IT'S WHAT MEETS THE EYE

THE BEST LIGHTING IS LIGHTING THAT GIVES YOU THE CLEAREST VISION

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1.1 INTRODUCTION

Many lighting companies and consumers have an incorrect view of how the eye handles light. This view has transformed into a prevalence of inefficient lighting, misconceptions and conflicting rules about the appropriate color of light and light levels.

To provide better and more efficient lighting for visual performance and brightness perception, Noribachi incorporates the calculations of pupil lumens. The purpose of this white paper is to give a better understanding of how we see light, how the mainstream lighting community has failed to implement a valuable attribute that characterizes the visual system spectral response, and how Noribachi's forward-thinking is introducing this concept to part of its lighting practice.

1.2 SCOTOPIC MEASUREMENTS: WHAT THE LIGHT METER DOESN'T CATCH

We know that our eyes have two types of photoreceptors, cones and rods. While cone light receptors control photopic vision, the scientific term for color detection in high light, rods control scotopic vision, the scientific term for visual perception in dim light. Cones are commonly described to handle "daytime vision," while rods are described as handling "nighttime vision." Cone cells are sensitive to red, blue, and green in high light conditions and rods are more sensitive to the color blue and primarily control the opening and closing of the pupil. However, these descriptions over-simplify how cones and rods create our vision.

Rods, specifically, are widely thought to only be important for night vision, when in actuality they contribute largely to vision behavior at various light levels. There are a range of light levels called the mesopic region, where both rods and cones affect the human visual system. Most outdoor lighting falls within the mesopic region.

However, surprisingly, lighting companies and consumers only rely on photopic lumen measurements to describe a lamp's brightness. Photopic lumens are the only lumens measured in LM79 tests and other current light simulation tests, which lamps are put through in order to determine their brightness (luminous flux), light distribution angles, and efficacy. Photopic lumens are usually the only lumens that are mentioned in marketing materials, and therefore the only lumens considered when purchasing a bulb.

1.3 SCOTOPIC SENSITIVITY

Two scientists, Dr. Sam Berman and Dr. Don Jewett, give a better understanding of the performance of the eye for lighting practice and lighting energy efficiency.

The two scientists show that rods primarily control the opening and closing of the pupil of the eye and that the perception of room brightness is substantially influenced by rod's functionality. Their tests show that lighting would be improved if it accounted for the responsiveness of the rods during workplace environments.

The rods' control of pupil size significantly influences vision; smaller pupils improve your depth of view, provide better acuity, and allow a higher quality in vision at certain light levels and color temperatures (Kelvin) illuminating the eyes. Unfortunately, most lighting practitioners crank up the light levels to reduce pupil size, which only wastes energy, adds glare and creates headaches for the onlooker.

Instead, the best way to reduce pupil size is to increase the color temperature, not increase the light level. The higher the color temperature, the more the lighting is scotopically elevated, or contributing to more rod activation. This is proven by studies that show subjects choose the scotopically enhanced light as brighter than a photopically enhanced light, even though the light level is measured 30% lower by the light meter. Today's lighting consumers are too focused on what the light meter claims and not focused enough on what they actually see.

1.4 PUPIL LUMENS: NORIBACHI EVALUATES BOTH PHOTOPIC AND SCOTOPIC RESPONSES FOR LIGHTING ENERGY EFFICIENCY

Different types of bulbs have different measures of photopic and scotopic light levels. For instance, depending on the temperature color, LEDs range from a high of 1.56 to 2.07. To determine the total of visually effective lumens (also called "pupil lumens"), we can multiply photopic lumens by (S/P)0.78. S/P is a ratio that describes scotopic to photopic quantities.

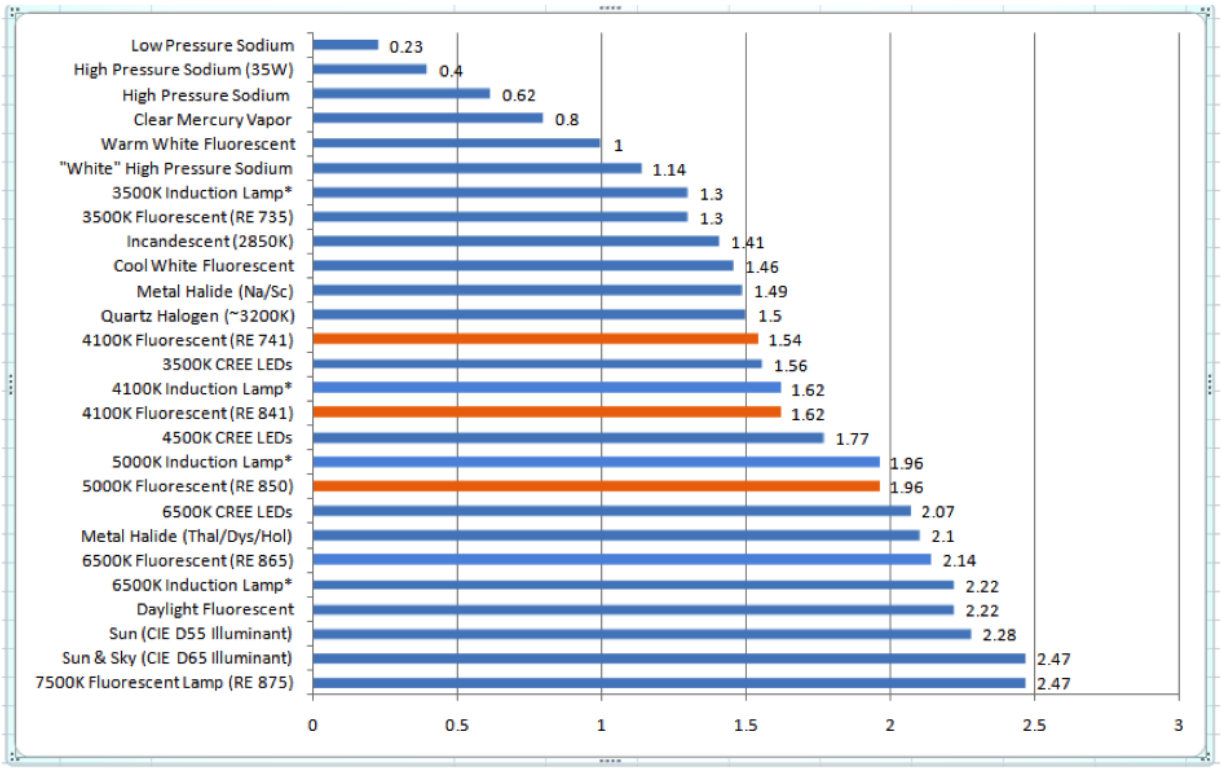

Figure 1: List of S/P ratios for different bulbs.

As an example, we will calculate the pupil lumen output of a 400W Metal Halide Lamp:

STEP 1: DETERMINE PHOTOPIC LUMENS

- Multiply wattage by efficacy (lumens/watt). (Note: the efficacy listed on LM-79 reports is based on photopic output)
- 400W x 57 Lumens/Watt = **22,800 photopic lumens**

It is important to note that this photopic lumen level is measured as an omni-directional output. Since, no light fixture allows 100% light output, we need to consider a light fixture lumen efficiency. In a typical "shoebox" fixture, this efficiency can be considered at 75% (50% direct and 25% reflected). Therefore the real photopic lumens can be calculated:

- 22,800 photopic lumens * .75 = **17,100 photopic lumens**

STEP 2: DETERMINE PUPIL LUMENS

- Multiply photopic lumens by $(S/P)^{0.78}$:
- 17,100 Lumens x $(1.49)^{0.78}$= **23,339 pupil lumens**

To find a Noribachi replacement with about the same light output:

STEP 1: DIVIDE THE PUPIL LUMENS OF THE METAL HALIDE BULB BY THE LED'S S/P RAISED TO 0.78

- $23{,}339/(S/P = 2.07)^{0.78} = 13{,}232$ lumens → Needed Photopic Lumens from a Noribachi Light Bulb

STEP 2: DIVIDE LUMENS TO FIND THE NUMBER OF COMMON LIGHTING UNITS (CLUS)

A common lighting unit (CLU) is a circuit board where diodes are secured. One linear Noribachi CLU (006.LIN) driven standard produces 896 lumens. One Noribachi hexagonal CLU (021.HEX) driven standard produces 3,135 lumens. To calculate the number of CLUs needed, divide the photopic lumens by the amout of lumens produced by either a linear or hexagonal CLU. The same can be done if the customer wants their lights driven medium. One Noribachi linear CLU (006.LIN) driven medium produces 1,264 lumens. One Noribachi hexagonal CLU (021.HEX) driven medium produces 4,426 lumens.

- 13,232 / 896 ~= 14.76 → Suggest a Shoebox.M Fixture with 90 LEDs (15 LIN CLUs)
- 13,232 / 3,135 ~= 4.22 → Suggest a Highbay.M Fixture with 84 LEDs (4 HEX CLUs)
- 13,232 / 1,264 ~= 10.46 → Suggest a Shoebox.M Fixture with 66 LEDs (11 LIN CLUs)
- 13,232 / 4,426 ~= 2.98 → Suggest a Highbay.M Fixture with 63 LEDs (3 HEX CLUs)

Although Noribachi evaluates an existing lighting system based on pupil lumens, we still compare photopic lumens and lumen maintenance to determine the best solution. For example, the photo below is of a high school parking lot with a 250W HPS bulb (right side) next to a 54W LED bulb (left side) at 6500K color.

Which one looks brighter and is easier to see true color? The LED bulb has a higher scotopic sensitivity, and thereby the perception of brighteness of the area is influenced by rods in the eyes and appears brighter. Although the 250W HPS bulb measures higher photopic lumens, 12,850 vs. 6,480, it has less overall pupil lumens, 8,851 vs. 11,430. Additionally, only 29% of the energy used in a HPS lamp produces light and will decrease rapidly in comparison to LED.

1.5 EXPLAINING THE CONCEPTS

In order to make energy-efficient lamps that deliver high quality light and promote clear vision, one must know how the eye adapts to light. Both scotopic and photopic components of light must be considered to provide excellent illumination and higher energy efficiency. When making lamps, the goal is not simply to put out the highest luminosity, but to make objects in the surroundings more visible, down to the very detail. Clear vision does not necessitate very high levels of luminance. Although pupil lumens are not to be underestimated in engineering the optimal light source, all factors are equally important. Ambiance, hours of runtime, what the light is used for (ie., fine tasks such as dentistry or lighting a large wall,) the type of fixture for which the lamp is intended–lamp and light makers take all of these things into consideration.

To decrease our global electricity demand of 20%, all aspects of lighting should be understood, from photopic lumens to pupil lumens, and lumen maintenance and energy consumption of different bulbs. With this approach, there is a substantial opportunity to achieve cost-effective quality lighting.