FUNDAMENTALS OF
ENERGY EFFICIENT LIGHTING

WHAT IS LIGHT?

We are all well aware of the relationship that exists between our ability to see and light. Without adequate light we cannot distinguish shapes, forms, size or colors. With too much light we experience glare and other problems that impact our ability to see. Therefore, we need adequate but not excessive light for proper vision. But what exactly is light?

Light is actually a form of radiant energy, much like radiant heat and ultraviolet, but somewhat different. Light is actually defined as that part of the electromagnetic spectrum that is capable of exciting the retina and producing a visual sensation. However, it is only a very narrow portion of the actual radiation energy spectrum.

Like other forms of radiant energy, light has the characteristic that it can be transmitted through a vacuum. This is how we receive light from the sun. The speed of light through a vacuum is constant at approximately 186,000 miles per second (slightly less in air). It is therefore understandable that we cannot see light waves. What we see is the reflection or emission of light from a surface.

COLOR AND LIGHT

Color is a term that describes the different wavelength combinations of the visible energy spectrum. Wave length range has a distinct band of color associated with it. Other colored pigments are achieved by additive or subtractive means. Light that contains a relatively balanced combination of the three additive primary colors (red, green and blue) is said to be "white" light. Yellow, cyan and magenta are the subtractive primary colors. Combined they produce black.

When light strikes art object only two things can happen. It can be reflected or it can be absorbed. Colored surfacers will tend to absorb all colors except for their own which will be reflected. A black surface will absorb all colors, while a pure white surface will reflect all colors of light.

COLOR TEMPERATURE

Color Temperature is a term used to describe the color of a light source, as it compares to that of a theoretical "blackbody". A perfect blackbody is capable of absorbing all of the energy that strikes it and then completely re-radiating the energy. In a blackbody color changes as its temperature rises, from dull red through blue. A standard incandescent lamp exhibits characteristics similar to that of a blackbody, in the visible energy spectrum.

To understand the meaning of color temperatures for various lamps, one must remember that the lower temperature lamps (i.e., 2,700 — 3,000 K) have significant red components. These will generally create a feeling of warmth. Reds, browns and earth tones show up well in this type of light. As lamp temperatures increase, the lamps will generally contain more blue color. This will create a cooler atmosphere. Blues and greens typically show up well under these higher temperature lamps. For reference purposes, several approximate color temperatures and associated sources are noted.

Candle flame	1,800 K
Incandescent	2,500 K
Fluorescent	
Warm White	3,000 K
White	3,500K
Cool White	4,100 K
High Intensity Discharge	
Mercury Vapor	5,800 K
Metal Halide	4,500 K
High Pressure Sodium	2,100 K

COLOR RENDERING INDEX

While color temperature gives an idea of the color appearance of a light source, it does not provide insight into its color rendering capabilities. To do this the Color Rendering Index (CR!) is used. Using a scale ranging from 0— 100, the CR1 is a measure of how accurately a light source can replicate the "natural color" of an object, as compared to a standard reference source of the same color temperature. Generally speaking, the higher the CR1, the better the color rendering capabilities of the lamp. Typical ranges for CR1 in fluorescent lamps would be 60- 90.

LIGHT MEASUREMENT.

To determine how much illumination a lighting system provides on a work surface, portable photometers or "light meters" are normally used. These pocket-size meters may be analog or digital in design and are manufactured by companies such as General Electric Company (analog), Osram Sylvania (digital), Minolta (digital) and others.

It should be noted that light meters are not precision instruments. Their overall accuracy can vary in the range of 3 percent to 15 percent, depending on frequency of calibration and care taken with the instrument. Some units cannot be calibrated without being returned to the factory. Normal accuracy for a light meter is about 5 percent, which is satisfactory for most applications.

HOW MUCH LIGHT IS ENOUGH?

In evaluating a lighting system the question arises, how much light is really needed for a particular space. With energy costs being a prime consideration, we want to provide sufficient light without over lighting and increasing our operating costs. So, exactly how much light is enough? Before we can answer that question we have to determine a number of factors that have a direct influence on the appropriate lighting level of a space.

- *What is the task?*

  The first, and most obvious, is what task (or tasks) is to be performed? If the task is general office work then one lighting level may be appropriate. However, if graphic design work is to be done, then another higher lighting level would be required. The Illuminating Engineering Society (IES) has established illuminance categories and illuminance values for generic types of activities. However, these only establish a range of appropriate values. Areas and activities have been further broken down to assist in selecting the appropriate range. Where, within these ranges, the appropriate lighting level falls depends on other factors.

- *How much time is spent at each task?*

  The amount of time that a worker spends at a task is an important factor in determining an appropriate lighting level. Visual comfort is directly impacted by the length of time a worker spends at a task. Lower lighting levels can be tolerated for short periods of time. Whereas, if the task were to be performed continuously, a higher lighting level might be appropriate.

- *Speed and accuracy*

  If a task requires speed and a high degree of accuracy, then lighting levels on the upper end of the recommended range should be used. Such tasks might include inspection of items on a conveyor system or the processing of accounts receivable. Higher lighting levels often make identification of imperfections or mistakes in payments easier to locate.

- *Age of the worker*

  As we age our eyes require increased levels of light. A lighting level that may be perfectly fine for someone twenty-five years of age may be totally inadequate for someone fifty years old, performing the same task. Therefore, the age of the workers in a space should be taken into consideration when making recommendations.

- *Safety and security*

  This is an obvious, but important, consideration. We always want to insure that proper lighting levels for safety and security are obtained. Safe and secure, however, does not mean low lighting levels. In the operation of machinery, lighting levels in excess of 100 fc may be required to insure that the operator of the equipment has proper vision. In most situations the IES recommended ranges provide sufficient lighting to meet this criteria.

- *Aesthetics*

  A company may want to create a certain atmosphere, impression or image with their lighting system. This can be effectively done, but may vary significantly from any recommended standards for a space.

- *Lighting operating costs*

  In surveying facilities you may note lighting levels in certain spaces or locations may be lower than the recommended IES ranges. The customers may choose to do nothing, if the employees are not complaining. “If it ain’t broke, don’t fix it”. Also, as an effort to reduce operating expenses, a customer may request lighting levels lower than the recommended ranges be used. While neither of these strategies are recommended, they do occur.

VISUAL COMFORT

Having enough light is important, but it is not all that there is to providing a good lighting system. Visual comfort is another important quality. Visual comfort is the term used to describe the environment’s freedom from visual problems, primarily glare. Glare can be one of the most harmful problems resulting from improperly controlled light or lighting systems. Frequently referred to as “stray light”, glare is the effect of brightness, or combination of brightness relationships, that create visual discomfort or disability (the inability to see properly). Discomfort glare produces visual discomfort and eye fatigue, over a period of time. But it does not necessarily interfere with visual performance. An example would be the sensation created by the bright headlights of an oncoming car at night. Disability glare is glare that interferes with visual performance. The glare from a glossy magazine page that makes the print unreadable would be an example of disability glare.

Glare is typically classified into two major categories: direct and reflected. DIRECT GLARE is caused by light that enters the eye directly from a bright light source, even though the person is not looking directly at the source. This type of glare can result from exposed incandescent or HID lamps or poorly designed or located fixtures. REFLECTED GLARE is the result of the reflection of light from a glossy or polished surface. It can cause visual discomfort and impair visual performance. Reflected glare, however, is not always a problem. Sometimes it is desirable. Reflected glare can be used to an advantage for quality control inspections and to make some merchandise stand out in retail displays.

VEILING REFLECTION is a term given to a form of reflected glare that applies primarily to reading tasks. A veiling reflection is the reflection of a large luminous area on a surface, such as a glossy magazine or book page. Repositioning the page typically lessens the problem. Veiling reflection is usually caused by locating a fixture (usually fluorescent) directly above or slightly in front of a work station. Corrective measures include repositioning of the fixtures or task and special polarized lenses.

For years the problems with glare were considered a lighting control problem and were addressed initially by the lighting designer. The advent of personal computers and CRTs in the work place have brought the problem of visual comfort to the forefront. Office lighting systems that were designed more than five years ago probably did not take into consideration the probability of each desk having a computer terminal. Therefore, a perfectly adequate lighting system from five years ago may now be deemed unacceptable, because of glare on the computer screens. Techniques, such as specialized lenses, are available to resolve these glare problems.

VISUAL COMFORT PROBABILITY (VCP) is a method used to predict a lighting system's potential for direct glare problems. VCP is an estimate of the percentage of people that would consider a given lighting arrangement visually comfortable. A VCP of 70 percent is considered acceptable by IES Standards. Tables are used to determine Visual Comfort Probability.

LIGHTING SOURCES — THEIR ADVANTAGES AND DISADVANTAGES

DO NOT RECOMMEND:

- Energy efficient fluorescent lamps for unheated areas
- Low pressure sodium lamps for area/street lighting
- Standard high pressure sodium (HPS) lamps for merchandising areas
- HID lamps as the only source of lighting in a facility.

WHY?

- Energy efficient fluorescent lamps have starting and flickering problems at low temperatures.

- While very efficient, low pressure sodium lamps are monochromatic and do not reproduce colors well.

- Standard HPS lamps do not produce acceptable color for merchandising areas.

- If a power interruption occurs, HID sources can require four to ten minutes to re-strike.

Because of these and other similar potential problems, it is essential that lighting designers and consultants know the advantages and disadvantages of each of the major lighting sources. Only by understanding the basics of lamp characteristics and applications can the designer assure that the system will perform as desired.

While the lighting industry produces 14,000 different types of lamps, they can all be classified into three basic categories: incandescent, fluorescent and high intensity discharge (HID). Each category is distinct unto itself, with its own characteristics that make it well suited for specific applications.

Before we examine the different lamps categories, a review of some common characteristics is in order. EFFICACY is the term used to describe the efficiency of a lighting source in lumens/watt. As percent efficiency describes the ratio of energy output of an electric motor to energy input, efficacy describes the lumen output of a lighting source per watt of electrical energy input. Edison's first carbon filament lamp had an efficacy of 1.4 lumens/watt. Today, efficacies range from about 14 lumens/watt, for small incandescent lamps to about 180 lumens/watt, for low pressure sodium lamps.

LAMP LUMEN DEPRECIATION (LLD) describes the deterioration of the lumen output of a lamp as it ages. The longer a lamp operates, the fewer lumens per watt it produces. Lumen Depreciation Curves show how the lumen output of different sources drop off with age. These curves are used to determine the mean lumen output for a given lighting source. LLD is a partial factor in determining the light loss (maintenance) factor used in lighting calculations.

Lamp life is dependent upon many factors, including: the lighting source, lamp design and operating conditions. However, lamp manufacturers, through extensive testing, have established Mortality Curves that estimate lamp life. Actually, what these curves predict is the percent of lamp failures at different points in their rated life. It is normal to anticipate 50 percent of the lamps in a group to fail by the time they reach 100 percent of the rated lamp life. Also, it should be stressed that mortality curves are valid only for large groups of lamps and should not be used to predict failures for small groups. Mortality curves are also referred to as cumulative frequency and Ogilve curves.

INCANDESCENT LAMPS

Thomas A. Edison produced the first commercially available incandescent lamp in 1879. He did so by creating a filament that would sustain high temperatures and "incandesce" without quickly burning up. The first successful lamp used a carbonized filament made of Coat's No.29 thread. Edison was one of the few people that understood that he had, in this single invention, created a whole new way of life. There was no longer a need to tolerate smoke, odors and irritating fumes to have indoor lighting.

Modern incandescent lamps represent the best known category of lamps. It is the type lamp we use in our homes and has more available configurations than the other two categories. Lamp construction centers around three major components.

- Bulb (or envelope). The bulb is the glass enclosure that contains the working parts of the lamp. While the bulb can be made of any number of different types of glass, they can be categorized as either: lime glass, heat resistant glass or quartz glass (used primarily with halogen lamps).

- Filament. Today filaments are made of tungsten wire. The wire is thinner than a human hair and wound into any number of coil configurations.

- Fill gas. Lamps with a rating of 40 watts or greater typically are filled with a mixture of inert gases. The most commonly used gases are nitrogen and argon. The purpose of the gas mixture is to retard the rate of filament evaporation by conducting heat away from the filament to the bulb wall. Krypton gas is used at times to improve efficacy or increase lamp life. Lamps of less than 40 watts generally utilize a vacuum, in lieu of an inert gas mixture.

Advantages

The incandescent category of lamps, despite its overall poor efficacy, offers a significant number of advantages. They are:

- *Inexpensive* - Manufacturing techniques and production of large quantities of these lamps makes them inexpensive.

- *Readily available* - Incandescent lamps can be purchased nearly everywhere, from electrical supply houses to grocery stores.

- Available in a Variety of Configurations and Colors - Numerous colors and lamp shapes are available.

- *Satisfactory Color* - Incandescent lamps typically operate in the 2,500°K — 2,700°K range. This provides light of a color that is acceptable for most situations.

- *Easily Controlled* - These lamps are well suited to dimming control.

- *Instantaneous* - Incandescent lamps do not require a warmup period.

Disadvantages

At first glance, the advantages previously noted would appear to make incandescent lamps a reasonable choice for most applications. However, there are several distinct disadvantages to these lamps.

- *Low Efficacy* - Depending on the type and size of incandescent lamp used, the efficacy may vary. A typical range for incandescent lamps is 15 to 20 lumens/watt.

- *Short Life* - The life of standard incandescent lamps is normally between 750 to 1,000 hours. Compared to other sources, this is a relatively short time.

- *Sensitivity*- Incandescent lamps are sensitive to voltage variations. These lamps are also sensitive to shock and vibration.

Halogen Lamps

One innovation in *incandescent lamp technology* that has greatly enhanced their performance is the addition of halogens. The term halogen means "salt producer". Lamp manufacturers discovered that by adding halogen elements (usually Iodine in conjunction with quartz) to a standard incandescent lamp, the efficacy and life could be improved. The efficacy of halogen lamps is in the 25 - 30 lumens/watt range and the lamp life is increased to about 2,000 hours.

FLUORESCENT LAMPS

The fluorescent lamp is a gaseous discharge lighting source. It has been called the most versatile package of light available on the market today. They are available in over forty different wattages and range in lumen output from 115 to 15,700 lumens, in standard sizes.

Modern fluorescent lamps are comprised of six major components. They are the:

- *Base* - The base serves to support the lamp in the fixture and provides a means of making the necessary electrical connections.

- *Bulb* - This is the tubular shaped glass enclosure that contains the essential parts and ensures a controlled environment for operation.

- *Electrodes* - Typically made of coiled tungsten wire, these hermetically sealed electrodes, commonly referred to as cathodes, are located at the ends of the tube. They act as terminals for the electric arc. Filled with a special "emission" material they are a source of free electrons.

- *Gas Fill* - fluorescent lamps may use a variety of gases to facilitate the starting of the arc. The most common are argon, neon and xenon. Newer energy saving lamps may also utilize krypton gas. These gases are nearly at a vacuum and ionize quickly when voltage is applied.

- *Mercury Vapor* - Mercury atoms within the bulb produce ultraviolet radiation that is converted into visible light.

- *Phosphors* - Applied in a thin layer to the inside of the bulb wall, phosphor coatings produce visible light from ultraviolet radiation by re-radiating the energy at different wavelengths.

Ballasts

Once the arc has been initiated in a fluorescent lamp, if left uncontrolled, the lamp would exhibit a negative electrical resistance characteristic. That is, the resistance to current flow within the lamp would decrease as the current increases. This current flow would rapidly destroy the lamp. Therefore, ballasts are used to control the current flow to desired limits. In addition to limiting the current flow, the ballast also provides the proper voltage for starting and operating the lamp. Thus, the function of the ballast is to stabilize the power supply to the lamp.

Standard (Electromagnetic) Ballasts - Most ballasts are simple current-limiting transformers. The main component of a common ballast consists of coils of coated copper or aluminum wire, wound around a core made of transformer grade steel. The entire assembly is impregnated with a non-magnetic insulating grade material, such as hot asphalt. This material aids in conducting heat away from the windings and provides insulation from the ballast case. A capacitor may be installed to correct power factor and to assist in lamp starting.. These ballasts are available in both high power factor and low (also called normal) power factor types.

For most smaller fluorescent lamps (20 watts and less) a simple reactance ballast, commonly referred to as a “choke coil” is typically used. The choke consists of a long piece of enameled copper magnet wire wound around a steel core. The high inductive reactance of the choke serves to limit the current. This type of ballast is applied in lamps where the operating voltage does not exceed the line voltage.

The Certified Ballast Manufacturers Association (CBM) has established industry standards for ballast performance. Ballasts that have CBM labels have been certified that they will produce 95 percent (plus or minus 2 1/2 percent) of the lamp manufacturer’s rated lumen output. In actual application most CBM rated ballasts operate at approximately 93 to 94 percent of the rated output. Non-CBM rated ballasts can be expected to operate at something less than 92 1/2 percent.

Energy Saving Ballasts - Energy saving ballasts are the result of years of enhancements in the standard electromagnetic ballast. Through improved design features, these ballasts provide significant energy savings (typically 10 —12 percent), operate from 10 to 20 degrees C cooler, and have improved service life.

Effective April 1, 1990 ballast manufacturers could no longer sell standard core-coil electromagnetic ballasts, for the three most popular ballast sizes, for commercial or industrial applications. All two-lamp ballasts for F96T12 slimline lamps, single and two-lamp ballasts for F40T12 rapid start lamps, and two-lamp ballasts for F96T12 highoutput rapid start lamps must have power factors of 90 percent or greater. Therefore, the minimum level of efficiency now sold is what we recently referred to as “energy efficient”.

Electronic Ballasts - The revolution in electronics has produced dramatic improvements in the performance of fluorescent ballasts. Electronic ballasts operate on an entirely different technology than the standard core-coil designed ballasts. Electromagnetic ballasts produced for use in the United States operate at a voltage frequency of 60 Hertz (Hz) or 60 cycles per second. Electronic ballasts, on the other hand, alter the voltage and limit the current, and usually employ an oscillator circuit to produce frequencies in the 20 — 60 kilohertz (KHz) range. Since fluorescent lamps respond favorably to increases in frequency, lamp efficacy increases and the system becomes more efficient.

Aside from the obvious advantage of improved efficiency electronic ballasts also offer other distinct advantages over electromagnetic ballasts.

- *Lighter in Weight* - Electronic ballasts are light in weight, compared to electromagnetic ballasts.

- *Longer Life* - Due to the cooler operation of electronic ballasts (by as much as 30 degrees C), their life expectancy is greatly enhanced over that of standard ballasts.

- *Dimming Capability* - Some manufacturers offer integral manual and continuous photocell dimming capability.

- *Elimination of Ballast "Hum"*- The hum often associated with fluorescent ballasts is produced by the vibrations of the steel laminations in the core-coil assembly. While some hybrid-electronic ballasts do employ the laminated core-coil assembly, fully solid state electronic ballasts do not, thereby eliminating the potential for this noise.

Advantages of Fluorescent Lamps

Fluorescent lamps have a number of advantages. They include:

- *Versatility* - Fluorescent lamps are available in a wide variety of shapes, sizes and color renditions. Over 40 different wattages of fluorescent lamps can be purchased.

- *Good Efficacy* - With 3—4 times better efficacy than high wattage incandescent lamps, fluorescent lamps typically provide 50-60 lumens per watt of power.

- *Long Life* - Fluorescent lamps usually have 9 to 15 times the expected life of general service incandescent lamps. The typical rated life is in the range of 15,000—20,000 hours.

- *No Warm-up Required* - Unlike high intensity discharge (HID) lamps, fluorescent lamps do not require a warm-up period when they are energized. Should a momentary power interruption occur, they do not need to cool down before they will restrike.

- *Conversation Potential* - A number of energy saving options are available with fluorescent systems. They include a variety of reduced wattage lamps — for example, using 34 watt lamps in lieu of 40 watt F40T12 lamps. Also, compact fluorescent lamps provide an energy saving alternative for many incandescent applications.

Disadvantages

As with all lighting sources, there are potential disadvantages that the lighting designer/ consultant must be aware. They include:

- *Voltage Sensitivity* - Low and high (over) voltage situations reduce efficiency and shorten fluorescent lamp life. This differs from filament type lamps, where low voltage reduces efficiency but increases lamp life.

- *Temperature Dependency* - Fluorescent lamps are designed to operate with a bulb temperature in the range of 100—120 degrees Fahrenheit. Light output decreases about 1 percent for every 1 degree F drop in bulb temperature below 100° F. And for every 3 degrees F rise above 120° F, light output will also drop about 1 percent.

- *Requires a Ballast* - Fluorescent lamps require a ballast to initiate and stabilize lamp operation. This adds weight to the system and increases overall cost.

- *Dimming* - Special dimming ballasts and controls, variable transformers or solid state devices are required for dimming fluorescent system.

Compact Fluorescent Lamps

One of the major innovations in fluorescent lighting in the past several years has been the introduction of compact fluorescent (CF) lamps. Utilizing a small "U" or spiral shaped bulb and ballast assembly, these lamps have widespread acceptance as replacements for incandescent lamps. Fixture manufacturers have recognized the potential for CF lamps and are currently designing fixtures solely for their use. Compact fluorescent lamps can be purchased in several color and temperature ranges and are available in wattages from 5 to 40 watts.

HIGH INTENSITY DISCHARGE LAMPS

The third major lamp category is high intensity discharge or simply, HID. These lamps are similar to fluorescent lamps in that they produce light by discharging an electric arc through a gas filled tube. HID lamps differ in their smaller size and higher pressures inside the tubes. Since HID lamps are a small light source, they can be effectively used with reflectors and refractors.

High intensity discharge lamps produce light by sustaining an electric arc in a small arc chamber or tube. Light is produced within the sealed arc tube containing electrodes, some form of metal that can be readily vaporized and ionized (to conduct the electric current), and a starting gas.

There are three basic lamp types that currently compose the HID category. They vary significantly in efficacy, color rendering and life. In order of increasing efficacy they are mercury vapor, metal halide, and high pressure sodium. We will examine each of these separately.

Mercury Vapor (MV)

Introduced in 1934, this was the first high pressure HID lamp. Producing a bluish light, these lamps were initially used in street lighting and other applications where good color reproduction was not essential. In 1950 phosphors were added to improve the lamp color rendering. However, mercury vapor lamps were still considered unacceptable for indoor applications, It was not until the mid 1960s, when Deluxe phosphors were introduced, that mercury vapor lamps were used in merchandising and office applications. Mercury vapor was the predominant choice for street and area lighting until the mid 1970s.

Today’s mercury vapor lamps usually contain a sealed arc tube, formed of fused quartz, contained within an outer bulb made of heat resistant glass. The mercury arc within the quartz tube radiates both near and far-ultraviolet energy, as well as visible light. The outer bulb absorbs all of the far-ultraviolet energy, thereby allowing only those energies naturally provided by the sun to radiate.

Some MV lamps have outer bulbs internally coated with phosphors that convert the near-ultraviolet energy to visible light. The use of various phosphors provides improved color characteristics, making them suitable for some indoor commercial applications.

Mercury vapor is a relatively inefficient lighting source, by today’s standards. It is seldom specified for street and area lighting or for interior use. Mercury vapor still, however, does have limited applications, such as landscaping, where its bluish-green light can be used to accent trees and plants.

Mercury vapor lamps are comprised of six basic components. They are the:

- *Arc Tube* - This sealed quartz tube contains the main electrodes, mercury (gas and metallic form) and argon gas. operating at about 1,000 degrees C, it transmits the energy radiated from the mercury arc.

- *Electrodes* - Mercury vapor lamps contain three electrodes. The two main electrodes act as terminals for the arc. The third electrode is a starting electrode used to facilitate starting.

- *Starting Resistor* - The purpose of this resistor is to limit current in the starting circuit to as low a value as possible. It also “disconnects” the starting electrode once the arc has been established.

- *Arc-Tube Mount Structure* - This serves as a framework to position the quartz arc tube within the outer bulb, at the desired location. It also conducts electricity to the electrodes and secures the assembly to the outer bulb.

- *Outer Envelope (Bulb)* - Made of heat-resistant glass and filled with an inert gas (usually nitrogen), the outer bulb helps to maintain a relatively constant arc tube temperature. In addition, it absorbs short wave ultraviolet energy. Many lamps have phosphors coating the inside surface of the outer bulb to enhance color quality.

- *Base* - The base serves to hold the lamp in the socket and to make electrical connections.

<u>*Advantages of MV*</u>

While mercury vapor lamps have been replaced in many applications by other sources, they still have several advantages.

- *Availability* - Mercury vapor lamps are available in a variety of configurations and in sizes from 40 watts to 1,000 watts.

- *Compact Size/High Output* - Mercury vapor lamps offer the combination of small size with high lumen output. For example, a single 400 watt MV lamps can produce 22,000 lumens, while it would take four F96T12/CW (75 watt) lamps or four 300 watt incandescent lamps to produce the equivalent amount of light.

- *Long Life* - Mercury vapor lamps have an expected life on the order of 10 to 20 times greater than general service incandescent lamps and 1.5 more than fluorescent lamps. Typical life for a MV lamp is 24,000 hours.

- *Not Temperature Sensitive* - Mercury vapor lamps can be used in normal temperature ranges without concern for operational problems.

<u>*Disadvantages*</u>

Some of the disadvantages associated with mercury vapor lamps include:

- *Efficacy* - Mercury vapor lamps are relatively inefficient. While significantly better than incandescent, they only provide 40—60 lumens per watt.

- *Color* - The color for MV lamps is usually bluish-white. They may even have a slight greenish tint. While this may be acceptable for outdoor non-color critical areas, it is not appropriate for most commercial indoor applications.

- *Requires a Ballast* - As with fluorescent lamps, mercury vapor lamps (and all other HID lamps) require a ballast for starting and stable operation.

- *Warm-up Period Required* - When a MV lamp is energized it typically takes 5 to 7 minutes for it to achieve full lumen output. Should a momentary power interruption occur, the lamp must first cool for several minutes before it can restrike.

Metal Halide (MH)

In an effort to improve the color rendering capability of mercury vapor lamps, in the early 1960s different metals were added. One of the attempts resulted in a lamp that not only had improved color, but also increased efficacy. The resulting variation became known as the multi-vapor or metal halide lamp.

After years of experimentation and improvement, metal halide lamps are commonly used in industrial facilities, offices, retail stores, facilities, offices, retail stores, automobile sales lots, schools, sports field and gymnasium lighting applications.

Metal halide lamps are nearly identical in construction to mercury vapor lamps. The primary difference being in the fused quartz arc tube. The arc tube is slightly smaller than that of a mercury vapor lamp and contains various halide metals (sodium iodide and scandium or thallium iodide, and Indium iodide) in addition to mercury. Another different feature is the metal halide lamp's frameless construction. By not having a frame, it minimizes the possibility of the sodium (in the arc tube) being disturbed by current flowing through the frame. This could result in damage to the tube.

Advantages of MV

Like mercury vapor lamps, metal halide lamps offer significant advantages. They include:

- *Availability* - Metal halide lamps are available in sizes normally ranging from 32 watts to 1,500 watts. Special application lamps up to 12,000 watts are available. In addition, they are available with a clear outer bulb or coated with phosphors.

- *Compact Size/High Output* - Sharing this attribute with other HID sources, metal halide lamps are a concentrated source of light and can be easily controlled.

- *High Efficacy* - With approximately 80—100 lumens per watt, metal halide lamps have a substantially higher efficacy than mercury vapor lamps.

- *Long Life* - Depending on the lamp selected, metal halide lamps have rated life ranging between 6,000 and 20,000 hours.

- *High Color Rendering* - These lamps provide acceptable color for numerous color critical applications. In addition, they have good color uniformity from lamp to lamp.

- *Can Be (Possibly) Retrofitted to Mercury Vapor* - Metal halide lamps can be used with mercury ballasts, under certain conditions. Manufacturer's specifications should be checked.

- *Not Temperature Sensitive* - Metal halide lamps can be used in normal temperature ranges without concern for operational problems. Note that when retrofitted to mercury ballasts, there are some restrictions.

Disadvantages

Some disadvantages associated with metal halide lamps include:

- *Wattage Variations* - Variations in voltage (lamp and line), in addition to ballast and fixture characteristics, can cause significant lamp-to-lamp wattage variations (approximately 20 percent).

- *Requires a Ballast* - As with mercury lamps, metal halide lamps require a ballast. Some lamps can be retrofitted to mercury ballasts.

- *Warm-up Period Required* - When a metal halide lamp is energized, a warm-up period is required. It may be from 2-5 minutes until the lamp reaches full lumen output. Also, a cool-down period (in excess of 10 minutes) is required, should a momentary power interruption occur, before the lamp will restrike.

- *Orientation Dependent* - Due to the burning characteristics within the arc tube, lamps with special configurated arc tubes are required to maximize the lamp performance in the horizontal position.

High Pressure Sodium (HPS)

The high pressure sodium lamp is the most efficient lighting source in widespread application. HPS lamps produce light by passing an electrical current through an arc tube filled with vaporized sodium under pressure at high temperature. The light has a color temperature around 2,000 degrees K and is a golden yellow. Its physical, electrical and photometric characteristics are different from other high intensity discharge sources.

The shape of HPS lamps is significantly different from mercury vapor and metal halide lamps. High pressure sodium lamps have a long narrow tube geometry in order to maximize efficiency. The translucent arc tube is made of a ceramic (polycrystalline aluminum oxide) in order to withstand the extremely high temperatures (1,300 degrees C) generated by the sodium arc.

Operating voltages and currents for HPS lamps are significantly different from those of other HID sources. Therefore, special ballasts are required. A ballast for an I-IFS lamp must provide the high starting voltage starting pulse (no starting electrode is present), limit the lamp current and regulate lamp power as a function of line voltage and lamp operating voltage. To do this the ballast incorporates an electronic starting circuit.

High pressure sodium lamps are widely applied in street and area lighting, industrial facilities and in some commercial applications.

Advantages of HPS

High pressure sodium lamps have advantages including:

- *Availability* - High pressure sodium lamps are manufactured in sizes from 35 to 1,000 watts. In the smaller sizes HPS reflector lamps (PAR 38) can be purchased.

- *Compact Size/High Output* - As with the other HID sources, HPS lamps are a concentrated light source and can be easily controlled.

- *High Efficacy* - Of the widely used lighting sources, HPS lamps have the highest efficacy (70 to 140 lumens/watt).

- *Long Life* - Commercially available HPS lamps have a rated life ranging from 10,000 to 24,000 hours, with the latter being the most prevalent.

Disadvantages

High pressure sodium lamps exhibit some of the same disadvantages of other HID sources, including:

- *Poor Color Rendering* - While the golden-yellow color provided by HPS lamps is acceptable for many industrial and outdoor applications, it is not suitable for color-critical tasks. Color corrected HPS lamps are now available in limited sizes.

- *Requires a Ballast* - As previously mentioned, operational characteristics of HPS lamps necessitate special ballasts.

- Warm-up Period Required. When a HPS lamp is energized it typically takes about 4 to 6 minutes for it to achieve full lumen output. As with other HID sources, If a momentary power interruption occurs, the lamp must first cool (less than 1 minute) before re-striking.

LOW PRESSURE SODIUM (LPS)

Often confused with HID lamps, low pressure sodium lamps fall into the same category as fluorescent. They are a *gaseous discharge type lamp*. Low pressure sodium lamps are the most efficient lighting source on the market today. currently, these lamps provide up to 180 lumens per watt of power. LPS lamps would be widely used were it not for their poor color rendering attributes. Low pressure sodium lamps are monochromatic. That is, they produce light in one color. Light produced by low pressure sodium lamps is a distinct yellowish color

While LPS lamps have gained some acceptance in Europe, the only notable application for low pressure sodium lighting in the United States has been in the area of safety/security and street lighting.