Evaluating Lighting Conditions in Spray Painting Facilities

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An often-overlooked yet integral aspect of spray booth function is proper lighting. The correct implementation of booth lighting can be the deciding factor between a satisfactory or exemplary finish. In the following article we will explore the *what*, *how*, *when*, and *where* of "light". We will examine *what characteristics* are important in evaluating "light", *how* we provide the "light" with the various types of fixtures available, *when* the various fixtures should be applied for painting applications, and *where* the design of the system will provide the best results for the particular application. Too often, when looking to upgrade a painting facility, lighting is not given the proper consideration necessary to provide for the quality finish results the end customer expects, or to meet what the competition offers. The result is a constant battle with the application professional who is asked to meet the standard in a poor environment. We hope that by reviewing this article you will be more familiar with the terms, how they apply to your situation, and be able to utilize them in specifying your next finishing environment. Now, let's learn more about the technical basics.

Light is a form of radiant energy belonging to the electromagnetic spectrum. The sun, earth, and other heavenly bodies radiate electromagnetic energy. The electromagnetic spectrum is a continuum of all electromagnetic energies arranged according to their various frequencies and wavelengths. The frequency of a wave is the number of complete cycles it makes in a single second and is measured in Hertz (Hz). Wavelength is the distance from peak to peak of the wave and is typically measured in meters. X-rays, microwaves, television and radio waves are all portions of the electromagnetic spectrum. Visible light accounts for the smallest portion of the electromagnetic spectrum ranging in waves of 380 to 760 nonometers (nm).

The higher the frequency of the wave the greater the energy level. The specific length of the wave also determines its color. Waves of different color, therefore, have different levels of energy. The wavelengths found in visible light correspond to the following hues:

- Less than 480 nm - blues
- 480 to 560 nm - green
- 560 to 590 nm - yellow
- 590 to 630 nm - orange
- 630 to 700 nm - red

Some hues are not naturally found in the visible spectrum. For example, mixing red and blue, which are at opposite ends of the spectrum, produces purple and magenta. White light is achieved through a balanced combination of light waves differing in color. Blending red, green, and blue light will create white light; hence, these three colors are considered the primary colors of light. When two primary colors combine, a secondary color is produced. Yellow light can be produced through the combination of red and green. Combining green and blue light produces cyan. White light will be produced when secondary colors are superimposed.

By contrast, the mixture of color pigments is an example of the subtractive principle. Here the primaries are yellow, cyan, and magenta. When combined, these three pigments produce black. Subtracting colors from black produces new colors. White represents an absence of color. A black body will absorb any color of light; similarly, white objects reflect all light. Colored objects absorb light of different color and reflect light of their same color. Thus, in order for an object to appear a particular color, that color must be contained in both the object and the light it is viewed in. This is important since light waves themselves are not visible, but their reflection or emissions from surfaces are.

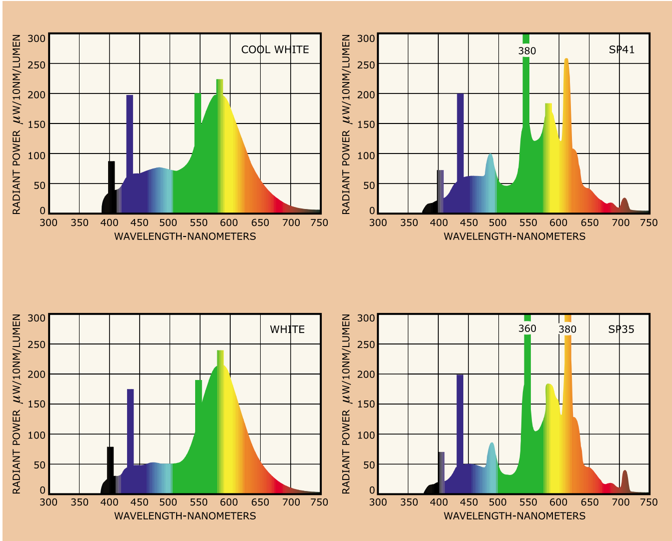

Figure 1. Spectral power distribution for various lamps

When selecting a lamp for a particular application, it is important to be able to predict its visual effect. The type and quantity of light emitted from a source affect the perception of colors rendered in it. Several methods of quantifying the color content of a particular light source exist to avail in predictions of this nature.

Color temperature is one method of quantifying the color of a light source. This method of color comparison assigns a Kelvin temperature to a range of hues for a "blackbody radiator" at the same temperature. The blackbody radiator is a theoretical object capable of absorbing all energies that hit it and then perfectly re-radiating this energy. At room

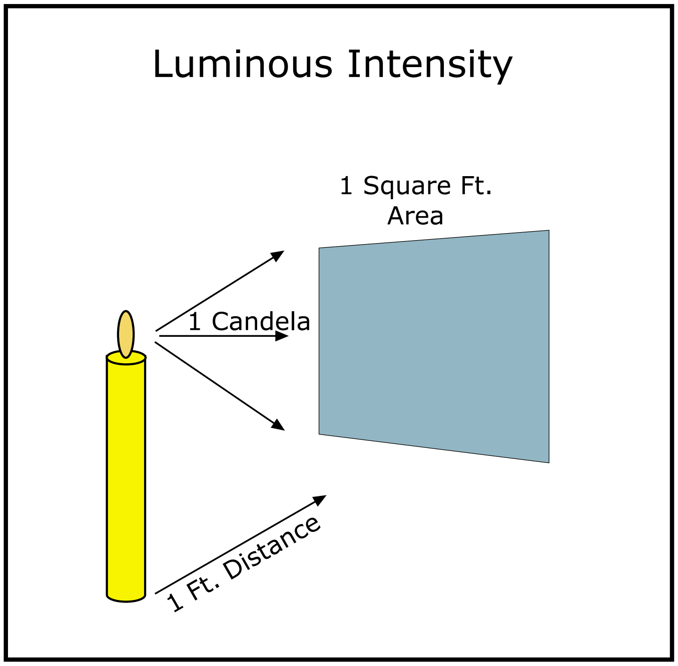

Figure 2. Luminous intensity.

temperature the blackbody appears black, at 800°K dulled red, at 3,000°K it appears yellow, white at 5,000°K, pale blue at 8,000°K, and bright blue at 50,000°K. An example of this would be an ingot of iron placed in a furnace. Initially the bar is dull gray. As it begins to heat it appears dull red. Slowly as the heat increases the bar glows bright red. Gradually, with increased heat, the bar's appearance will shift to orange, yellow, and finally a bluish white hue. This type of color correlation is the least accurate measure of an object's color. Technically, this method is only applicable for incandescent sources. When applied to fluorescent fixtures or high-intensity discharge lights, such as metal halide fixtures, the terms "apparent color temperature" or "correlated color temperature" is applied.

Another system of color quantification defines colors in terms of tristimulus values. This is a method developed by the International Commission on Illumination (CIE), an organization dedicated to standardization in illumination and related areas. The tristimulus values are the percentages of each primary in an additive color mixture: X (red primary), Y (green primary), and Z (blue primary).

Color coordinates are then calculated from the tristimulus values. Lower case x, y, and z are used to designate the color coordinates. The color coordinates represent relative percentages of each primary required to produce it.

$$x = X (X + Y + Z)$$

$$y = Y/(X + Y + Z)$$

$$l = x + y + Z$$

Any possible color can be designated by its x and y coordinate on the CIE diagram. If two colors with different color coordinates are mixed, a line connecting their points on the CIE diagram will indicate all the possible mixtures they can achieve.

Another method of quantifying a light source is the Color Rendering Index (CRI). The CRI is qualitative evaluation of how a light source affects our color perception. A lamp's CRI rating is determined by comparing the change in color of a reference lamp. Eight standard samples are used for the comparison. The reference lamp and source to be rated must both have the same color temperature. A CRI of 100 indicates perfect color correlation. There are several manufacturers of "light booths" and multi-source lights that can be used as reference lamps in this form of color evaluation.

A final method of color evaluation for a light source is by direct examination of its spectral power distribution. The spectral power distribution plots a curve of the radiant power of a light source versus the wavelengths of the visible spectrum. A light source will be able to

Table I. Illuminance Categories for Generic Tasks

Lamp	Life Span	Operating Temperature	Spectral Power	General
Incandescent	750 to 2,500 hours	Operates well at any temperature	Strongest in red emissions. Weakest in blue emissions.	3 to 10,000 Watt ranges available
Fluorescent	Frequent starts and stops reduce life span. Ballast life 15 to 20 years.	Lamps designed for specified operating ranges. Generally have problems with low-temperature operation. Indoor-use fixtures have ballasts that trip at coil temperatures above 105°C.	Available in any given spectral range. CRI values as high as 98.	Available in anything from 115 to 16,500 lumens. Over 40 different Wattages available in standard sizes.
HID	5,00 to 20,000 hours. Reduced by frequent starts and stops. (Over 24,000 hours for high-pressure sodium.)	Any temperature range	Strongest in blue and green emission. Generally emitting pale light. (Yellow and white light with high CRI for high-pressure sodium.)	Physically small compared to other types of fixtures. Low Wattage and low efficacy. Shut off with power interruptions and will not start until sufficiently cooled.

render colors well for wavelengths where its radiant power is high. Rendering will be poor for wavelengths where the radiant power is substantially lower. Spectral power data can be obtained from the specific lamp manufacturer (see Fig. 1).

The next focus for quantifying a lighting design is on proper level of illumination. The Candela (or Candle) is the basic unit of light measure. The Candle is described as source's luminous intensity, or the intensity of light in a given direction. An ordinary wax candle has a luminous intensity of one Candela in a horizontal direction.

The time rate flow of light is described as luminous flux. The standard unit of luminous flux is the Lumen (L). The L differs from the Candle in that it is a measure of light flux irrespective of direction. One L is the light flux transmitted on a one ft^2 area where every point on the area is one foot away from a one Candela source (see Fig. 2).

Illumination is the density of luminous flux on a surface. Illumination is measured in units of foot-candle (F-C). An F-C is the illumination at a point on a surface, which is one foot from perpendicular to a uniform point source of one Candle.

Brightness is described as luminous intensity in a given direction per unity of projected area. A surface or an object has brightness by reason of light emitted, reflected, or transmitted. Brightness is ordinarily independent of distance of observation. Symbolized by either B or B^1, brightness is measured in Candle per square inch (C/in^2) or footlambert (fl). Brightness can be expressed either as Candles per unit area, or L per unit area. A surface emitting or reflecting light in a given direction at the rate of one C/in^2 of projected area has a brightness in that direction of one C/in^2. A surface, which has a brightness equal to the uniform brightness of a perfectly diffusing surface emitting or reflecting one lumen per ft^2, has a brightness of one fl. The fl is also the average brightness of any surface emitting or reflecting light at the rate of one L per ft^2. A lambert is the brightness of a surface emitting or reflecting one lumen per square centimeter.

The Illuminating Engineering Society (I.E.S.) has created several guidelines for lighting areas suited for various tasks ranging from reading rooms and athletic centers to work on assembly lines and manufacturing of electrical components. Table 1, published by the I.E.S., contains illuminance categories for generic tasks. First, illumination values are defined in ranges of F-Cs for the type of activity. Then, areas and activities are grouped into these illumination categories. The range of illumination identified by the I.E.S. for paint shop applications is 20 to 500 F-Cs. A more precise determination is dependent on the specific task. For example, dipping and simple spraying have been identified as requiring 20 to 50 F-Cs or 200 to 500 lux. Extra-fine hand painting and finishing is listed as requiring 200 to 500 F-Cs. For further insight into these illuminations categories refer to the "IES Lighting Handbook-Application Volume." The IES also provides on-line samples of room and building lighting calculations and evaluations. (Lighting power density models at www.iesna.org). It must be remembered that these values are guidelines based on calculations and partly generalizations of the specifics of an activity or area of consideration. A factor to consider when determining the type and level of illumination necessary in particular for a spraying operation is the end use of the part being finished. If a finished part will be highly scrutinized or rarely visible are factors that will affect the degree of illumination needed on the job.

With a desired level of lighting in mind the task now turns to one of generating a lighting design. Quality lighting not only refers to the desired illumination levels, but the selection of proper equipment for the desired visual effect.

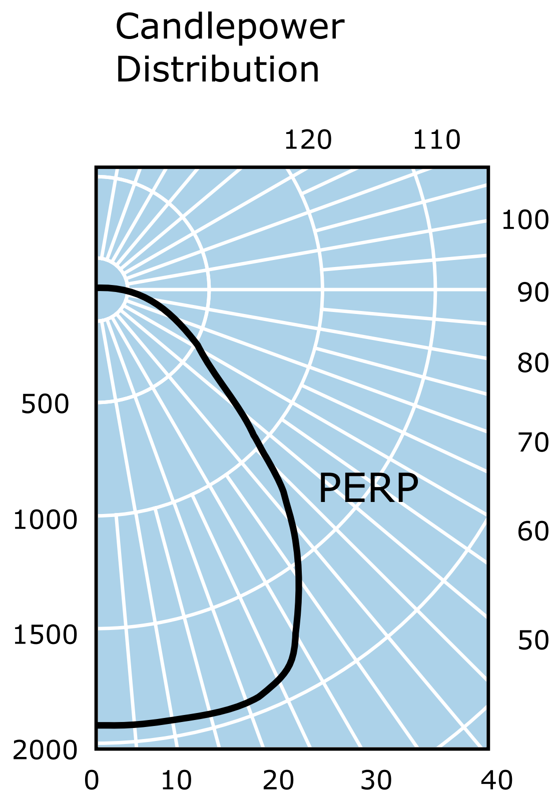

Figure 3. Candlepower versus angular position for specificed source and housing

A quality lighting design will take into account the evenness of lighting across working surface and surroundings. Having sufficient illumination in a work area is not enough. Uneven lighting will cause a room to have contrasting areas of light and dark, and cast unwanted shadows. A person exposed to such an environment will experience constant dilation of the eye. This is caused by continuous adjustment of the eye to varying lighting levels. The end result will be fatigue and tiredness, which can disrupt the concentration and ability of the person working in the area. A proper lighting design will ensure even level lighting. Fixtures should be located where they can properly illuminate the surroundings and not be obtrusive to workers. Avoid locating fixtures where they are in the direct line of sight of workers. If a person is forced to look directly at light sources they can be temporarily blinded (see spots) or again be severely dilated. Designs that continuously place the worker between their focal point and the light source should similarly be avoided. Such a design would cause the individual to continuously cast shadows into their work area.

The choice of a particular light fixture will depend heavily on the application and also configuration of the environment. There are various types of optical housing each with advantages and disadvantages, such as the fixture geometry, number and type of bulb, and how the fixture is accessed. These characteristics tend to be very subjective and selections will depend on the particular operator or designer. What should be considered when selecting a particular housing is how it will impact lighting effect and levels. An effective fixture will provide a reflective surface for the enclosed light source. The fixture should not absorb or obstruct light generated by its bulbs. (See Fig. 3.)

There are literally thousands of different types of lamps available, each with very unique characteristics and purposes. Generally, the types of bulbs used in industrial settings are either incandescent, fluorescent, or high-intensity discharge lamps (HID). Each group has varying efficiencies, operating ranges, and life expectancies.

Incandescent lamps have a standard life span ranging from 750 to 2,500 hours. They operate well at any temperature. Only small portions of their emissions radiate in the visible spectrum of light. Their greatest region of radiation is in the infrared region. In the visible spectrum, incandescent lamps radiate in the red region. These lamps have a very weak blue emission. The highest efficacy standard incandescent lamp available is the 10,000-W studio lamp rated at 33.5 L per W with a 75-hour life span. In contrast the 3-W indicator lamp has a 3,000-hour life and an efficacy of 4 L per W.

Fluorescent lamps are the most versatile of any style of light available. They typically range from 155 L to 16,500 with over 40 different Wattages in standard sizes. When operating these lamps a negative electrical resistance characteristic is experienced, which means that as current increases the lamp's resistance to current decreases. A ballast is thus required to limit the lamp's current and protect it from destroying itself. Ballasts used in indoor settings contain thermal protection switches. The switches open when the internal coil temperature exceeds 105°C. These are known as "Class P" ballasts and are required by N.E.C. code when used indoors. Regular on/off cycling of lamps is an indicator of ballast failure. The Certified Ballast Manufacturers Association (CBM) has established standards for ballast performance. Well-ventilated ballasts can expect a life of 15 to 20 years. The ballast also acts as a transformer. Though a lamp may be rated for a particular voltage and Wattage, such as 101 or 29 V, it may actually be powered by 120 or 277 V through the ballast. Lamp life is better for lamps that are used over lengthy periods with few starts and stops as opposed to those used with frequent starts and stops over short periods. Each fluorescent lamp is designed for use at a specific temperature range. Most commonly, this is ambient temperature. Typically, fluorescent fixtures are available in any given visible spectral range. These lamps can be as high as 98 CRI for tough color applications.

HID lamps are physically smaller than the preceding types of lights. Three types of HID lamps are commonly used industrially: mercury vapor, metal halide, and high-pressure sodium lamps. Mercury vapor lamps are low Wattage and generally inefficient when compared to other lamps. Mercury and metal halide lamps also produce ultraviolet radiation when operating. Because of this their outer bulbs are constructed of borosilicate glass, which can shield the ultraviolet radiation. Mercury vapor and metal halide lamps are strong spectrally in the blue and green regions generally emitting pale light. Metal halide lights can be constructed with good color-rendering ability. Their average useful life is 5,000 to 20,000 hours but reduces significantly with frequent starts and stops.

High pressure sodium lamps average a life of over 24,000 hours. They generally produce a yellowing light. There are sodium lamps with CRIs in the 80s that can produce a white light similar to some incandescent sources. High-pressure sodium lamps sport low operating costs and high efficacy.

HID lamps share the negative resistance characteristic experienced with fluorescent lamps. Ballasts are required to regulate their internal power. HID lamps also experience stroboscopic effects. When supplied by a 60 Hz source, HID lamps will cycle on and off 120 times per second. An object rotating at speeds that are multiples of 60 Hz will appear motionless when viewed under these lamps. Using three-phase power and alternating the phases used can minimize this stroboscopic effect by adjacent lamps. HID lamps shut off when there is even momentary power interruption. The lamps will not restart until they have cooled sufficiently.

The selection of the right design can be challenging with the range of information one must know to make the right choices for a particular application. Utilizing a professional is encouraged so you can establish the needed results and let those in the know design the system. If they are not using the terms above, then you should question their understanding of what's right for your operation. Too many see lighting design as "just provide lots of light fixtures". The result could be disastrous for everyone. Make sure you establish your needs and develop the confidence that the supplier has the knowledge to give you "the results necessary for your product's success!"

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