FLORIDA SOLAR ENERGY CENTER®

Stand-Alone Photovoltaic Lighting Systems

A Decision-Maker's Guide

Volume 4: Lighting Fundamentals and Equipment

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STAND-ALONE PHOTOVOLTAIC LIGHTING SYSTEMS

A Decision-Maker's Guide

Volume 4: Lighting Fundamentals and Equipment

Prepared for:

Florida Energy Office / Department of Community Affairs

By:

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First Edition September 1998

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Abstract

This document provides an overview of lighting fundamentals and equipment, and is intended for those individuals that specify, design, and/or integrate photovoltaic (PV) lighting systems. The information includes definitions of photometric properties and laws, description of common light sources, and the basics of lighting system design.

Preface

This document is one of four topical reports on stand-alone photovoltaic (PV) lighting systems. The information is based on current state-of-the-art understanding, and is intended for those individuals and organizations evaluating the potential of using PV systems for a number of lighting applications. These documents may also be useful to PV lighting system suppliers, by helping educate prospective customers in the process of identifying and implementing practical and cost-effective PV lighting solutions.

Principal target groups for this document include:

- Federal, state and local government agencies
- Transportation and navigational authorities
- Planners, developers and builders
- Electric utilities
- Consumers and homeowners
- Emergency management officials
- Development and conservation organizations
- PV lighting system manufacturers and suppliers

The information presented in this set of topical reports provides an overview of PV lighting systems from a technical perspective. The content covers considerations for evaluating the feasibility of PV lighting applications, PV lighting components and system design, developing technical project specifications, and fundamentals of lighting design and lighting equipment. At the end of each report, sources for PV lighting equipment and a reference list are provided.

The four documents in this set of topical reports are:

Volume 1:	Photovoltaic Lighting Applications
Volume 2:	PV Lighting Components and System Design
Volume 3:	Technical Specifications and Case Studies
Volume 4:	Lighting Fundamentals and Equipment

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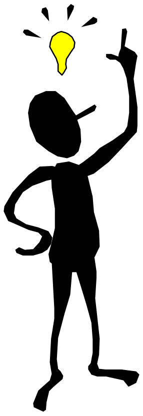
1. INTRODUCTION



"How do we cost-effectively provide power to our lighting needs in cases where utility power is not practical or available?"

This question is asked by many public and private concerns, including facilities managers, municipal planners and developers, navigation and transportation authorities, outdoor advertisers, utilities, contractors and property owners. For many, ***solar photovoltaic (PV)*** lighting systems have provided a practical and cost-effective solution for powering a diversity of lighting applications.

Thousands of PV lighting systems are being installed annually throughout the world, including applications for remote area lighting, sign lighting, flashing and signaling systems, consumer devices and for home lighting systems. PV lighting systems are simple, easy to install, and if properly designed and maintained, can provide years of exceptional service.

1.1 Advance Organizer for PV Lighting Systems

Figure 1-1 shows an ***"advanced organizer"*** for stand-alone PV lighting systems. This simplified diagram is intended to organize the reader's thinking about the major components and interactions in stand-alone PV lighting systems.

In typical PV lighting systems, the light source is powered by a battery, which is recharged during the day by direct-current (DC) electricity produced by the PV array. Electronic controls are used between the battery, light source and PV array to protect the battery from overcharge and overdischarge, and to control the timing and operation of the light.

In a basic way, these systems operate like a bank account. Withdrawals from the battery to power the light source must compensated for by commensurate deposits of energy from the PV array. As long as the system is designed so that deposits exceed withdrawals on an average daily basis during the critical design period, the battery remains charged and the light source is reliably powered.

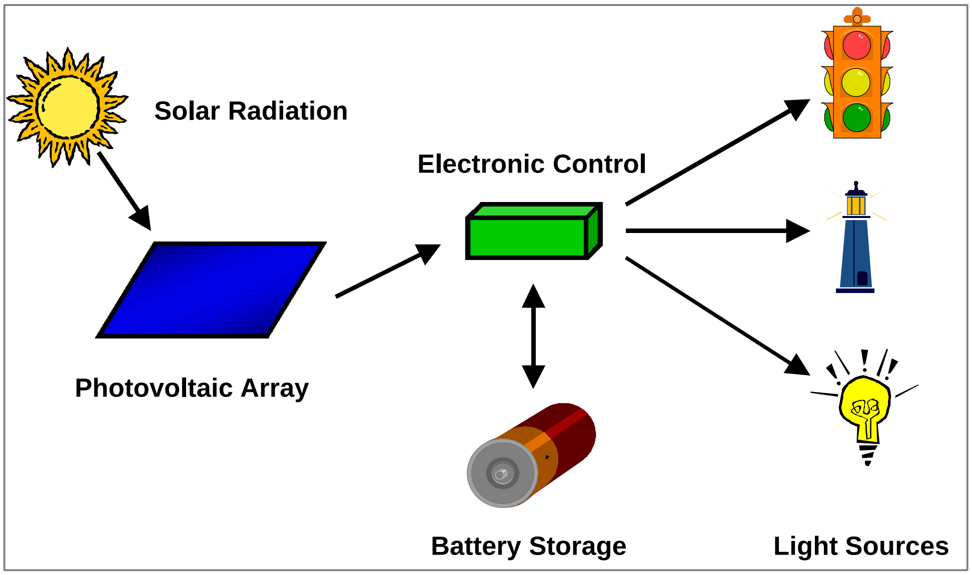


Figure 1-1. PV lighting system advance organizer.

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2. Lighting Fundamentals

Knowledge of basic photometric properties, light sources, and lighting requirements are an important part of specifying the performance of photovoltaic-powered lighting systems. The information presented in this section is intended to provide an overview of these topics for those specifying, designing and/or installing PV lighting systems.

2.1 Photometric Properties

The following technical definitions describe the more important photometric properties and laws.

Illuminance (E). Illuminance or the illumination, is the luminous flux density *incident* on a surface. Illuminance is generally expressed in units of *footcandles* (lumens/ft^2), or in international units of *lux* (lumens/m^2). One footcandle is the illumination at a point on a surface, which is one foot from and perpendicular to a uniform point source of one candela (Figure 2-1). In most cases, lighting levels are expressed in terms of the average and uniformity of illuminance over a given area. For unit conversions, one footcandle equals 10.76 lux.

Luminance (L). Luminance or photometric *brightness* represents light that is *reflected or emitted* from a surface, as opposed to the light flux *incident* on a surface (illuminance). A surface that uniformly emits or reflects one lumen per square foot (one footcandle) has a luminance in that direction of one *footlambert* (fl). In international units, luminance is expressed in units of *nits*, where one footlambert equals 3.426 nits. For a diffusing reflecting surface, the luminance in footlamberts is equal to the footcandles reflected multiplied by the reflectance.

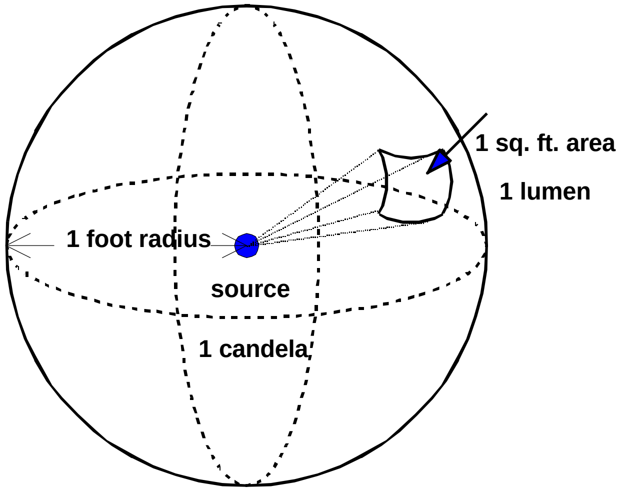


Figure 2-1. Luminous flux and intensity.

Luminous Intensity (I): The luminous intensity is the light density of a source, measured in a specified direction and within a very small solid angle. The candela (cd) is the basic unit of luminous intensity. An ordinary wax candle has a luminous intensity in a horizontal direction of one candela. The luminous intensity of a light source expressed in candelas is its candlepower (cp). *Candlepower distribution curves* represent the luminous intensity of a light source in many directions, and are used in lighting system design to determine illuminance distribution patterns on surfaces. An approximation of candlepower can be estimated by multiplying the normal flux in footcandles by the square of the distance in feet.

Luminous Flux (ƒ): The total luminous power emitted from a source is expressed in units of *lumens* (lm). One lumen is the light flux falling on a surface one square foot in area, every part of which is one foot away from a light source having a luminous intensity of one candela in all directions (Figure 2-1). The lumen is a measurement of light flux, and is used to express the total output of a source, incident light over a specified area or region, or the amount of light reflected, absorbed or transmitted.

Reflection, Transmission and Absorption. When light rays strike a surface, they can be reflected, transmitted, and/or absorbed. *Reflectance* (ρ) is defined as the ratio of light reflected from a surface to the incident light. Reflections can be either specular or diffuse, depending on the nature of the surface. Reflectance is normally expressed as the ratio of the brightness in footlamberts and the illuminance in footcandles. Reflection properties have importance in lighting fixture design and the materials used on externally illuminated signs. The *transmittance* (τ) is defined as the ratio of light transmitted through a material to the incident light. Transmission of light is an important feature of lens materials for lighting fixtures. Light rays passing through transparent or translucent materials are *absorbed* if they are not reflected of transmitted. The *absorptance* (α) is defined as the ratio of light absorbed in a material to the incident light. By definition, the sum of the reflectance, transmittance and absorptance equals one.

Refraction. Light rays that pass obliquely from one medium to another, for example from air through a glass or water interface, are *refracted*. The *refractive index* of a material or medium defines the extent to which light rays are bent when passing through the material.

Color. The spectral content or wavelength determines the color of light. The visible spectrum consists of the colors of a rainbow, ranging from violet at one end to red at the other end. Wavelengths in the visible spectrum range from about 0.4 to 0.7 micrometer (μm). Ultraviolet light has wavelengths shorter than 0.4 μm, while infrared radiation has wavelengths longer than 0.7 μm. The color of light sources is an important consideration in lighting design.

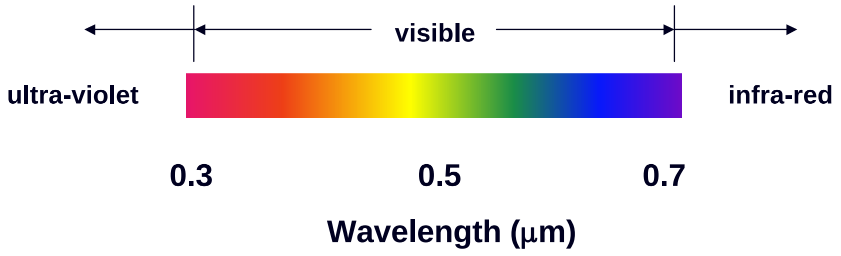


Figure 2-2. Visible spectrum.

2.2 Photometric Laws

Two basic photometric laws are used in almost all lighting design practice – the *Inverse Square Law* and the *Cosine Law of Incidence*.

2.2.1 *Inverse Square Law*

The *inverse square law* states that illumination is inversely proportional to the square of the distance between the source and the surface. In other words, the illumination two feet away from a source is one quarter of the illumination level at one foot away. Similarly, the illumination three feet away from a source is one ninth of the illumination one foot away. The inverse square law generally applies if the distance at which measurements are taken is at least five times the greatest dimension of the light source. Figure 2-3 illustrates the inverse square law.

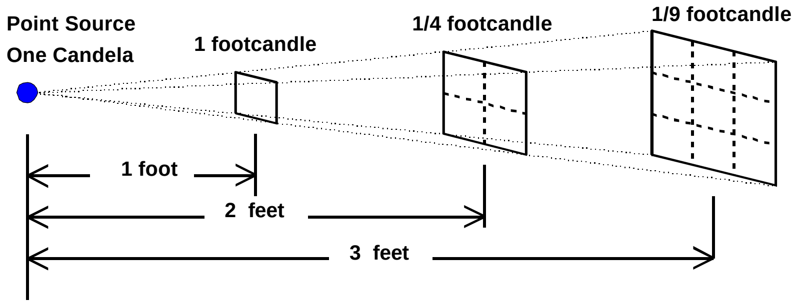
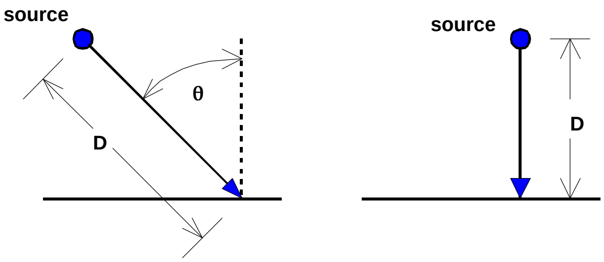


Figure 2-3. Inverse square law.

2.2.2 *Cosine Law of Incidence*

The *cosine law of incidence* states that the illumination is proportional to the cosine of the angle of incidence, or the angle between the direction of the incident light and the perpendicular (normal) to the surface. Figure 2-4 illustrates the cosine law of incidence.



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

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

for perpendicular incidence

Where,

E = illuminance in footcandles
I = source intensity in candelas
D = distance in feet
θ = angle of incidence

Figure 2-4. Cosine law of incidence.

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3. Lighting Equipment and Terminology

Lighting equipment consists of lamps, sockets, fixtures or housings, reflectors/diffusers, lenses, ballasts, controls, power source and mounting hardware. The following defines some basic for lighting equipment.

Source. Common terminology for a light source, lamp or luminaire.

Luminaire. A luminaire is a complete lighting unit, including lamps, ballasts, diffusers/lenses, fixture and other components.

Ballast. A device that modifies incoming voltage and current to provide the circuit conditions necessary to start and operate electric discharge lamps. Incandescent lamps and LEDs do not require a ballast for starting or operation.

Luminous Efficacy. A representation of lamp or luminaire efficiency, generally expressed in lumens emitted per watt of power consumed (lm/W). Typical lamp efficacies range from a low of 15 lm/W for some incandescent lamps, up to 180 lm/W for low-pressure sodium lamps.

Coefficient of Utilization (CU). The CU rating of a luminaire is defined as the ratio of the light output from the luminaire that strikes the work plane and the light output of the lamp(s) alone. The CU quantifies the efficiency of a lighting application.

Lamp Lumen Depreciation (LLD). Sometimes referred to as lumen maintenance, LLD refers to a lamp's lumen output reduction over its lifetime, generally expressed as a percentage of initial rated output as a function of lamp burn hours. For some types of lamps, depreciation of lamp lumen output makes it practical to replace many lamps before they actually burn out.

Luminaire Dirt Depreciation (LDD). Luminaire dirt depreciation refers to the reduction in light output of a luminaire, as a function of the luminaire design and environmental conditions. In particularly dirty environments such as cities and dusty areas, periodic maintenance and cleaning may be required to maintain illumination levels.

Color Temperature. Color temperature is a term used to describe the color of a light source by comparing it with the color of a blackbody, a theoretical complete radiator, emitting light with a continuous distribution according to its temperature. The higher the color temperature of a source, the whiter the light source appears. Blue sky has a color temperature of between 10,000 and 30,000 degrees Kelvin (K), fluorescent lamps range between 3,000 and 7,000^{o} K, and incandescent lamps range between 2,000 and 4,000^{o} K. Note that color temperature is not a measure of actual temperature, only an approximation of light source color.

Chromaticity and Color Rendition. Chromaticity refers to color, or spectral composition of the light source. Chromaticity coordinates give a specific, quantifiable representation of the color and spectral constant of a light source. Color rendition refers to the manner in which a lamp's light output affects color perception, as compared with color perception when viewed under natural daylight.

3.1 Light Sources

The choice of light source is an important decision in any lighting system design, particularly for PV lighting applications where the energy efficiency of the light affects the size and cost of the power source. Factors to be considered in lamp selection include efficacy, color, lifetime and lumen depreciation.

Light sources can be categorized into three groups - incandescents, fluorescents and high intensity discharge (HID) sources. HID lamps include four major categories - high-pressure sodium, metal halide, mercury vapor and low-pressure sodium. Common lamp types used in PV lighting systems include standard and compact fluorescents, low-pressure sodium and some metal-halide lamps. Due to their lower efficacies, incandescent lamps are generally only used in PV powered flashing and signaling applications. Table 1 lists general characteristics of common lamp types and Table 2 compares the efficacies of various light sources.

Table 1. Light Source Comparison

Lamp Type	Efficacy (lm/W)	Typical Lifetime (hr)	Lumen Maintenance	Color Rendition	Size Range (W)
Incandescent	8 - 25	750 - 3,500	Good to Excellent	Good to Excellent	15 - 1500
Fluorescent	40 - 100	6,000 - 24,000	Good to Excellent	Good to Excellent	4 - 215
Mercury Vapor	40 - 60	12,000 - 24,000	Very Good	Fair	40 - 1000
Metal Halide	80 - 125	5,000 - 20,000	Good to Excellent	Very Good	70 - 2000
High Pressure Sodium	72 - 140	7,500 - 28,000	Excellent	Good	35 - 1000
Low Pressure Sodium	100 - 180	12,000 - 18,000	Excellent	Poor	18 - 180

Note: Data are for comparison only. Actual lamp specifications vary considerably depending on the design, lamp wattage, manufacturing and operational environment.

Table 2. Efficacies of Various Light Sources

Light Source	Lumens per Watt *Lamp Only
Candle (Luminous Efficacy Equivalent)	1.4
Oil Lamp (Luminous Efficacy Equivalent)	0.3
Original Incandescent Lamp (1879)	1.4
60-Watt Carbon Filament Lamp (1905)	4.0
60-Watt Coiled Tungsten Filament Lamp (1968)	15
40-Watt Fluorescent Lamp (1968)	80*
400-Watt Metal Halide Lamp	85*
1000-Watt Metal Halide Lamp	100*
400-Watt High Pressure Sodium Lamp	125*
180-Watt Low Pressure Sodium Lamp	183*

3.1.1 *Incandescent Lamps*

Incandescent lamps are generally constructed with a wire-wound tungsten filament and enclosed in an evacuated or gas-filled glass bulb. When power is applied, the resistive filament is heated to incandescence by the flow of electric current through it. The filament essentially becomes 'white-hot', emitting a continuous spectrum of long-wave visible radiation. The higher the temperature of the filament, the greater the portion of emitted energy that lies in the visible spectrum. Figure 3-1 shows common incandescent lamps.

Figure 3-1. Incandescent lamps.

Types of incandescents include common household bulbs, halogens and other inert gas filament lamps. Initially, the bulbs were evacuated to keep the filament from burning up by removing oxygen. Later, it was discovered that the pressure exerted by an inert gas retards the evaporation of tungsten, allowing for higher filament temperatures and higher efficiencies. While incandescent lamps are inexpensive and convenient to use because they do not need a ballast, they generally have low efficiencies and short lifetimes compared to electric discharge lamps. For these reasons, incandescents are seldom used in PV applications except for short duration or flashing type signals, such as navigational aids.

3.1.2 *Fluorescent Lamps*

Fluorescent lamps are electric discharge devices that utilize an arc between two cathodes to excite a low-pressure mercury vapor, resulting in the emission of ultraviolet (UV) radiation. The UV radiation is then absorbed by a phosphor coating on the inside of a glass tube where the radiation is re-emitted at longer, visible wavelengths. The phosphor composition determines the spectral distribution of the light emitted from a fluorescent lamp. While older fluorescent lamps were limited in their color spectra to primarily blue colors, new rare earth phosphors have allowed designers to achieve a broader and warmer range of color characteristics for fluorescent lamps.

Standard fluorescent lamps with lengths from 6 to 96 inches are commonly used in PV lighting applications. A "T" designation is used for these lamps, which refers to the tube diameter in eighths of an inch. For example, the F40-T12 CW lamp designation refers to a 40-watt cool-white fluorescent lamp with a tube diameter of 1-1/2 inches. The length of a fluorescent lamp is related to its power rating, typically about 8-10 watts per foot for standard lamps. For example, an 18-inch tube is typically rated at 12-15 watts and a 48-inch tube is rated at 32 to 40 watts, depending on the type of lamp.

Compact fluorescent lamps are very popular in PV lighting due to their small size, high efficacy, long life and simple ballast design requirements (Figure 3-2). Typical power ratings for these compact fluorescent lamps include 5,7,9,13, 24 and 36 watts, although other wattages are available in dual- or quad-tube lamp arrangements. The light output from a 13-watt compact fluorescent is often compared with that of a 60-watt incandescent lamp, and has approximately ten times the rated life.

Figure 3-2. Compact fluorescent lamps.

Fluorescent lamps typically convert twenty percent of the input power to visible light, compared with incandescents, which are generally less than ten percent efficient. The efficacy for larger fluorescent lamps is higher than for smaller lamps because the power consumed at the electrodes is approximately the same, regardless of the lamp size. This suggests using a few larger lamps rather than many smaller lamps where applicable.

Several starting options have been used for fluorescent lamps. Original fluorescent lamps developed in 1938 were the preheat type, requiring a separate starter which supplied a few seconds of current flow through the cathodes to preheat them prior to lamp ignition. When the cathodes are heated, thermionic emission aids in liberation of electrons from the cathode, and allows the lamp arc to be initiated at lower voltages. Instant start lamps, on the other hand, rely on ballasts to supply a high enough voltage to strike the arc, without the need for preheating. Rapid start lamps utilize windings in the ballast to heat the cathodes, and start almost as smoothly as instant start ballasts; however they are less efficient. Ballasts are required on all fluorescent lamps to limit the arc current after the lamp is started.

The lifetimes of many types of fluorescent lamps exceed 10,000 hours, compared with 1,000 hours for typical incandescent lamps. During the first 100 hours of operation, the lumen depreciation for fluorescent lamps may be as much as ten percent, with a more gradual reduction over the rest of its life. The two principal causes are a gradual deterioration of the phosphor coating and blackening on the inner surface of the bulb from the emissive material produced by the cathodes. Rated lifetime for fluorescent lamps is decreased for shorter burn cycles (more frequent starts) – the primary reason why they are not used for high frequency on-off or flashing applications. A disadvantage of fluorescent lamps is that the light output decreases considerably with decreasing lamp temperature. Lower temperatures lower the mercury vapor pressure, which reduces light output and makes the lamp more difficult to start.

3.1.3 *High Intensity Discharge Lamps*

High intensity discharge (HID) lamps produce light by an electric arc passing through a vapor or gas inside a quartz tube, rather than through a wire filament as with incandescent lamps. Unlike fluorescent lamps, it is the arc that primarily produces the light, not phosphors inside the bulb. The quartz arc tube is enclosed in a larger glass bulb, sometimes coated with phosphors, and acting as a filter for harmful UV radiation. Starting of HID lamps is not instantaneous, and may require several minutes to achieve maximum output depending on the ambient temperature. All HID lamps require a high-reactance transformer or other ballast to limit the arc current.

Mercury Vapor Lamps

Mercury vapor lamps belong to the classification of HID lamps, using mercury as the primary ionizing gas, with a trace of more readily ionized argon to aid in starting. Mercury vapor lamps have a characteristic blue spectral distribution and lifetimes up to 24,000 hours (Figure 3-5).

Metal Halide Lamps

Another HID lamp and similar in operation to mercury vapor lamps, metal halide lamps contain metal iodides added to the mercury to contribute additional radiation lines to the spectral distribution of the lamp. Metal halides are commonly used indoors and for sign lighting where good color rendition is desired. They have lifetimes up to 20,000 hours (Figure 3-3).

High Pressure Sodium Lamps

High-pressure sodium (HPS) lamps use metal sodium as the main ionizing gas in the arc tube (Figure 3-4). The high gas pressure broadens the otherwise monochromatic sodium radiation spectra of 0.59 μm (yellow light), which is characteristic of low-pressure sodium lamps. High-pressure sodium lamps have fair color rendition, high efficiencies and long lifetimes up to 28,000 hours.

Figure 3-5. Mercury-vapor lamps.

Figure 3-3. Metal-halide lamps.

Figure 3-4. High-pressure sodium lamps.

3.1.4 *Low Pressure Sodium Lamps*

The low-pressure sodium (LPS) lamp is the most efficient light source available, with efficiencies as high as 200 lumens per watt. The lamp design and construction keep thermal and radiant losses to a minimum, resulting in the high efficacies. For this reason, they are often used in PV lighting applications. LPS lamps have lifetimes between 12,000 and 18,000 hours while achieving nearly 100 percent lumen maintenance.

The inner tube of the LPS lamp contains condensed sodium and neon starting gas. The space between the inner and outer tubes is highly evacuated. In operation, an electrical arc ionizes the neon gas causing a red glow during the first few minutes of operation. As the lamp reaches temperature, the sodium is vaporized and ionized by the arc, creating a monochromatic 0.59 μm (yellow light) source. Because of this monochromatic color, LPS lamps are used in applications where color rendition is not important. As with other arc discharge lamps, a ballast is required with LPS lamps to limit the arc current and supply the minimum open-circuit voltage required for starting the lamp. LPS lamps must also be operated in a specified orientation.

Figure 3-6. Low pressure sodium lamps.

3.1.5 *Light Emitting Diodes (LEDs)*

Commonly used as indicator lamps and in digital displays, light emitting diodes are becoming popular for internally-illuminated signs and even for some task lighting needs. While individual LEDs operate at low voltages and at low light output, arrays of LEDs can be wired in series and parallel to operate at 12 volts DC and produce reasonable light output for some low-illumination tasks. Although most LEDs in the past were red, green or other color, new generation ‘white light’ LEDs offer considerable promise. LEDs are a potentially attractive light source because they do not require a special ballast (they operate with DC power) and have projected lifetimes up to 100,000 hours.

4. Photometry and Basics of Lighting Design

Lighting system design involves consideration of many variables, including the *quantity* and *quality* of illumination required, the purpose or application, economic factors and other issues. *Photometry* refers to the data that quantifies the light output characteristics of a luminaire, and is essential information in lighting system design. Any lighting system design begins with the following steps:

- Defining the visual task
- Identifying the illuminance category
- Establishing illuminance and uniformity target values.

4.1 Quantity of Light

The most significant measure of a lighting installation is the amount of illumination it provides. The required illumination levels are related to the tasks to be performed under the illumination. Thus, critical tasks involving long hours working with small parts such as electronics assembly require high illumination levels, while parking lots and storage yards require less illumination due to the nature of the anticipated activity. For signal lighting applications, the luminance (brightness) of the source is the quantitative measure of system performance. Table 3 gives recommended values of illumination for various activities. Table 4 lists representative levels of illumination from common sources such as daylight.

Table 3. Recommended Illumination Levels

Area/Activity	Range of Illumination (fc)
General	
Classroom	50 - 100
Reading	20 - 100
Stairways	20 - 10-20
Wash rooms	10 - 20
Building exteriors	1 - 5
Residences	
general	5 - 10
kitchen and bath	20 - 100
Assembly, inspection	
simple	20 - 50
difficult	100 - 200
exacting	500 - 1000
Recreation activities	
tennis	10 - 30
baseball	15 - 150
football	10 - 100
parks	2 - 20
Roadways	0.6 - 2
bus stops	2 - 10
billboards, signs	15 - 100
parking lots	0.5 - 4
Storage yards	0.2 - 20

Table 4. Representative Levels of Illumination

Source	Footcandles
Starlight	0.0002
Moonlight	0.02
Street Lighting	0.06-1.8
Daylight	
At North Window	50.200
In Shade (Outdoors)	100-1000
Direct Sunlight	5000-10000
Office Lighting	70-150

4.2 Quality of Light

Adequate quantity of light does not necessarily ensure good illumination. Other factors such as glare, color and uniformity of distribution are some of the more important quality features. Maintaining adequate distributions is at least as important as illumination levels. Proper selection of lamp types and luminaires can generally achieve the quality requirements of most lighting installations. Light sources without good reflectors and diffusion generally exhibit poor light quality. Good quality illumination helps keep visual tasks easy to perform over prolonged periods.

4.3 Candlepower Distribution Curves

Lighting fixtures are designed to distribute light in various ways, depending on the application. This distribution of light from a luminaire can be represented by its *candlepower distribution curve.* These distribution curves are the result of taking candlepower measurements at various angles around a light source or luminaire. The illumination on any surface can be calculated from candlepower distribution data on the source given the luminaire geometry with respect to the surface. Where the inverse square law applies, the illumination at a given point can be calculated by dividing the candlepower at the required angle by the square of the distance in feet, and multiplying by the cosine of the incidence angle. Figure 4-1 shows a typical candlepower distribution curve for a street lighting luminaire in the horizontal plane.

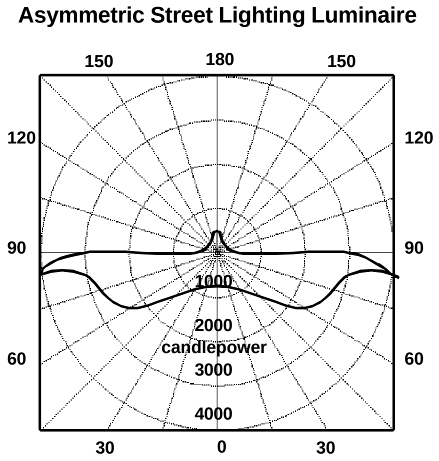

Figure 4-1. Horizontal candlepower distribution

4.3.1 *Iso-Footcandle Diagrams*

An *iso-footcandle or iso-lux diagram* is a quantitative measure of a lighting system design, produced from either measured data or calculations from system layout and candlepower distribution curves. These diagrams provide contours showing regions receiving the same amount of illumination on the working surface, as shown in Figure 4-2.

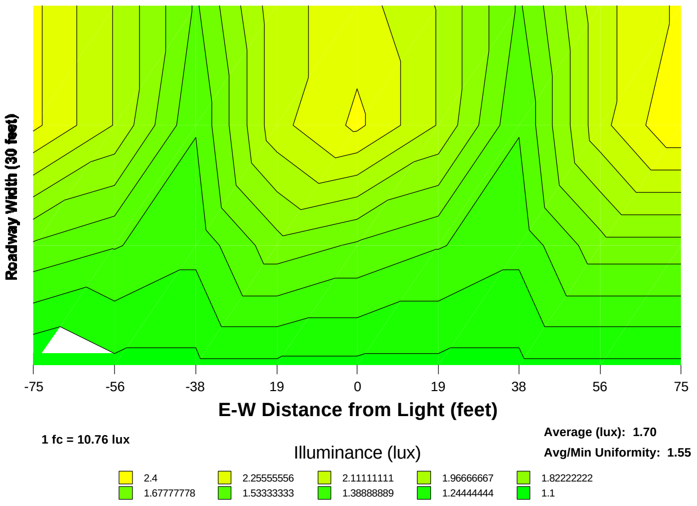

Figure 4-2. Iso-footcandle diagram for roadway lighting application.

Figure 4-3 shows a type of iso-footcandle diagram where distances on the work plane are represented in multiples of the mounting height to allow translation of the data to other mounting heights. Footcandles for other mounting heights are determined by multiplying the values on the given curves by the ratio of the square of the present mounting height to the square of the new mounting height.

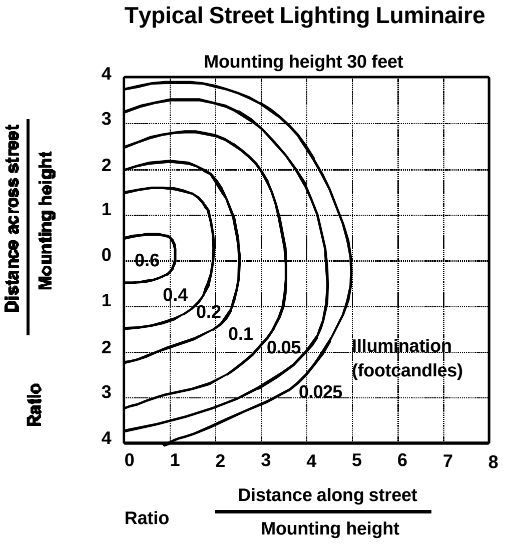

Figure 4-3. Iso-footcandle diagram.

4.4 Photometric Instruments and Measurements

4.4.1 *Illuminance Meter*

A basic photometric instrument, an illuminance meter utilizes a light-sensitive photovoltaic cell that produces a small current when illuminated. The current output can be calibrated to read directly in units of *foot-candles* or *lux*. Color correcting filters are used to approximate the response of the human eye, and cosine correction is often employed to compensate for reflection and other errors at high incidence angles. Illuminance meters are commonly used to measure the light distribution on surfaces in the field. Figure 4-4 shows two typical illuminance meters.

Figure 4-4. Illuminance meters.

4.4.2 *Luminance Meter*

Luminance meters measure light reflected or emitted from a surface, in units of footlamberts or candelas per square meter. The instrument is aimed directly at the test surface, and a photoelectric tube produces a current that is translated to *footlamberts*. Often, luminance measurements are used to quantify the contrast, or brightness difference between an object and its background (for example, letters on a sign). Visual acuity depends on maintaining minimum contrast with a focus object and its background. Figure 4-5 shows a luminance meter.

Figure 4-5. Luminance meter.

5. Sources for PV Lighting Systems and Equipment

The following lists suppliers of PV lighting systems and equipment. This list is not comprehensive, and appearance of any company on this list does not imply endorsement or approval by the author nor by the Florida Solar Energy Center.

Effective September 1998

Advanced Energy Systems, Inc.
9 Cardinal Dr.
Longwood, FL 32779 USA
Phone: (407) 333-3325
Fax: (407) 333-4341
magicpwr@magicnet.net
http://www.advancednrg.com/

ALTEN srl
Via della Tecnica 57/B4
40068 S. Lazzaro di Savena
Bologna, Italy
Tel: 39 51 6258396
Fax: 39 51 6258398
alten@mbox.vol.it
http://www.bo.cna.it/cermac/alti.htm

Alternative Energy Engineering
1155 Redway Drive - Box 339
Redway, CA 95560, USA
Tel: (707) 923-2277
Fax: (707) 923-3009
energy@alt-energy.com
http://www.alt-energy.com/

Applied Power Corporation
1210 Homann Drive SE
Lacey, WA 98503, USA
Tel: (360) 438-2110
Fax: (360) 438-2115
info@appliedpower.com
http://www.appliedpower.com/

Ascension Technology
235 Bear Hill Road
Waltham, MA 02451 USA
Tel: (781) 890-8844
Fax: (781) 890-2050
info@ascensiontech.com
http://www.ascensiontech.com/

Atlantic Solar Products, Inc.
P.O. Box 70060
Baltimore, MD 21237 USA
Tel: (410) 686-2500
Fax: (410) 686-6221
mail@atlanticsolar.com
http://www.atlanticsolar.com/

BP Solar, Inc.
2300 N. Watney Way
Fairfield, CA 94533 USA
Tel: (707) 428-7800
Fax: (707) 428-7878
solarusa@bp.com
http://www.bp.com/bpsolar/

C-RAN Corp.
699 4th Street, N.W.
Largo, FL 34640-2439 USA
Tel: (813) 585-3850
Fax: (813) 586-1777
http://www.scild.com/web/cran/

Cornette and Co.
P.O. Box 3443
Tampa, FL 33601-3443 USA
Tel: (813) 251-5915

Eco-Wise
110 W. Elizabeth
Austin, TX 78704
Tel: (512) 326-4474
eco@ecowise.com
http://www.ecowise.com/

Energy Conservation Services of North Florida
6120 SW 13th Street
Gainesville, FL 32608 USA
Tel: (352) 377-8866
Fax: (352) 338-0056

Electro Solar Products, Inc.
502 Ives Place
Pensacola, FL 32514 USA
Tel: (850) 479-2191
Fax: (850) 857-0070
espsolar@cheney.net
http://scooby.cheney.net/~espsolar/

Golden Genesis (Photocomm)
7812 Acoma Drive
Scottsdale, AZ 85260 USA
Tel: (602) 948-8003
Fax: (602) 951-4381
info@goldengenesis.com
http://www.photocomm.com/

GeoSolar Energy Systems, Inc.
P.O. Box 812467
Boca Raton, FL 33481 USA
Tel: (561) 218-3007
Fax: (561) 487-0821
abtahi@geosolar.com
http://www.geosolar.com/

Hutton Communications, Inc.
1775 McLeod Drive
Lawrenceville, GA 30043 USA
Tel: (800) 741-3811
Tel: (770) 963-1380
Fax: (770) 963-7796
locker@huttoncom.com
http://www.huttoncom.com/

IOTA Engineering
1301 E. Wieding Road
Tucson, AZ 85706 USA
Tel: (520) 294-3292
Fax: (520) 741-2837
iotaeng@iotaengineering.com
http://www.iotaengineering.com/

Jade Mountain Inc.
P.O. Box 4616
Boulder, CO 80306 USA
Tel: (800) 442-1972
Fax: (303) 449-8266
jade-mtn@indra.com
http://www.jademountain.com/

Morningstar Corporation
1098 Washington Crossing Road
Washington Crossing, PA 18977 USA
Tel: (215) 321-4457
Fax: (215) 321-4458
http://www.morningstarcorp.com/

Neste Advanced Power Systems
PL 3, 02151
Espoo, Finland
Tel: 358 204 501
Fax: 358 204 50 4447
jaana.sirkia@neste.com
http://www.neste.com

Precision Solar Controls
2915 National Court
Garland, TX 75041 USA
Tel: (972) 278-0553
Fax: (972) 271-9853

Real Goods Trading Co.
555 Leslie St.
Ukiah, CA 95482-5576 USA
Tel: (800) 762-7325
http://www.realgoods.com/

Quasar Solar Electric Co.
001 Tullamore
Offaly, Ireland
Tel: 353 882 706 775
Fax: 353 506 41650
quasar@tinet.ie
http://homepage.tinet.ie/~quasar

Trace Engineering
5916 195th St. NE
Arlington, WA 98223
Tel: (360) 435-8826
Fax: (360) 435-2229
inverters@traceengineering.com
http://www.traceengineering.com/

Siemens Solar Industries
P.O. Box 6032, Dept. FL
Camarillo, CA 93011 USA
Tel: (800) 947-6527
Fax: (805) 388-6395
http://www.solarpv.com/

Simpler Solar Systems
3118 W. Tharpe St.
Tallahassee, FL 32303 USA
Tel: (850) 576-5271
Fax: (850) 576-5274
simpler@simplersolar.com
http://www.simplersolar.com/

Solar Depot
8605 Folsom Blvd.
Sacramento, CA 95826 USA
Tel: (916) 381-0235
Fax: (916) 381-2603
solrdpo@calweb.com
http://www.solardepot.com

Solar Electric Light Co.
35 Wisconsin Circle Suite 510
Chevy Chase, MD 20815 USA
Tel: (301) 657-1161
Fax: (301) 657-1165
bcook@selco-intl.com
http://www.selco-intl.com

Solar Electric Light Fund
1734 20th Street, NW
Washington, DC 20009 USA
Tel: (202) 234-7265
Fax: (202) 328-9512
solarlite@self.org
http://www.self.org/

Solar Electric Power Co.
7984 Jack James Drive
Stuart, FL 34997 USA
Tel: (561) 220-6615
Fax: (561) 220-8616
sepco@tcol.net
http://www.sepco-solarlighting.com/new/

Solar Electric Specialties Co.
101 North Main St.
Mail: PO Box 537
Willits, CA 95490 USA
Tel: (707) 459-9496
Fax: (707) 459-5132
ses@solarelectric.com
http://www.solarelectric.com/

Solar Electric Systems of Kansas City
13700 W. 108th Street
Lenexa, KS 66215 USA
Tel: (913) 338-1939
Fax: (913) 469-5522
solarelectric@compuserve.com
solarbeacon@msn.com

Solar Outdoor Lighting, Inc.
3131 S.E. Waaler Street
Stuart, FL 34997, USA
Tel: (800) 959-1329
Tel: (561) 286-9461
Fax: (561) 286-9616
info@solarlighting.com
http://www.solarlighting.com/

Solarex Corp.
630 Solarex Court
Frederick, Maryland 21703 USA
Tel: (301) 698-4200
Fax: (301) 698-4201
info@solarex.com
http://www.solarex.com/

Sollatek
Unit 4/5, Trident Industrial Estate
Blackthorne Road
Poyle Slough, SL3 0AX
United Kingdom
Tel: 44 1753 688-3000
Fax: 44 1753 685306
sales@sollatek.com
http://www.sollatek.com/

Sunelco
PO Box 1499
Hamilton, MT 59840, USA
Tel: (406) 363-6924
Fax: (406) 363-6046
info@sunelco.com
http://www.sunelco.com

Sunalex Corp.
5955-T N.W. 31st Avenue
Ft. Lauderdale, FL 33309 USA
Tel: (954) 973-3230
Fax: (954) 971-3647

SunWize Technologies, Inc.
90 Boices Lane
Kingston, NY 12401 USA
Tel: (914) 336-0146
Tel: (800) 817-6527
Fax: (914) 336-0457
sunwize@besicorp.com
http://www.sunwize.com/

The Bodine Company
236 Mount Pleasant Road
Collierville, TN 38017 USA
Tel: (800) 223-5728
Tel: (901) 853-7211
Fax: (901) 853-5009
ldailey@bodine.com
http://www.bodine.com/
http://www.tran-bal.com/

Tideland Signal Corp.
P.O. Box 52430-2430
Houston, TX 77052 USA
Tel: (713) 681-6101
Fax: (713) 681-6233
hq@tidelandsignal.com
http://www.tidelandsignal.com

Traffic Control Devices, Inc.
P.O. Box 418
Altamonte Springs, FL 32715-0418 USA
Tel: (407) 869-5300

Work Area Protection Corp.
2500-T Production Dr.
P.O. Box 87
St. Charles, IL 60174 -0087 USA
Tel: (630) 377-9100
Fax: (630) 377-9270

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