendering, or less color shift. CRIs in the range of 75-100 are considered excellent, while 65-75 are good. The range of 55-65 is fair, and 0-55 is poor. Under higher CRI sources, surface colors appear brighter, improving the aesthetics of the space. Sometimes, higher CRI sources create the illusion of higher illuminance levels.

The CRI values for selected light sources are tabulated with other lamp data in Exhibit 3.

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LIGHT SOURCES

Commercial, industrial, and retail facilities use several different light sources. Each lamp type has particular advantages; selecting the appropriate source depends on installation requirements, life-cycle cost, color qualities, dimming capability, and the effect wanted. Three types of lamps are commonly used:

- incandescent
- fluorescent
- high intensity discharge
- mercury vapor
- metal halide
- high pressure sodium
- low pressure sodium

Before describing each of these lamp types, the following sections describe characteristics that are common to all of them.

Characteristics of Light Sources

Electric light sources have three characteristics: efficiency, color temperature, and color rendering index (CRI). Exhibit 4 summarizes these characteristics.

Efficiency

Some lamp types are more efficient in converting energy into visible light than others. The efficacy of a lamp refers to the number of lumens leaving the lamp compared to the number of watts required by the lamp (and ballast). It is expressed in lumens per watt. Sources with higher efficacy require less electrical energy to light a space.

Color Temperature

Another characteristic of a light source is the color temperature. This is a measurement of "warmth" or "coolness" provided by the lamp. People usually prefer a warmer source in lower illuminance areas, such as dining areas and living rooms, and a cooler source in higher illuminance areas, such as grocery stores.

Color temperature refers to the color of a blackbody radiator at a given absolute temperature, expressed in Kelvins. A blackbody radiator changes color as its temperature increases (first to red, then to orange, yellow, and finally bluish white at the highest temperature. A ***"warm"*** color **light source actually has a lower color temperature**. For example, a cool-white fluorescent lamp appears bluish in color with a color temperature of around 4100 K. A warmer fluorescent lamp appears more yellowish with a color temperature around 3000 K. Refer to Exhibit 5 for color temperatures of various light sources.

Color Rendering Index

The CRI is a relative scale (ranging from 0 - 100). indicating how perceived colors match actual colors. It measures the degree that perceived colors of objects, illuminated by a given light source, conform to the colors of those same objects when they are lighted by a reference standard light source. The higher the color rendering index, the less color shift or distortion occurs.

The CRI number does not indicate which colors will shift or by how much; it is rather an indication of the average shift of eight standard colors. Two different light sources may have identical CRI values, but colors may appear quite different under these two sources.

Incandescent Lamps

Standard Incandescent Lamp

Incandescent lamps are one of the oldest electric lighting technologies available. With efficacies ranging from 6 to 24 lumens per watt, incandescent lamps are the least energy-efficient electric light source and have a relatively short life (750-2500 hours).

Light is produced by passing a current through a tungsten filament, causing it to become hot and glow. With use, the tungsten slowly evaporates, eventually causing the filament to break.

These lamps are available in many shapes and finishes. The two most common types of shapes are the common ***"A-type***" lamp and the ***reflector-shaped*** lamps.

Tungsten-Halogen Lamps

The tungsten halogen lamp is another type of incandescent lamp. In a halogen lamp, a small quartz capsule contains the filament and a halogen gas. The small capsule size allows the filament to operate at a higher temperature, which produces light at a higher efficacy than standard incandescents. The halogen gas combines with the evaporated tungsten, redepositing it on the filament. This process extends the life of the filament and keeps the bulb wall from blackening and reducing light output.

Because the filament is relatively small, this source is often used where a highly focused beam is desired. Compact halogen lamps are popular in retail applications for display and accent lighting. In addition, tungsten-halogen lamps generally produce a whiter light than other incandescent lamps, are more efficient, last longer, and have improved lamp lumen depreciation.

Incandescent A-Lamp

More efficient halogen lamps are available. These sources use an infrared coating on the quartz bulb or an advanced reflector design to redirect infrared light back to the filament. The filament then glows hotter and the efficiency of the source is increased.

Fluorescent Lamps

Fluorescent lamps are the most commonly used commercial light source in North America. In fact, fluorescent lamps illuminate 71% of the commercial space in the United States. Their popularity can be attributed to their relatively high efficacy, diffuse light distribution characteristics, and long operating life.

- Fluorescent lamp construction consists of a glass tube with the following features:
- filled with an argon or argon-krypton gas and a small amount of mercury
- coated on the inside with phosphors
- equipped with an electrode at both ends

Fluorescent lamps provide light by the following process:

- An ***electric discharge (current)*** is maintained between the electrodes through the mercury vapor and inert gas.
- This current excites the mercury atoms, causing them to emit non-visible ***ultraviolet (UV) radiation.***
- This UV radiation is converted into ***visible light*** by the phosphors lining the tube.

Discharge lamps (such as fluorescent) require a ballast to provide correct starting voltage and to regulate the operating current after the lamp has started.

Full-Size Fluorescent Lamps

Full-size fluorescent lamps are available in several shapes, including straight, U-shaped, and circular configurations. Lamp diameters range from 1" to 2.5". The most common lamp type is the four-foot (F40), 1.5" diameter (T12) straight fluorescent lamp. More efficient fluorescent lamps are now available in smaller diameters, including the T10 (1.25 ") and T8 (1").

Fluorescent lamps are available in color temperatures ranging from warm (2700(K) "incandescent-like" colors to very cool (6500(K) "daylight" colors. "Cool white" (4100(K) is the most common fluorescent lamp color. Neutral white (3500(K) is becoming popular for office and retail use.

Improvements in the phosphor coating of fluorescent lamps have improved color rendering and made some fluorescent lamps acceptable in many applications previously dominated by incandescent lamps.

Performance Considerations

The performance of any luminaire system depends on how well its components work together. With fluorescent lamp-ballast systems, light output, input watts, and efficacy are sensitive to changes in the ambient temperature. When the ambient temperature around the lamp is significantly above or below 25C (77F), the performance of the system can change. Exhibit 6 shows this relationship for two common lamp-ballast systems: the F40T12 lamp with a magnetic ballast and the F32T8 lamp with an electronic ballast.

As you can see, the optimum operating temperature for the F32T8 lamp-ballast system is higher than for the F40T12 system. Thus, when the ambient temperature is greater than 25C (77F), the performance of the F32T8 system may be higher than the performance under ANSI conditions. Lamps with smaller diameters (such as T-5 twin tube lamps) peak at even higher ambient temperatures.

Compact Fluorescent Lamps

Advances in phosphor coatings and reductions of tube diameters have facilitated the development of compact fluorescent lamps.

Manufactured since the early 1980s, they are a long-lasting, energy-efficient substitute for the incandescent lamp.

Various wattages, color temperatures, and sizes are available. The wattages of the compact fluorescents range from 5 to 40 (replacing incandescent lamps ranging from 25 to 150 watts (and provide energy savings of 60 to 75 percent. While producing light similar in color to incandescent sources, the life expectancy of a compact fluorescent is about 10 times that of a standard incandescent lamp. Note, however, that the use of compact fluorescent lamps is very limited in dimming applications.

The compact fluorescent lamp with an Edison screw-base offers an easy means to upgrade an incandescent luminaire. Screw-in compact fluorescents are available in two types:

- Integral Units. These consist of a compact fluorescent lamp and ballast in self-contained units. Some integral units also include a reflector and/or glass enclosure.
- Modular Units. The modular type of retrofit compact fluorescent lamp is similar to the integral units, except that the lamp is replaceable.

A **Specifier Report** that compares the performance of various name-brand compact fluorescent lamps is now available from the National Lighting Product Information Program ("Screw-Base Compact Fluorescent Lamp Products," Specifier Reports, Volume 1, Issue 6, April 1993).

High-Intensity Discharge Lamps

High-intensity discharge (HID) lamps are similar to fluorescents in that an arc is generated between two electrodes. The arc in a HID source is shorter, yet it generates much more light, heat, and pressure within the arc tube.

Originally developed for outdoor and industrial applications, HID lamps are also used in office, retail, and other indoor applications. Their color rendering characteristics have been improved and lower wattages have recently become available (as low as 18 watts.

There are several advantages to HID sources:

- relatively long life (5,000 to 24,000+ hrs)
- relatively high lumen output per watt
- relatively small in physical size

However, the following operating limitations must also be considered. First, HID lamps require time to warm up. It varies from lamp to lamp, but the average warm-up time is 2 to 6 minutes. Second, HID lamps have a "restrike" time, meaning a momentary interruption of current or a voltage drop too low to maintain the arc will extinguish the lamp. At that point, the gases inside the lamp are too hot to ionize, and time is needed for the gases to cool and pressure to drop before the arc will restrike. This process of restriking takes between 5 and 15 minutes, depending on which HID source is being used. Therefore, good applications of HID lamps are areas where lamps are not switched on and off intermittently.

The following HID sources are listed in increasing order of efficacy:

- mercury vapor
- metal halide
- high pressure sodium
- low pressure sodium

Mercury Vapor

Clear mercury vapor lamps, which produce a blue-green light, consist of a mercury-vapor arc tube with tungsten electrodes at both ends. These lamps have the lowest efficacies of the HID family, rapid lumen depreciation, and a low color rendering index. Because of these characteristics, other HID sources have replaced mercury vapor lamps in many applications. However, mercury vapor lamps are still popular sources for landscape illumination because of their 24,000 hour lamp life and vivid portrayal of green landscapes.

The arc is contained in an inner bulb called the arc tube. The arc tube is filled with high purity mercury and argon gas. The arc tube is enclosed within the outer bulb, which is filled with nitrogen.

Color-improved mercury lamps use a phosphor coating on the inner wall of the bulb to improve the color rendering index, resulting in slight reductions in efficiency.

Metal Halide

These lamps are similar to mercury vapor lamps but use metal halide additives inside the arc tube along with the mercury and argon. These additives enable the lamp to produce more visible light per watt with improved color rendition.

Wattages range from 32 to 2,000, offering a wide range of indoor and outdoor applications. The efficacy of metal halide lamps ranges from 50 to 115 lumens per watt (typically about double that of mercury vapor. In short, metal halide lamps have several advantages.

- high efficacy
- good color rendering
- wide range of wattages

However, they also have some operating limitations:

- The rated life of metal halide lamps is shorter than other HID sources; lower-wattage lamps last less than 7500 hours while high-wattage lamps last an average of 15,000 to 20,000 hours.
- The color may vary from lamp to lamp and may shift over the life of the lamp and during dimming.

Because of the good color rendition and high lumen output, these lamps are good for sports arenas and stadiums. Indoor uses include large auditoriums and convention halls. These lamps are sometimes used for general outdoor lighting, such as parking facilities, but a high pressure sodium system is typically a better choice.

High Pressure Sodium

The **high pressure sodium (HPS)** lamp is widely used for outdoor and industrial applications. Its higher efficacy makes it a better choice than metal halide for these applications, especially when good color rendering is not a priority. HPS lamps differ from mercury and metal-halide lamps in that they do not contain starting electrodes; the ballast circuit includes a high-voltage electronic starter. The arc tube is made of a ceramic material which can withstand temperatures up to 2372F. It is filled with xenon to help start the arc, as well as a sodium-mercury gas mixture.

The efficacy of the lamp is very high (as much as 140 lumens per watt. For example, a 400-watt high pressure sodium lamp produces 50,000 initial lumens. The same wattage metal halide lamp produces 40,000 initial lumens, and the 400-watt mercury vapor lamp produces only 21,000 initially.

Sodium, the major element used, produces the "golden" color that is characteristic of HPS lamps. Although HPS lamps are not generally recommended for applications where color rendering is critical, HPS color rendering properties are being improved. Some HPS lamps are now available in "deluxe" and "white" colors that provide higher color temperature and improved color rendition. The efficacy of low-wattage "white" HPS lamps is lower than that of metal halide lamps (lumens per watt of low-wattage metal halide is 75-85, while white HPS is

50-60 LPW).

Low Pressure Sodium

Although **low pressure sodium (LPS)** lamps are similar to fluorescent systems (because they are low pressure systems), they are commonly included in the HID family. LPS lamps are the most efficacious light sources, but they produce the poorest quality light of all the lamp types. Being a monochromatic light source, all colors appear black, white, or shades of gray under an LPS source. LPS lamps are available in wattages ranging from 18-180.

LPS lamp use has been generally limited to outdoor applications such as security or street lighting and indoor, low-wattage applications where color quality is not important (e.g. stairwells). However, because the color rendition is so poor, many municipalities do not allow them for roadway lighting.

Because the LPS lamps are "extended" (like fluorescent), they are less effective in directing and controlling a light beam, compared with "point sources" like high-pressure sodium and metal halide. Therefore, lower mounting heights will provide better results with LPS lamps. To compare a LPS installation with other alternatives, calculate the installation efficacy as the average maintained footcandles divided by the input watts per square foot of illuminated area. The input wattage of an LPS system increases over time to maintain consistent light output over the lamp life.

The low-pressure sodium lamp can explode if the sodium comes in contact with water. Dispose of these lamps according to the manufacturer's instructions.

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BALLASTS

All discharge lamps (fluorescent and HID) require an auxiliary piece of equipment called a ballast. Ballasts have three main functions:

- provide correct **starting voltage**, because lamps require a higher voltage to start than to operate
- **match the line voltage** to the operating voltage of the lamp
- **limit the lamp current** to prevent immediate destruction, because once the arc is struck the lamp impedance decreases

Because ballasts are an integral component of the lighting system, they have a direct impact on light output. The ballast factor is the ratio of a lamp's light output using a standard reference ballast, compared to the lamp's rated light output on a laboratory standard ballast. General purpose ballasts have a ballast factor that is less than one; special ballasts may have a ballast factor greater than one.

Fluorescent Ballasts

The two general types of fluorescent ballasts are magnetic and electronic ballasts:

Magnetic Ballasts

Magnetic ballasts (also referred to as electromagnetic ballasts) fall into one of the following categories:

- standard core-coil (no longer sold in the US for most applications)
- high-efficiency core-coil
- cathode cut-out or hybrid

Standard core-coil magnetic ballasts are essentially core-coil transformers that are relatively inefficient in operating fluorescent lamps. The high-efficiency ballast replaces the aluminum wiring and lower grade steel of the standard ballast with copper wiring and enhanced ferromagnetic materials. The result of these material upgrades is a 10 percent system efficiency improvement. However, note that these "high efficiency" ballasts are the least efficient magnetic ballasts that are available for operating full-size fluorescent lamps. More efficient ballasts are described below.

"Cathode cut-out" (or **"hybrid**") ballasts are high-efficiency core-coil ballasts that incorporate electronic components that cut off power to the lamp cathodes (filaments) after the lamps are lit, resulting in an additional 2-watt savings per standard lamp. Also, many partial-output T12 hybrid ballasts provide up to 10% less light output while consuming up to 17% less energy than energy-efficient magnetic ballasts. Full-output T8 hybrid ballasts are nearly as efficient as rapid-start two-lamp T8 electronic ballasts.

Electronic Ballasts

In nearly every full-size fluorescent lighting application, electronic ballasts can be used in place of conventional magnetic "core-and-coil" ballasts. Electronic ballasts improve fluorescent system efficacy by converting the standard 60 Hz input frequency to a higher frequency, usually 25,000 to 40,000 Hz. Lamps operating at these higher frequencies produce about the same amount of light, while **consuming 12 to 25 percent less power**. Other advantages of electronic ballasts include less audible noise, less weight, virtually no lamp flicker, and dimming capabilities (with specific ballast models).

There are three electronic ballast designs available:

Standard T12 electronic ballasts (430 mA)

These ballasts are designed for use with conventional (T12 or T10) fluorescent lighting systems. Some electronic ballasts that are designed for use with 4' lamps can operate up to four lamps at a time. Parallel wiring is another feature now available that allows all companion lamps in the ballast circuit to continue operating in the event of a lamp failure. Electronic ballasts are also available for 8' standard and high-output T12 lamps.

T8 Electronic ballasts (265 mA)

Specifically designed for use with T8 (1-inch diameter) lamps, the T8 electronic ballast provides the highest efficiency of any fluorescent lighting system. Some T8 electronic ballasts are designed to start the lamps in the conventional rapid start mode, while others are operated in the instant start mode. The use of instant start T8 electronic ballasts may result in up to 25 percent reduction in lamp life (at 3 hours per start) but produces slight increases in efficiency and light output. (Note: Lamp life ratings for instant start and rapid start are the same for 12 or more hours per start.)

Dimmable electronic ballasts

These ballasts permit the light output of the lamps to be dimmed based on input from manual dimmer controls or from devices that sense daylight or occupancy.

Types of Fluorescent Circuits

There are three main types of fluorescent circuits:

- rapid start
- instant start
- preheat

The specific fluorescent circuit in use can be identified by the label on the ballast.

The **rapid start** circuit is the most used system today. Rapid start ballasts provide continuous lamp filament heating during lamp operation (except when used with a cathode cut-out ballast or lamp). Users notice a very short delay after "flipping the switch," before the lamp is started.

The **instant start** system ignites the arc within the lamp instantly. This ballast provides a higher starting voltage, which eliminates the need for a separate starting circuit. This higher starting voltage causes more wear on the filaments, resulting in reduced lamp life compared with rapid starting.

The **preheat circuit** was used when fluorescent lamps first became available. This technology is used very little today, except for low-wattage magnetic ballast applications such as compact fluorescents. A separate starting switch, called a starter, is used to aid in forming the arc. The filament needs some time to reach proper temperature, so the lamp does not strike for a few seconds.

HID Ballasts

Like fluorescent lamps, HID lamps require a ballast to start and operate. The purposes of the ballast are similar: to provide starting voltage, to limit the current, and to match the line voltage to the arc voltage.

With HID ballasts, a major performance consideration is lamp wattage regulation when the line voltage varies. With HPS lamps, the ballast must compensate for changes in the lamp voltage as well as for changes in the line voltages.

Installing the wrong HID ballast can cause a variety of problems:

- waste energy and increase operating cost
- severely shorten lamp life
- significantly add to system maintenance costs
- produce lower-than-desired light levels
- increase wiring and circuit breaker installation costs
- result in lamp cycling when voltage dips occur

Capacitive switching is available in new HID luminaires with special HID ballasts. The most common application for HID capacitive switching is in occupancy-sensed bi-level lighting control. Upon sensing motion, the occupancy sensor will send a signal to the bi-level HID system that will rapidly bring the light levels from a standby reduced level to approximately 80% of full output, followed by the normal warm-up time between 80% and 100% of full light output. Depending on the lamp type and wattage, the standby lumens are roughly 15-40% of full output and the input watts are 30-60% of full wattage. Therefore, during periods that the space is unoccupied and the system is dimmed, savings of 40-70% are achieved.

Electronic ballasts for some types of HID lamps are starting to become commercially available. These ballasts offer the advantages of reduced size and weight, as well as better color control; however, electronic HID ballasts offer minimal efficiency gains over magnetic HID ballasts.

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LUMINAIRES

A luminaire, or light fixture, is a unit consisting of the following components:

- lamps
- lamp sockets
- ballasts
- reflective material
- lenses, refractors, or louvers
- housing

Luminaire

The main function of the luminaire is to direct light using reflective and shielding materials.

Many lighting upgrade projects consist of replacing one or more of these components to improve fixture efficiency. Alternatively, users may consider replacing the entire luminaire with one that I designed to efficiently provide the appropriate quantity and quality of illumination.

There are several different types of luminaires. The following is a listing of some of the common luminaire types:

- general illumination fixtures such as 2x4, 2x2, & 1x4 fluorescent troffers
- downlights
- indirect lighting (light reflected off the ceiling/walls)
- spot or accent lighting
- task lighting
- outdoor area and flood lighting

Luminaire Efficiency

The efficiency of a luminaire is the percentage of lamp lumens produced that actually exit the fixture. The use of louvers can improve visual comfort, but because they reduce the lumen output of the fixture, efficiency is reduced. Generally, the most efficient fixtures have the poorest visual comfort (e.g. bare strip industrial fixtures). Conversely, the fixture that provides the highest visual comfort level is the least efficient. Thus, a lighting designer must determine the best compromise between efficiency and VCP when specifying luminaires. Recently, some manufacturers have started offering fixtures with excellent VCP and efficiency. These so-called **"super fixtures**" combine state-of-the-art lens or louver designs to provide the best of both worlds.

Surface deterioration and accumulated dirt in older, poorly maintained fixtures can also cause reductions in luminaire efficiency. Refer to Lighting Maintenance for more information.

Directing Light

Each of the above luminaire types consist of a number of components that are designed to work together to produce and direct light. Because the subject of light production has been covered by the previous section, the text below focuses on the components used to direct the light produced by the lamps.

Reflectors

Reflectors are designed to redirect the light emitted from a lamp in order to achieve a desired distribution of light intensity outside of the luminaire.

In most incandescent spot and flood lights, highly specular (mirror-like) reflectors are usually built into the lamps.

One energy-efficient upgrade option is to install a custom-designed reflector to enhance the light control and efficiency of the fixture, which may allow partial delamping. Retrofit reflectors are useful for upgrading the efficiency of older, deteriorated luminaire surfaces. A variety of reflector materials are available: highly reflective white paint, silver film laminate, and two grades of anodized aluminum sheet (standard or enhanced reflectivity). Silver film laminate is generally considered to have the highest reflectance, but is considered less durable.

Proper design and installation of reflectors can have more effect on performance than the reflector materials. In combination with delamping, however, the use of reflectors may result in reduced light output and may redistribute the light, which may or may not be acceptable for a specific space or application. To ensure acceptable performance from reflectors, arrange for a trial installation and measure "before" and "after" light levels using the procedures outlined in Lighting Evaluations. For specific name-brand performance data, refer to Specifier Reports, "Specular Reflectors," Volume 1, Issue 3, National Lighting Product Information Program.

Lenses and Louvers

Most indoor commercial fluorescent fixtures use either a lens or a louver to prevent direct viewing of the lamps. Light that is emitted in the so-called "glare zone" (angles above 45 degrees from the fixture's vertical axis) can cause visual discomfort and reflections, which reduce contrast on work surfaces or computer screens. Lenses and louvers attempt to control these problems.

Lenses. Lenses made from clear ultraviolet-stabilized acrylic plastic deliver the most light output and uniformity of all shielding media. However, they provide less glare control than louvered fixtures. Clear lens types include prismatic, batwing, linear batwing, and polarized lenses. Lenses are usually much less expensive than louvers. White translucent diffusers are much less efficient than clear lenses, and they result in relatively low visual comfort probability. New low-glare lens materials are available for retrofit and provide high visual comfort (VCP>80) and high efficiency.

Louvers. Louvers provide superior glare control and high visual comfort compared with lens-diffuser systems. The most common application of louvers is to eliminate the fixture glare reflected on computer screens. So-called "deep-cell" parabolic louvers (with 5-7" cell apertures and depths of 2-4" (provide a good balance between visual comfort and luminaire efficiency. Although small-cell parabolic louvers provide the highest level of visual comfort, they reduce luminaire efficiency to about 35-45 percent. For retrofit applications, both deep-cell and small-cell louvers are available for use with existing fixtures. Note that the deep-cell louver retrofit adds 2-4" to the overall depth of a troffer; verify that sufficient plenum depth is available before specifying the deep-cell retrofit.

Distribution

One of the primary functions of a luminaire is to direct the light to where it is needed. The light distribution produced by luminaires is characterized by the Illuminating Engineering Society as follows:

- Direct (90 to 100 percent of the light is directed downward for maximum use.
- Indirect (90 to 100 percent of the light is directed to the ceilings and upper walls and is reflected to all parts of a room.
- Semi-Direct (60 to 90 percent of the light is directed downward with the remainder directed upward.
- General Diffuse or Direct-Indirect (equal portions of the light are directed upward and downward.
- Highlighting (the beam projection distance and focusing ability characterize this luminaire.

The lighting distribution that is characteristic of a given luminaire is described using the candela distribution provided by the luminaire manufacturer (see diagram on next page). The candela distribution is represented by a curve on a polar graph showing the relative luminous intensity 360 around the fixture (looking at a cross-section of the fixture. This information is useful because it shows how much light is emitted in each direction and the relative proportions of downlighting and uplighting. The cut-off angle is the angle, measured from straight down, where the fixture begins to shield the light source and no direct light from the source is visible. The **shielding angle** is the angle, measured from horizontal, through which the fixture provides shielding to prevent direct viewing of the light source. The shielding and cut-off angles add up to 90 degrees.

The lighting upgrade products mentioned in this document are described in more detail in Lighting Upgrade Technologies.

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SELECTED REFERENCES

Individual Listings

Advanced Lighting Guidelines: 1993, Electric Power Research Institute (EPRI)/California Energy Commission (CEC)/United States Department of Energy (DOE), May 1993.

EPRI, the CEC, and the DOE have collaborated to produce the 1993 update of the Advanced Lighting Guidelines (originally published in 1990 by the CEC). The Guidelines include four new chapters that address lighting controls. This series of guidelines provides comprehensive and objective information about current lighting equipment and controls.

The Guidelines address the following areas:

- lighting design practice
- computer-aided lighting design
- luminaires and lighting systems
- energy-efficient fluorescent ballasts
- full-size fluorescent lamps
- compact fluorescent lamps
- tungsten-halogen lamps
- metal halide and HPS lamps
- daylighting and lumen maintenance
- occupant sensors
- time-scheduling systems
- retrofit control technologies

Besides providing technology overviews and applications, each chapter concludes with guideline specifications to use in accurately designating lighting upgrade components. The Guidelines also tabulate representative performance data, which can be very difficult to locate in product literature.

To obtain a copy of the Advanced Lighting Guidelines (1993), contact your local utility (if your utility is a member of EPRI). Otherwise, call the CEC at (916) 654-5200.

The Association of Energy Engineers uses this text to prepare applicants to take the Certified Lighting Efficiency Professional (CLEP) examination. This 480-page book is particularly useful for learning about illuminance calculations, basic design considerations, and the operating characteristics of each light source family. It also provides application guidelines for industrial, office, retail, and outdoor lighting.

You can order this textbook from the Association of Energy Engineers by calling (404) 925-9558.

ASHRAE/IES Standard 90.1-1989, American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) and Illuminating Engineering Society (IES), 1989.

Commonly known as "Standard 90.1," ASHRAE/IES 90.1-1989 is the efficiency standard that Green Lights participants agree to follow when designing new lighting systems. Standard 90.1 is currently a national, voluntary consensus standard. However, this standard is becoming law in many states. The Energy Policy Act of 1992 requires that all states certify by October 1994 that their commercial energy code provisions meet or exceed the requirements Standard 90.1.

Green Lights participants only need to meet the lighting system portion of the standard. Standard 90.1 sets maximum wattage densities (W/SF) for lighting systems based on the type of building or expected uses within each space. The lighting portion of Standard 90.1 does not apply to the following: outdoor manufacturing or processing facilities, theatrical lighting, specialty lighting, emergency lighting, signage, retail display windows, and dwelling unit lighting. Daylighting and lighting controls receive consideration and credits, and minimum efficiency standards are specified for fluorescent lamp ballasts based on the Federal Ballast Standards.

You can purchase Standard 90.1 by contacting ASHRAE at (404) 636-8400 or IES at (212) 248-5000.

Lighting Management Handbook, Craig DiLouie, 1993.

This 300-page non-technical reference provides a clear overview of lighting management principles. It places special emphasis on the importance of effective maintenance and the benefits of a well planned and executed lighting management program. The contents are organized as follows:

- Fundamentals and Technology
- The Building Survey
- Effective Illumination (for People)
- Retrofitting Economics
- Maintenance
- Retrofitting Financing
- Green Engineering (Environmental Impacts)
- Getting Help
- Success Stories

In addition, the book's appendices include general technical information, worksheets, and product guides. To purchase this reference, call the Association of Energy Engineers at (404) 925-9558.

Illuminations: A Training Textbook for Senior Lighting Technicians, interNational Association of Lighting Management Companies (NALMCO), First Edition, 1993.

Illuminations is a 74-page course workbook for use by Apprentice Lighting Technicians (NALMCO designation) for upgrading their status to Senior Lighting Technician. The workbook consists of seven chapters, each with a quiz for self-testing. Answers are provided in the back of the book.

- Service Basics (e.g., electricity, instrumentation, disposal issues, etc.)

- Lamp Operation (e.g., lamp construction and operation (all types, color effects)

- Ballast Operation (e.g., fluorescent & HID ballast components, types, wattage, ballast factor, harmonics, starting temperature, efficacy, replacement)

- Troubleshooting (e.g., visual symptoms, possible causes, explanations and/or remedies)
- Controls (e.g., photocells, time clocks, occupancy sensors, dimmers, EMS)

- Lighting Upgrade Devices and Technologies (e.g., reflectors, compact fluorescents, ballast upgrades, correcting overlit situations, lenses and louvers, HID conversions, measuring energy effectiveness)

- Emergency Lighting (e.g., exit signs, fixture types, applications, batteries, maintenance)

Illuminations is clear and understandable. The publication's greatest strength is its extensive illustrations and photos, which help to clarify the ideas discussed. The textbook for Apprentice Lighting Technicians is also available (entitled Lighten Up (and is recommended for newcomers to the lighting field.

To order, call the NALMCO at (609) 799-5501.

Electric Power Research Institute (EPRI)

Commercial Lighting Efficiency Resource Book, EPRI, CU-7427, September 1991.

The Commercial Lighting Efficiency Resource Book provides an overview of efficient commercial lighting technologies and programs available to the end-user. Besides providing an overview of lighting conservation opportunities, this 144-page document provides valuable information about lighting education and information in the following areas:

- directory of energy and environmental groups extensive annotated lighting reference bibliographies
- directory of lighting demonstration centers
- summaries of regulations and codes related to lighting
- directory of lighting education institutions, courses, and seminars
- listings of lighting magazines and journals
- directory and descriptions of lighting research organizations
- directory of lighting professional groups and trade associations

To obtain a copy of EPRI Lighting Publications, contact your local utility (if your utility is a member of EPRI) or contact the EPRI Publications Distribution Center at (510) 934-4212.

The following lighting publications are available from EPRI. Each publication contains a thorough description of the technologies, their advantages, their applications, and case studies.

- High Intensity Discharge Lighting (10 pages), BR-101739
- Electronic Ballasts (6 pages), BR-101886
- Occupancy Sensors (6 pages), BR-100323
- Compact Fluorescent Lamps (6 pages), CU.2042R.4.93
- Specular Retrofit Reflectors (6 pages), CU.2046R.6.92
- Retrofit Lighting Technologies (10 pages), CU.3040R.7.91

In addition, EPRI offers a series of 2-page informational bulletins that cover such topics as lighting maintenance, lighting quality, VDT lighting, and lamp life.

To obtain a copy of EPRI Lighting Publications, contact your local utility (if your utility is a member of EPRI). Otherwise, contact the EPRI Publications Distribution Center at (510) 934-4212.

Lighting Fundamentals Handbook, Electric Power Research Institute, TR-101710, March 1993.

This handbook provides basic information on lighting principles, lighting equipment, and other considerations related to lighting design. It is not intended to be an up-to-date reference on current lighting products and equipment. The handbook has three major sections:

- Physics of Light (e.g., light, vision, optics, photometry)
- Lighting Equipment and Technology (e.g., lamps, luminaires, lighting controls)
- Lighting Design Decisions (e.g., illuminance targets, quality, economics, codes, power quality, photobiology and waste disposal)

To obtain a copy of EPRI Lighting Publications, contact your local utility (if your utility is a member of EPRI) or contact the EPRI Publications Distribution Center at (510) 934-4212.

Illuminating Engineering Society (IES)

ED-100 Introductory Lighting

Consisting of approximately 300 pages in a binder, this education program is an updated version of the 1985 fundamentals training materials. This set of 10 lessons is intended for those who want a thorough overview of the lighting field.

- Light and Color
- Light, Vision, and Perception
- Light Sources
- Luminaires and their Photometric Data
- Illuminance Calculations
- Lighting Applications for Visual Performance
- Lighting for Visual Impact
- Exterior Lighting
- Energy Management/Lighting Economics
- Daylighting

ED-150 Intermediate Lighting

This course is the "next step" for those who have already completed the ED-100 fundamentals program or who wish to increase their knowledge gained through practical experience. The IES Technical Knowledge Examination is based on the ED-150 level of knowledge. A 2-inch binder contains thirteen lessons.

- Vision
- Color
- Light Sources & Ballasts
- Optical Control
- Illuminance Calculations
- Psychological Aspects of Lighting
- Design Concepts
- Computers in Lighting Design and Analysis
- Lighting Economics
- Daylighting Calculations
- Electrical Quantities/Distribution
- Electrical Controls
- Lighting Mathematics

IES Lighting Handbook, 8th Edition, IES of North America, 1993.

This 1000-page technical reference is a combination of two earlier volumes that separately addressed reference information and applications. Considered the "bible" of illumination engineering, the Handbook provides broad coverage of all phases of lighting disciplines. The 34 chapters are organized into five general areas.

- Science of Lighting (e.g., optics, measurement, vision, color, photobiology)
- Lighting Engineering (e.g., sources, luminaires, daylighting, calculations)
- Elements of Design (e.g., process, illuminance selection, economics, codes & standards)
- Lighting Applications, which discusses 15 unique case studies
- Special Topics (e.g., energy management, controls, maintenance, environmental issues)

In addition, the Handbook contains an extensive GLOSSARY and index, as well as many illustrations, graphs, charts, equations, photographs and references.

The Handbook is an essential reference for the practicing lighting engineer. You can purchase the manual from the publications office of IES at (212) 248-5000. IES members receive a price discount on the Handbook.

IES Lighting Ready Reference, IES, 1989.

This book is a compendium of lighting information, including the following: terminology, conversion factors, light source tables, illuminance recommendations, calculation data, energy management considerations, cost analysis methods, and lighting survey procedures. The Ready Reference includes the most often used material from the IES Lighting Handbook.

You can purchase the 168-page reference from the publications office of IES at (212) 248-5000. IES members receive the Ready Reference upon joining the society.

VDT Lighting: IES Recommended Practice for Lighting Offices Containing Computer Visual Display Terminals. IES of North America, 1990. IES RP-24-1989.

This lighting practice handbook provides recommendations for lighting offices where computer VDTs are used. It also offers guidelines regarding light requirements for visual comfort and good visibility, with an analysis of the impact of general lighting on VDT visual tasks.

To purchase a copy of RP-24, contact the IES at (212) 248-5000.

National Lighting Bureau (NLB)

The NLB is an information service established by the National Electrical Manufacturers Association (NEMA). Its purpose is to create more awareness and appreciation of the benefits of good lighting. NLB promotes all aspects of lighting energy management, ranging from productivity to lumen output. Each year the NLB publishes articles in various periodicals and guidebooks written for the lay person. These articles discuss specific lighting systems design, operation, maintenance techniques, and system components.

The following publications are basic references that provide an overview of the subject and include lighting applications.

- Office Lighting and Productivity
- Profiting from Lighting Modernization
- Getting the Most from Your Lighting Dollar
- Solving the Puzzle of VDT Viewing Problems
- NLB Guide to Industrial Lighting
- NLB Guide to Retail Lighting Management
- NLB Guide to Energy Efficient Lighting Systems
- Lighting for Safety and Security
- Performing a Lighting System Audit
- Lighting and Human Performance

To request a catalog or to order publications, call NLB at (202) 457-8437.

NEMA Guide to Lighting Controls, National Electrical Manufacturers Association, 1992.

This guide provides an overview of the following lighting control strategies: on/off, occupancy recognition, scheduling, tuning, daylight harvesting, lumen depreciation compensation, and demand control. In addition, it discusses hardware options and applications for each control strategy.

To order, call NLB at (202) 457-8437.

National Lighting Product Information Program (NLPIP)

This program publishes objective information about lighting upgrade products, and is co-sponsored by four organizations: EPA's Green Lights, the Lighting Research Center, the New York State Energy Research and Development Authority, and Northern States Power Company. Two types of publications are available (Specifier Reports and Lighting Answers.

To purchase these publications, fax your request to the Lighting Research Center, Rensselaer Polytechnic Institute at (518) 276-2999 (fax).

Specifier Reports

Each Specifier Report examines a particular lighting upgrade technology. Specifier Reports provide background information about the technology and independent performance test results of name-brand lighting upgrade products. NineSpecifier Reports have been published as of July 1994.

- Electronic Ballasts, December 1991
- Power Reducers, March 1992
- Specular Reflectors, July 1992
- Occupancy Sensors, October 1992
- Parking Lot Luminaires, January 1993
- Screwbase Compact Fluorescent Lamp Products, April 1993
- Cathode-Disconnect Ballasts, June 1993
- Exit Sign Technologies, January 1994
- Electronic Ballasts, May 1994

The Specifier Reports to be published in 1994 will address five topics: exit signs, electronic ballasts, daylighting controls, compact fluorescent lamp luminaires, and replacements for incandescent reflector lamps. HID systems for retail display lighting will also be researched in 1994.

Lighting Answers

Lighting Answers provide informative text about the performance characteristics of specific lighting technologies but do not include comparative performance test results. Lighting Answers published in 1993 addressed T8 fluorescent systems and polarizing panels for fluorescent luminaires. Additional Lighting Answers planned for publication in 1994 will cover task lighting and HID dimming. Other topics under consideration are electronic ballast electromagnetic interference (EMI) and 2'x4' lighting systems.

Periodicals

Energy User News, Chilton Publications, Published Monthly.

This monthly publication addresses many aspects of the energy industry. Each edition contains a section devoted to lighting, usually featuring a case study and at least one article discussing a lighting product or issue. Some Energy User News issues feature product guides, which are technology-specific tables that list the participating manufacturers (with phone numbers) and the attributes of their products. The September 1993 edition featured lighting as the centerpiece, and contained the following information.

- several lighting articles and product announcements
- special report about lighting retrofit planning and power quality
- technology report on tungsten-halogen lamps
- commentary on successful occupancy sensor retrofits
- product guides for CFLs, halogens, HIDs, reflectors, electronic ballasts

To order back issues, call (215) 964-4028.

Lighting Management & Maintenance, NALMCO, Published Monthly.

This monthly publication addresses issues and technologies directly related to upgrading and maintaining commercial and industrial lighting systems. The following are some topics addressed in Lighting Management and Maintenance: the lighting industry, legislation, new products and applications, waste disposal, surveying, and the lighting management business.

To order a subscription, call NALMCO at (609) 799-5501.

Other EPA Green Lights Publications

Besides the Lighting Upgrade Manual, EPA publishes other documents, which are available free of charge from the Green Lights Customer Service Center. Additionally, EPA's new faxline system enables users to request and receive Green Lights marketing and technical information within minutes by calling (202) 233-9659.

Green Lights Update

This monthly newsletter is the primary vehicle for informing Green Lights participants (and other interested parties) about the latest program enhancements. Each month's newsletter addresses lighting technologies, applications, case studies, and special events. Every issue contains the latest schedule for Lighting Upgrade Workshops and a copy of the reporting form used by participants to report completed projects for EPA.

To receive a free subscription to the Update, contact Green Lights Customer Service at (202) 775-6650 or fax (202) 775-6680.

Power Pages

Power Pages are short publications that address lighting technologies, applications, and specific questions or issues about the Green Lights program. Look for announcements of Power Pages in the Update newsletter.

These documents are available through the Green Lights faxline. **To request fax delivery, call the faxline at (202) 233-9659. Periodically contact the faxline to retrieve the latest information from Green Lights. If you do not have a fax machine, contact Green Lights Customer Service at (202) 775-6650.**

Light Briefs

EPA publishes 2-page Light Briefs on various implementation issues. These publications are intended to provide an introduction to technical and financial issues affecting upgrade decisions. Four Light Briefs focus on technologies: occupancy sensors, electronic ballasts, specular reflectors, and efficient fluorescent lamps. Other releases cover rolling financing strategies, financing options, measuring lighting upgrade profitability, and waste disposal. Current copies have been mailed to all Green Lights participants.

For additional information, please contact Green Lights Customer Service at (202) 775-6650 or fax (202) 775-6680.

Green Lights Brochure

EPA has produced a four-color brochure for marketing the Green Lights program. It outlines the program's goals and commitments, while describing what some of the participants are doing. This document is an essential tool for any Green Lights marketing presentation.

To order copies of the brochure, please contact Green Lights Customer Service at (202) 775-6650 or fax (202) 775-6680

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GLOSSARY

A,B,C,D,E,F,G,H,I,L,M,N,O,P,Q,R,S,T,U,V,W,Z

AMPERE: The standard unit of measurement for electric current that is equal to one coulomb per second. It defines the quantity of electrons moving past a given point in a circuit during a specific period. Amp is an abbreviation.

ANSI: Abbreviation for American National Standards Institute.

ARC TUBE: A tube enclosed by the outer glass envelope of a HID lamp and made of clear quartz or ceramic that contains the arc stream.

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BAFFLE: A single opaque or translucent element used to control light distribution at certain angles.

BALLAST: A device used to operate fluorescent and HID lamps. The ballast provides the necessary starting voltage, while limiting and regulating the lamp current during operation.

BALLAST CYCLING: Undesirable condition under which the ballast turns lamps on and off (cycles) due to the overheating of the thermal switch inside the ballast. This may be due to incorrect lamps, improper voltage being supplied, high ambient temperature around the fixture, or the early stage of ballast failure.

BALLAST EFFICIENCY FACTOR: The ballast efficiency factor (BEF) is the ballast factor (see below) divided by the input power of the ballast. The higher the BEF (within the same lamp-ballast type (the more efficient the ballast.

BALLAST FACTOR: The ballast factor (BF) for a specific lamp-ballast combination represents the percentage of the rated lamp lumens that will be produced by the combination.

CANDELA: Unit of luminous intensity, describing the intensity of a light source in a specific direction.

CANDELA DISTRIBUTION: A curve, often on polar coordinates, illustrating the variation of luminous intensity of a lamp or luminaire in a plane through the light center.

CANDLEPOWER: A measure of luminous intensity of a light source in a specific direction, measured in candelas (see above).

CBM: Abbreviation for Certified Ballast Manufacturers Association.

CEC: Abbreviation for California Energy Commission.

COEFFICIENT OF UTILIZATION: The ratio of lumens from a luminaire received on the work plane to the lumens produced by the lamps alone. (Also called "CU")

COLOR RENDERING INDEX (CRI): A scale of the effect of a light source on the color appearance of an object compared to its color appearance under a reference light source. Expressed on a scale of 1 to 100, where 100 indicates no color shift. A low CRI rating suggests that the colors of objects will appear unnatural under that particular light source.

COLOR TEMPERATURE: The color temperature is a specification of the color appearance of a light source, relating the color to a reference source heated to a particular temperature, measured by the thermal unit Kelvin. The measurement can also be described as the "warmth" or "coolness" of a light source. Generally, sources below 3200K are considered "warm;" while those above 4000K are considered "cool" sources.

COMPACT FLUORESCENT: A small fluorescent lamp that is often used as an alternative to incandescent lighting. The lamp life is about 10 times longer than incandescent lamps and is 3-4 times more efficacious. Also called PL, Twin-Tube, CFL, or BIAX lamps.

CONSTANT WATTAGE (CW) BALLAST: A premium type of HID ballast in which the primary and secondary coils are isolated. It is considered a high performance, high loss ballast featuring excellent output regulation.

CONSTANT WATTAGE AUTOTRANSFORMER (CWA) BALLAST: A popular type of HID ballast in which the primary and secondary coils are electrically connected. Considered an appropriate balance between cost and performance.

CONTRAST: The relationship between the luminance of an object and its background.

CRI: (SEE COLOR RENDERING INDEX)

CUT-OFF ANGLE: The angle from a fixture's vertical axis at which a reflector, louver, or other shielding device cuts off direct visibility of a lamp. It is the complementary angle of the shielding angle.

DAYLIGHT COMPENSATION: A dimming system controlled by a photocell that reduces the output of the lamps when daylight is present. As daylight levels increase, lamp intensity decreases. An energy-saving technique used in areas with significant daylight contribution.

DIFFUSE: Term describing dispersed light distribution. Refers to the scattering or softening of light.

DIFFUSER: A translucent piece of glass or plastic sheet that shields the light source in a fixture. The light transmitted throughout the diffuser will be redirected and scattered.

DIRECT GLARE: Glare produced by a direct view of light sources. Often the result of insufficiently shielded light sources. (See GLARE)

DOWNLIGHT: A type of ceiling luminaire, usually fully recessed, where most of the light is directed downward. May feature an open reflector and/or shielding device.

EFFICACY: A metric used to compare light output to energy consumption. Efficacy is measured in lumens per watt. Efficacy is similar to efficiency, but is expressed in dissimilar units. For example, if a 100-watt source produces 9000 lumens, then the efficacy is 90 lumens per watt.

ELECTROLUMINESCENT: A light source technology used in exit signs that provides uniform brightness, long lamp life (approximately eight years), while consuming very little energy (less than one watt per lamp).

ELECTRONIC BALLAST: A ballast that uses semi-conductor components to increase the frequency of fluorescent lamp operation (typically in the 20-40 kHz range. Smaller inductive components provide the lamp current control. Fluorescent system efficiency is increased due to high frequency lamp operation.

ELECTRONIC DIMMING BALLAST: A variable output electronic fluorescent ballast.

EMI: Abbreviation for electromagnetic interference. High frequency interference (electrical noise) caused by electronic components or fluorescent lamps that interferes with the operation of electrical equipment. EMI is measured in micro-volts, and can be controlled by filters. Because EMI can interfere with communication devices, the Federal Communication Commission (FCC) has established limits for EMI.

ENERGY-SAVING BALLAST: A type of magnetic ballast designed so that the components operate more efficiently, cooler and longer than a "standard magnetic" ballast. By US law, standard magnetic ballasts can no longer be manufactured.

ENERGY-SAVING LAMP: A lower wattage lamp, generally producing fewer lumens.

FC: (SEE FOOTCANDLE)

FLUORESCENT LAMP: A light source consisting of a tube filled with argon, along with krypton or other inert gas. When electrical current is applied, the resulting arc emits ultraviolet radiation that excites the phosphors inside the lamp wall, causing them to radiate visible light.

FOOTCANDLE (FC): The English unit of measurement of the illuminance (or light level) on a surface. One footcandle is equal to one lumen per square foot.

FOOTLAMBERT: English unit of luminance. One footlambert is equal to 1/p candelas per square foot.

GLARE: The effect of brightness or differences in brightness within the visual field sufficiently high to cause annoyance, discomfort or loss of visual performance.

HALOGEN: (SEE TUNGSTEN HALOGEN LAMP)

HARMONIC DISTORTION: A harmonic is a sinusoidal component of a periodic wave having a frequency that is a multiple of the fundamental frequency. Harmonic distortion from lighting equipment can interfere with other appliances and the operation of electric power networks. The total harmonic distortion (THD) is usually expressed as a percentage of the fundamental line current. THD for 4-foot fluorescent ballasts usually range from 20% to 40%. For compact fluorescent ballasts, THD levels greater than 50% are not uncommon.

HID: Abbreviation for high intensity discharge. Generic term describing mercury vapor, metal halide, high pressure sodium, and (informally) low pressure sodium light sources and luminaires.

HIGH-BAY: Pertains to the type of lighting in an industrial application where the ceiling is 20 feet or higher. Also describes the application itself.

HIGH OUTPUT (HO): A lamp or ballast designed to operate at higher currents (800 mA) and produce more light.

HIGH POWER FACTOR: A ballast with a 0.9 or higher rated power factor, which is achieved by using a capacitor.

HIGH PRESSURE SODIUM LAMP: A high intensity discharge (HID) lamp whose light is produced by radiation from sodium vapor (and mercury).

HOT RESTART or HOT RESTRIKE: The phenomenon of re-striking the arc in an HID light source after a momentary power loss. Hot restart occurs when the arc tube has cooled a sufficient amount.

IESNA: Abbreviation for Illuminating Engineering Society of North America.

ILLUMINANCE: A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly called light level. It is expressed as lumens per square foot (footcandles), or lumens per square meter (lux).

INDIRECT GLARE: Glare produced from a reflective surface.

INSTANT START: A fluorescent circuit that ignites the lamp instantly with a very high starting voltage from the ballast. Instant start lamps have single-pin bases.

LAMP CURRENT CREST FACTOR (LCCF): The peak lamp current divided by the RMS (average) lamp current. Lamp manufacturers require <1.7 for best lamp life. An LCCF of 1.414 is a perfect sine wave.

LAMP LUMEN DEPRECIATION FACTOR (LLD): A factor that represents the reduction of lumen output over time. The factor is commonly used as a multiplier to the initial lumen rating in illuminance calculations, which compensates for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.

LAY-IN-TROFFER: A fluorescent fixture; usually a 2' x 4' fixture that sets or "lays" into a specific ceiling grid.

LED: Abbreviation for light emitting diode. An illumination technology used for exit signs. Consumes low wattage and has a rated life of greater than 80 years.

LENS: Transparent or translucent medium that alters the directional characteristics of light passing through it. Usually made of glass or acrylic.

LIGHT LOSS FACTOR (LLF): Factors that allow for a lighting system's operation at less than initial conditions. These factors are used to calculate maintained light levels. LLFs are divided into two categories, recoverable and non-recoverable. Examples are lamp lumen depreciation and luminaire surface depreciation.

LIFE-CYCLE COST: The total costs associated with purchasing, operating, and maintaining a system over the life of that system.

LOUVER: Grid type of optical assembly used to control light distribution from a fixture. Can range from small-cell plastic to the large-cell anodized aluminum louvers used in parabolic fluorescent fixtures.

LOW POWER FACTOR: Essentially, an uncorrected ballast power factor of less than 0.9 (SEE NPF)

LOW-PRESSURE SODIUM: A low-pressure discharge lamp in which light is produced by radiation from sodium vapor. Considered a monochromatic light source (most colors are rendered as gray).

LOW-VOLTAGE LAMP: A lamp (typically compact halogen (that provides both intensity and good color rendition. Lamp operates at 12V and requires the use of a transformer. Popular lamps are MR11, MR16, and PAR36.

LOW-VOLTAGE SWITCH: A relay (magnetically-operated switch) that allows local and remote control of lights, including centralized time clock or computer control.

LUMEN: A unit of light flow, or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp.

LUMINAIRE: A complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source. Also called a fixture.

LUMINAIRE EFFICIENCY: The ratio of total lumen output of a luminaire and the lumen output of the lamps, expressed as a percentage. For example, if two luminaires use the same lamps, more light will be emitted from the fixture with the higher efficiency.

LUMINANCE: A photometric term that quantifies brightness of a light source or of an illuminated surface that reflects light. It is expressed as footlamberts (English units) or candelas per square meter (Metric units).

LUX (LX): The metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter. One lux equals 0.093 footcandles.

MAINTAINED ILLUMINANCE: Refers to light levels of a space at other than initial or rated conditions. This terms considers light loss factors such as lamp lumen depreciation, luminaire dirt depreciation, and room surface dirt depreciation.

MERCURY VAPOR LAMP: A type of high intensity discharge (HID) lamp in which most of the light is produced by radiation from mercury vapor. Emits a blue-green cast of light. Available in clear and phosphor-coated lamps.

METAL HALIDE: A type of high intensity discharge (HID) lamp in which most of the light is produced by radiation of metal halide and mercury vapors in the arc tube. Available in clear and phosphor-coated lamps.

MR-16: A low-voltage quartz reflector lamp, only 2" in diameter. Typically the lamp and reflector are one unit, which directs a sharp, precise beam of light.

NADIR: A reference direction directly below a luminaire, or "straight down" (0 degree angle).

NEMA: Abbreviation for National Electrical Manufacturers Association.

NIST: Abbreviation for National Institute of Standards and Technology.

NPF (NORMAL POWER FACTOR): A ballast/lamp combination in which no components (e.g., capacitors) have been added to correct the power factor, making it normal (essentially low, typically 0.5 or 50%).

OCCUPANCY SENSOR: Control device that turns lights off after the space becomes unoccupied. May be ultrasonic, infrared or other type.

OPTICS: A term referring to the components of a light fixture (such as reflectors, refractors, lenses, louvers) or to the light emitting or light-controlling performance of a fixture.

PAR LAMP: A parabolic aluminized reflector lamp. An incandescent, metal halide, or compact fluorescent lamp used to redirect light from the source using a parabolic reflector. Lamps are available with flood or spot distributions.

PAR 36: A PAR lamp that is 36 one-eighths of an inch in diameter with a parabolic shaped reflector (SEE PAR LAMP).

PARABOLIC LUMINAIRE: A popular type of fluorescent fixture that has a louver composed of aluminum baffles curved in a parabolic shape. The resultant light distribution produced by this shape provides reduced glare, better light control, and is considered to have greater aesthetic appeal.

PARACUBE: A metallic coated plastic louver made up of small squares. Often used to replace the lens in an installed troffer to enhance its appearance. The paracube is visually comfortable, but the luminaire efficiency is lowered. Also used in rooms with computer screens because of their glare-reducing qualities.

PHOTOCELL: A light sensing device used to control luminaires and dimmers in response to detected light levels.

PHOTOMETRIC REPORT: A photometric report is a set of printed data describing the light distribution, efficiency, and zonal lumen output of a luminaire. This report is generated from laboratory testing.

POWER FACTOR: The ratio of AC volts x amps through a device to AC wattage of the device. A device such as a ballast that measures 120 volts, 1 amp, and 60 watts has a power factor of 50% (volts x amps = 120 VA, therefore 60 watts/120 VA = 0.5). Some utilities charge customers for low power factor systems.

PREHEAT: A type of ballast/lamp circuit that uses a separate starter to heat up a fluorescent lamp before high voltage is applied to start the lamp.

QUAD-TUBE LAMP: A compact fluorescent lamp with a double twin tube configuration.

RADIO FREQUENCY INTERFERENCE (RFI): Interference to the radio frequency band caused by other high frequency equipment or devices in the immediate area. Fluorescent lighting systems generate RFI.

RAPID START (RS): The most popular fluorescent lamp/ballast combination used today. This ballast quickly and efficiently preheats lamp cathodes to start the lamp. Uses a "bi-pin" base.

ROOM CAVITY RATIO (RCR): A ratio of room dimensions used to quantify how light will interact with room surfaces. A factor used in illuminance calculations.

REFLECTANCE: The ratio of light reflected from a surface to the light incident on the surface. Reflectances are often used for lighting calculations. The reflectance of a dark carpet is around 20%, and a clean white wall is roughly 50% to 60%.

REFLECTOR: The part of a light fixture that shrouds the lamps and redirects some light emitted from the lamp.

REFRACTOR: A device used to redirect the light output from a source, primarily by bending the waves of light.

RECESSED: The term used to describe the doorframe of a troffer where the lens or louver lies above the surface of the ceiling.

REGULATION: The ability of a ballast to hold constant (or nearly constant) the output watts (light output) during fluctuations in the voltage feeding of the ballast. Normally specified as +/- percent change in output compared to +/- percent change in input.

RELAY: A device that switches an electrical load on or off based on small changes in current or voltage. Examples: low voltage relay and solid state relay.

RETROFIT: Refers to upgrading a fixture, room, or building by installing new parts or equipment.

SELF-LUMINOUS EXIT SIGN: An illumination technology using phosphor-coated glass tubes filled with radioactive tritium gas. The exit sign uses no electricity and thus does not need to be hardwired.

SEMI-SPECULAR: Term describing the light reflection characteristics of a material. Some light is reflected directionally, with some amount of scatter.

SHIELDING ANGLE: The angle measured from the ceiling plane to the line of sight where the bare lamp in a luminaire becomes visible. Higher shielding angles reduce direct glare. It is the complementary angle of the cutoff angle. (See CUTOFF ANGLE).

SPACING CRITERION: A maximum distance that interior fixtures may be spaced that ensures uniform illumination on the work plane. The luminaire height above the work plane multiplied by the spacing criterion equals the center-to-center luminaire spacing.

SPECULAR: Mirrored or polished surface. The angle of reflection is equal to the angle of incidence. This word describes the finish of the material used in some louvers and reflectors.

STARTER: A device used with a ballast to start preheat fluorescent lamps.

STROBOSCOPIC EFFECT: Condition where rotating machinery or other rapidly moving objects appear to be standing still due to the alternating current supplied to light sources. Sometimes called "strobe effect."

T12 LAMP: Industry standard for a fluorescent lamp that is 12 one-eighths (1 inches) in diameter. Other sizes are T10 (1 inches) and T8 (1 inch) lamps.

TANDEM WIRING: A wiring option in which a ballasts is shared by two or more luminaires. This reduces labor, materials, and energy costs. Also called "master-slave" wiring.

THERMAL FACTOR: A factor used in lighting calculations that compensates for the change in light output of a fluorescent lamp due to a change in bulb wall temperature. It is applied when the lamp-ballast combination under consideration is different from that used in the photometric tests.

TRIGGER START: Type of ballast commonly used with 15-watt and 20-watt straight fluorescent lamps.

TROFFER: The term used to refer to a recessed fluorescent light fixture (combination of trough and coffer).

TUNGSTEN HALOGEN LAMP: A gas-filled tungsten filament incandescent lamp with a lamp envelope made of quartz to withstand the high temperature. This lamp contains some halogens (namely iodine, chlorine, bromine, and fluorine), which slow the evaporation of the tungsten. Also, commonly called a quartz lamp.

TWIN-TUBE: (SEE COMPACT FLUORESCENT LAMP)

ULTRA VIOLET (UV): Invisible radiation that is shorter in wavelength and higher in frequency than visible violet light (literally beyond the violet light).

UNDERWRITERS' LABORATORIES (UL): An independent organization whose responsibilities include rigorous testing of electrical products. When products pass these tests, they can be labeled (and advertised) as "UL listed." UL tests for product safety only.

VANDAL-RESISTANT: Fixtures with rugged housings, break-resistant type shielding, and tamper-proof screws.

VCP: Abbreviation for visual comfort probability. A rating system for evaluating direct discomfort glare. This method is a subjective evaluation of visual comfort expressed as the percent of occupants of a space who will be bothered by direct glare. VCP allows for several factors: luminaire luminances at different angles of view, luminaire size, room size, luminaire mounting height, illuminance, and room surface reflectivity. VCP tables are often provided as part of photometric reports.

VERY HIGH OUTPUT (VHO): A fluorescent lamp that operates at a "very high" current (1500 mA), producing more light output than a "high output" lamp (800 mA) or standard output lamp (430 mA).

VOLT: The standard unit of measurement for electrical potential. It defines the "force" or "pressure" of electricity.

VOLTAGE: The difference in electrical potential between two points of an electrical circuit.

WALLWASHER: Describes luminaires that illuminate vertical surfaces.

WATT (W): The unit for measuring electrical power. It defines the rate of energy consumption by an electrical device when it is in operation. The energy cost of operating an electrical device is calculated as its wattage times the hours of use. In single phase circuits, it is related to volts and amps by the formula: Volts x Amps x PF = Watts. (Note: For AC circuits, PF must be included.)

WORK PLANE: The level at which work is done and at which illuminance is specified and measured. For office applications, this is typically a horizontal plane 30 inches above the floor (desk height).

ZENITH: The direction directly above the luminaire (180(angle).

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