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Use of LED or Other New Technology to Replace Standard Overhead and Sign Lighting (Mercury and/or Sodium)

FINAL REPORT
June 2005

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16. Abstract

The New Jersey Department Of Transportation (NJDOT) has an increasing concern that the quality and energy use for roadway lighting is outdated. The current lamps and energy usage is based on old practices and technologies. To research the state-of-the-art, NJDOT has contracted Rutgers/Center for Advanced Infrastructure and Transportation (CAIT). The main issues to be addressed include: 1) Introduce the existing and latest technologies in roadway lighting, and evaluate the current and proposed alternatives (taking into consideration illumination, visibility, maintenance, spectral power distribution, lumen depreciation, mean life, and color rendering). In addition, the research team is to provide NJDOT with the field verification on two key issues: visibility and color rendering, which are implemented on Sodium and white light sources. 2) Present the life cycle cost analysis on the introduced technologies and compare them to current lamps used in street lighting (High Pressure Sodium), with the proposed alternatives. Thus, the study will provide not only the most cost effective alternative to using High Pressure Sodium in roadway lighting, but also the most practical.

Based on the research, white light sources demonstrated superior light quality. QL, Icetron, Restrike HPS, and LEDs were all shown to be equivalent or superior in light quality based on Lumen Effective Multiplier (LEM). Also, based on the Life Cycle Cost Analysis (LCCA) the QL, Icetron, Restrike HPS, and LEDs had superior cost savings. However QL, Icetron, and LED may not meet current light distribution specifications; which are currently being revised on a national level.

In summary, Restrike HPS lamps are recommended for immediate implementation; whereas QL, Icetron, and LED should wait for acceptance on a national level. In some situations where lighting is not specifically governed by the specifications, and NJDOT would like to further evaluate the technologies, QL type lamps are recommended for implementation.

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ABSTRACT

The New Jersey Department Of Transportation (NJDOT) has an increasing concern that the quality and energy use for roadway lighting is outdated. The current lamps and energy usage is based on old practices and technologies. To research the state-of-the-art, NJDOT has contracted Rutgers/Center for Advanced Infrastructure and Transportation (CAIT). The main issues to be addressed include: 1) Introduce the existing and latest technologies in roadway lighting, and evaluate the current and proposed alternatives (taking into consideration illumination, visibility, maintenance, spectral power distribution, lumen depreciation, mean life, and color rendering). In addition, the research team is to provide NJDOT with the field verification on two key issues: visibility and color rendering, which are implemented on Sodium and white light sources. 2) Present the life cycle cost analysis on the introduced technologies and compare them to current lamps used in street lighting (High Pressure Sodium), with the proposed alternatives. Thus, the study will provide not only the most cost effective alternative to using High Pressure Sodium in roadway lighting, but also the most practical.

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In summary, Restrike HPS lamps are recommended for immediate implementation; whereas QL, Icetron, and LED should wait for acceptance on a national level. In some situations where lighting is not specifically governed by the specifications, and NJDOT would like to further evaluate the technologies, QL type lamps are recommended for implementation.

BACKGROUND

The New Jersey Department of Transportation (NJDOT) is statutorily obliged to maintain and improve the lighting conditions on New Jersey roadways. When attempting to improve these conditions it is important that cost, efficiency, and illumination issues are addressed. The primary purpose of lighting is to increase visibility of signs, roadways, and the immediate environment, while acknowledging other factors, such as light distribution, glare, and contrast of objects in drivers' line of sight. Due to the high price of today's lighting equipment and ever increasing energy prices, the research team will identify and evaluate both current and new technology (LED, HPS, Fluorescent, etc.) that may potentially be integrated into existing light fixtures to minimize expenses.

PROJECT GOALS

The goal of this study is to provide NJDOT with information concerning the replacement of standard overhead and sign lighting with LED or new technology. The study should meet four basic objectives:

1. Reduce operating costs while upholding the quality of the roadway environment in relationship to nighttime visibility.
2. Provide NJDOT with information such that they can substitute out-of-date technology with newer, more efficient lighting equipment, such as bright white LED light, QL lighting, and other technologies.
3. Supply NJDOT with a lighting plan that is able to offer equal or better illumination with significantly lower energy consumption and cost.
4. Establish recommendations that are sensitive to lamp replacement, cleaning, and equipment maintenance that ensure quality lighting, while enabling NJDOT maintenance staff to focus on higher priority tasks.

INTRODUCTION

Roadway lighting can be an effective tool to provide efficient and safe traffic movement during evening or nighttime driving. There is a growing concern in the New Jersey Department of Transportation (NJDOT) to identify cutting-edge technology and quantify the key issues of energy efficiency and associated cost in roadway lighting.

To attain these goals, the research team analyzed the facts on roadway lighting to assist the NJDOT on future purchases, plans, and costs.

This report was organized to include three phases of work. The initial research phase consisted of a literature search focusing on the basic factors of vision, and introducing issues in lighting. In addition, it covered the construction and important features of almost all lamps and technologies used in street lighting, from past to present, namely Mercury Vapor, Metal Halide, Low Pressure Sodium (LPS), High Pressure Sodium (HPS), HPS retro-white, HPS Restrike, QL, Icetron, Fluorescent, LED, and Solar. However, based on the needs of the NJDOT this research focused on two lamps: High Pressure Sodium and induction. HPS lamps are widely used in street lighting and induction lamps are one of the most promising new technologies. In addition to the main objective of this project, overhead lighting, the research team also presented some new and existing technologies in tunnel and bridge lighting for future consideration.

The second phase investigated the small target visibility and color rendering on two light sources: sodium light source and white light source with testing conducted at the NJDOT complex just outside Ewing in Trenton, NJ. The research team anticipated evaluating small target visibility and color rendering for four major lamps: HPS 250W, HPS 150W, QL 150W, and QL 85W. These specific wattages were considered because of proposed and suitable replacement of HPS 250W, and 150W with QL 150W, and 85W, respectively. However, due to time constraints, the scope was refined to compare sodium (yellow) light with a white light source. The simplified test results are included in the report and imply that QL induction lamps might be a suitable alternative to HPS.

The third phase, decision support, covered the Life Cycle Cost Analysis (LCCA) for the following lamps: Mercury Vapor, High Pressure Sodium (HPS), HPS retro-white, HPS Restrike, QL, Icetron, and LED with different wattages over a 20 year duration. After introducing applied cost for each lamp during the 20 year LCCA, cumulative costs were applied for current (HPS 150W and 250W) lamps and proposed lamps (previously mentioned). Subsequently, the LCCA was implemented for New Jersey roadway lighting for current and alternative NJDOT specific scenarios.

BACKGROUND AND THEORY OF VISION

There are two types of receptors on the eye's retina: rods and cones. The rods operate at low light levels, the cones operate at high light levels, and both operate over a range at intermediate light levels. Rod vision does not provide color response or high visual acuity. In fact, there is no rod vision along the line of sight; in looking for a very faint signal light on a dark night, one must look about 15 degrees to the side of it. The cones are responsible for color vision and the high acuity necessary for reading and seeing small details. Figure 1 indicates the approximate ranges for rod and cone operation.

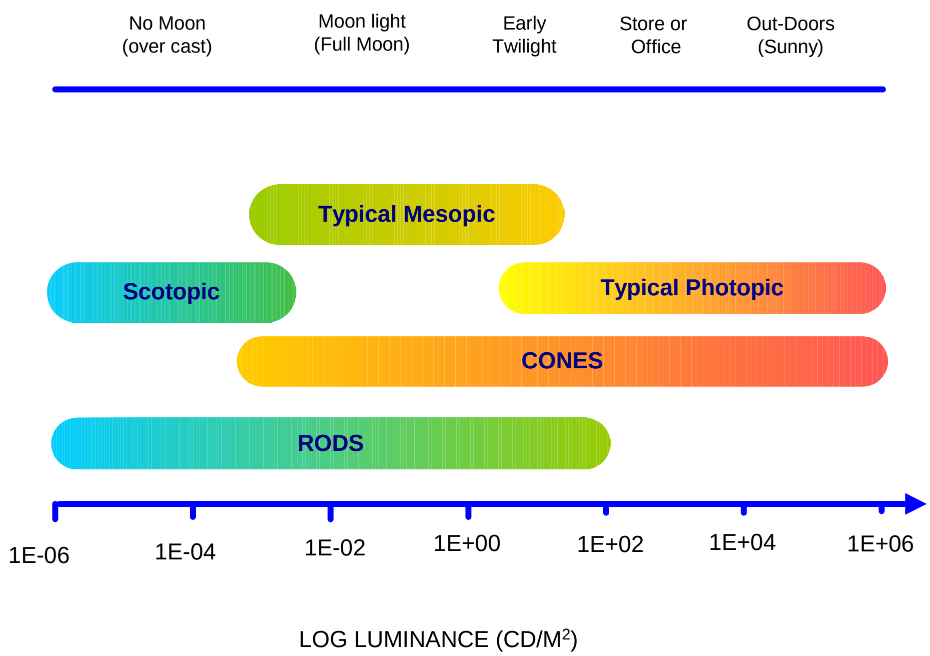


Figure 1: Range of Vision

Since the ranges of cone and rod depend on the luminance (" brightness") in the field of view, rather than on illuminance (footcandles or lux), typical lighting conditions at which these luminances occur are indicated across the top of the chart. Rod vision is known as *scotopic* vision, cone vision is known as *photopic* vision, and the region where both rods and cones contribute to vision is called *mesopic* vision. Light (lumens) is radiant power in watts weighted at each wavelength by a luminous efficiency value, i.e., by the eye's brightness response to power at that wavelength. It is then possible to derive the lumen value of a light by this spectral weighting process using the photopic or the scotopic response function. Figure 2 shows the standardized spectral weighting functions for photopic and scotopic lumens. The change in response functions is known as the *Purkinje shift*.

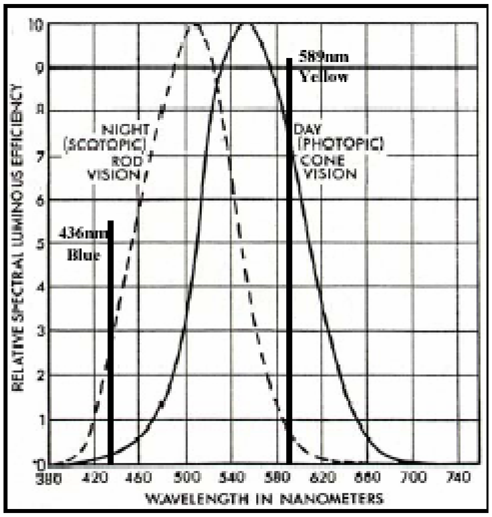


Figure 2: The V(λ) curve for photopic vision
and the curve for scotopic vision[2]

In the mesopic region, as the light level decreases from photopic to scotopic vision, the spectral response gradually changes from the photopic to the scotopic curve. There is a continuous range of mesopic curves changing in both shape and maximum sensitivity, and the appropriate curve depends on such factors as the light level and the distribution of light in the field of view. In 1935, CIE (Commission on Illumination) (International Commission on Illumination- abbreviated as CIE from its French title Commission Internationale de l'Eclairage) described the following calculation for Lumens.

$$\text{Lumens} = K \sum power(\lambda) * V(\lambda)\Delta\lambda \qquad \text{Equation(1)}$$

Where
K is a constant used to account for units
λ is the wavelength
V(λ) is the CIE international standard representing the luminous sensitivity curve of the eye, under certain conditions

V(λ) defines the spectral response of a typical person under “photopic” conditions. This is shown by the bold curve in Figure 2. "Photopic” refers to high light levels typical of daylight and interior lighting. Note also that the V(λ) curve is applicable only to the center small central area of the eye’s field of view. However, if viewing conditions change and V(λ) is no longer applicable, the lamp lumen figure will not be indicative of the effective light output of the lamp. Likewise, the luminance of a surface will not give a true picture of the brightness of the surface as seen by the eye.

As a result of this and a range of other problems, there is no agreement within the United States, nor internationally, on a standard method for computing lumens in the mesopic region. Although some works have been completed by Professor Adrian and Professor He for deriving equivalent lumens for several light sources, such research is discussed later in this report.

As illustrated in Figure 2 , the wavelength of 436nm has the strongest mercury emission line, which is a powerful line in Metal Halide lamp output, while 589nm is the region of the maximum output of sodium (these light sources are described in detail in following sections).

TECHNICAL OVERVIEW AND KNOWLEDGE BASE

The research team's objective while conducting this study is to provide recommendations to decision makers based on the following research. This section covers the technical approach to attain the team's goal. This study is vital because future technology selection is based on such technical overview and field research.

In the first section, two different existing light sources which can be used in outdoor lighting, are introduced (Sodium and white light source). By comparison, the authors believe white light source is more efficient than sodium light source.

Section two presents a study on lighting level, sensitivity to contrast, and reaction time in the aforementioned light sources and concludes that white light sources are more efficient than sodium light sources.

Afterward, the abstract of Professor Adrian's and Professor He's research on brightness matching and reaction time is being presented for the aforementioned light sources.

The third section includes a discussion on Lumen Effectiveness Multiplier (LEM), which converts "normal" photopic or lamp lumens to "effective" lumens for the particular lighting design. Extensive research efforts are underway on LEM across the country.

Two different light sources

Whereas lighting level and the color response of the eye are two important factors for producing vision, any light source that can respond to these two factors efficiently could be the best choice. In the following section, these factors are considered for two light sources which can be applied to road lighting, sodium light source and white light source. Sodium light source (LS) can be divided into two LS categories: Low Pressure Sodium and High Pressure Sodium.

<u>Sodium Light Source</u>

The maximum energy output of sodium lies in a yellow region where the eye is very sensitive. Spectral power distribution of typical Low Pressure Sodium (LPS) lamp is shown in Figure 3. Practically all the energy output is in the yellow region, giving very high photopic lumen output. At low light levels, however, there is almost no energy output at wavelengths where rods are most sensitive. LPS lamps therefore have significantly reduced effectiveness for rod vision, versus what their ratings suggest.

At the mesopic lighting levels relevant to roadway lighting, these effects will be reduced, as vision is normally achieved by use of both rods and cones. The amount of reduction will depend on many factors, including the exact lighting level, the visual task, and other factors.

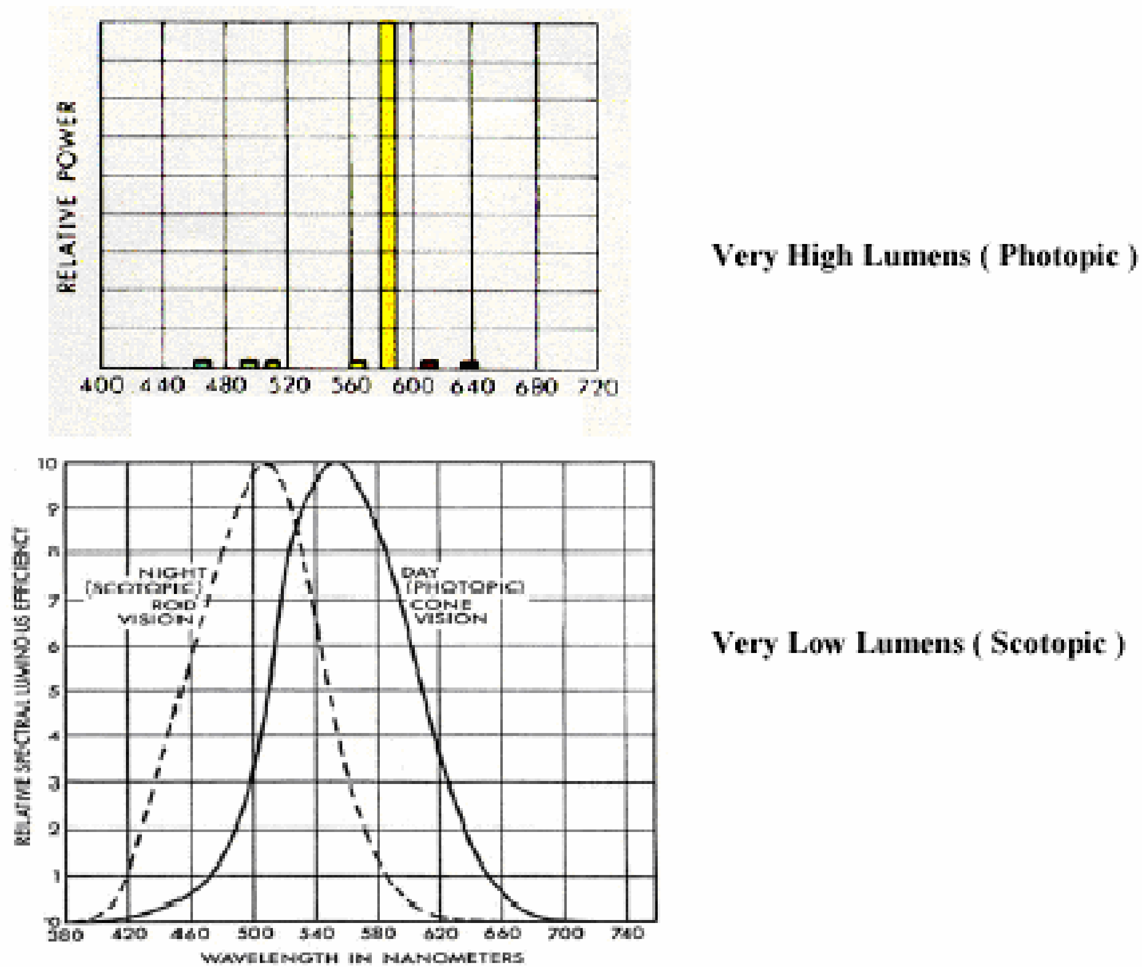


Figure 3: Spectral Power Distribution of a Typical LPS Lamp(2)

Figure 4 illustrates the spectral power distribution of typical High Pressure Sodium (HPS) lamps. Because the lumen output, by convention, has always been calculated as the amount of light perceived by the eye under photopic conditions (the bold curve), HPS lamps have high lumen ratings. It is not significant that the sodium lamp produces a high power output, but rather that its energy peak is near the maximum photopic sensitivity wavelength of the eye.

As shown in Figure 4, the HPS lamp has diminutive power output at wavelengths shorter than the peak. Therefore, the lumens as they apply to rod vision (the dashed curve), are much lower than the rated or conventional lumens.

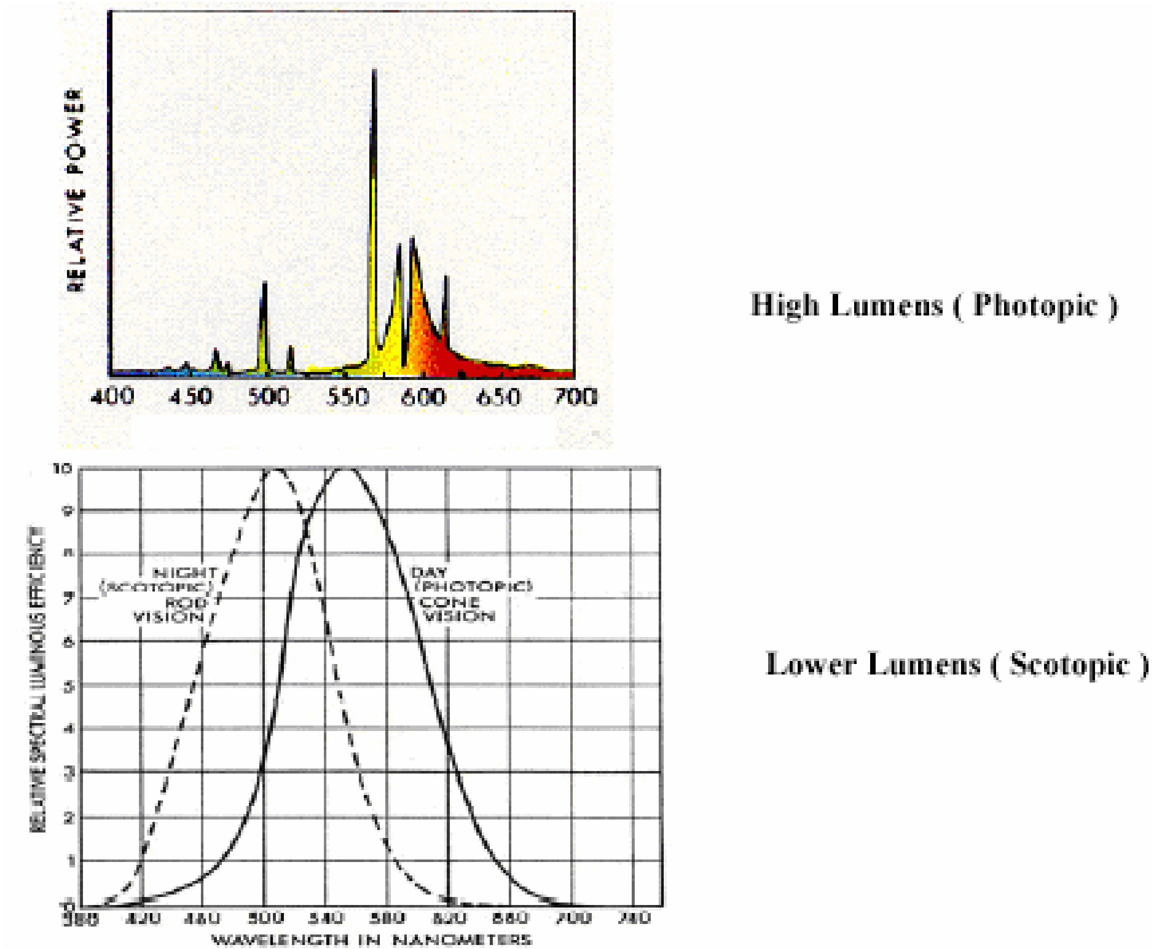


Figure 4: Spectral Power Distribution of a Typical HPS Lamp[2]

The more wavelengths produced by a light's source, the closer it will be to natural day light. Thus, the HPS, in comparison to LPS, will produce more blue and green energy and be a better quality light. There is no doubt that HPS is "better" than LPS for most lighting applications. It has even been reported that LPS causes headaches and discomfort to people subjected to the light over time. However, in evaluating the lumens of HPS & LPS, the results are surprising. HPS produces 45-110[16] lumens per watt, but LPS produces 80-180[16] lumens per watt. Thus, LPS provides almost twice the lumen/watt as HPS, but for all intents is inferior for roadway lighting. Clearly, there are other factors than lumens which need to be considered when selecting a lighting technology, such as the spectral power distribution of a lamp in relation to the scotopic vision.

White Light Source

White light sources, such as Metal Halide, produce all wavelengths of light, including a high proportion of blue and green energy. Since the proportion of light produced in the yellow region is less than sodium sources, Metal Halide sources have lower lumens per watt. High lumen output is found by multiplying the power output curve of the Metal Halide lamp by the photopic sensitivity curve; however, this amount is not quite as high as HPS (as it appears in Figure 5).

It can be observed that some peaks in the Metal Halide power output lie in the high sensitivity region of the eye for low light levels (by the dashed curve for the rods). Likewise, the significant range of blue/green energy also lines up with the peak of the scotopic eye sensitivity curve. In conclusion, the effectiveness of a Metal Halide lamp increases as the light level reduces versus what might be expected from its rated lumens.

Furthermore, a strong yellow output is present, which triggers the cones.

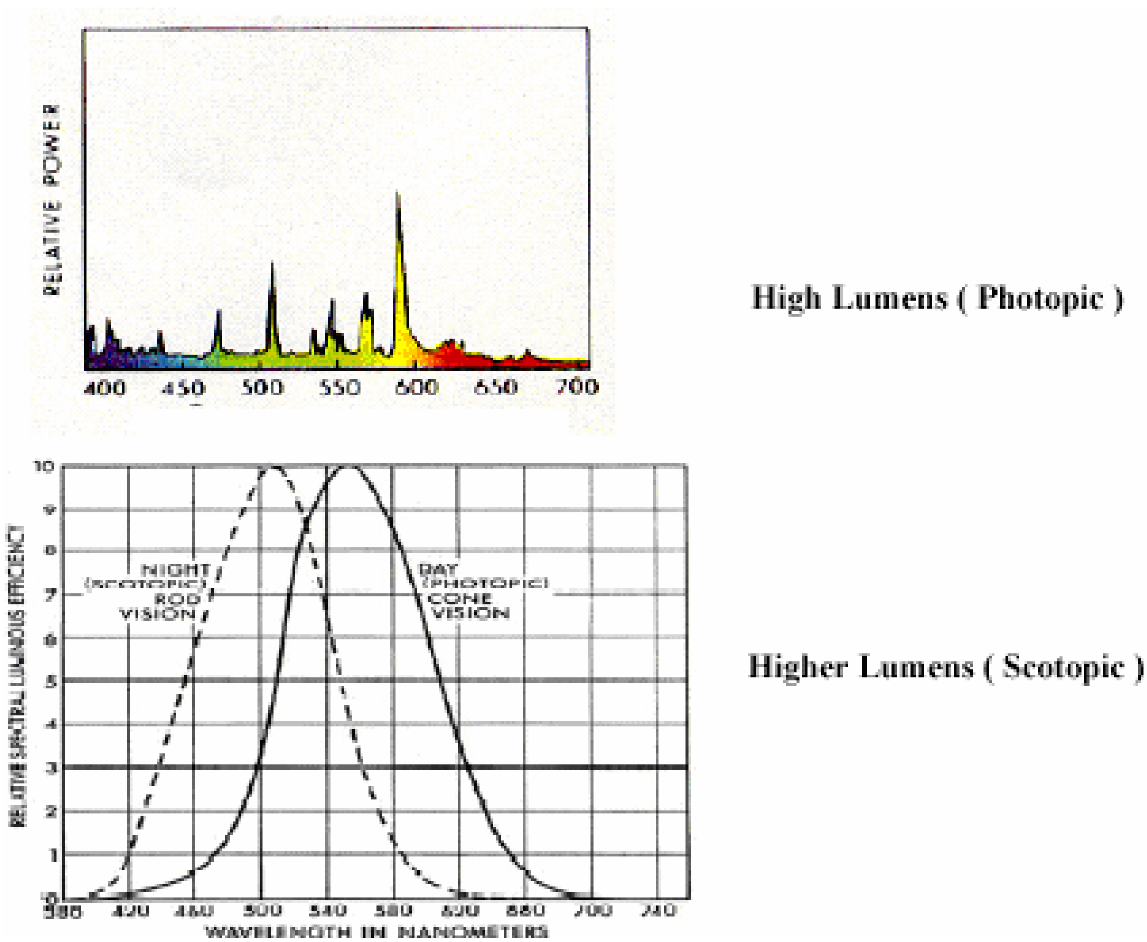


Figure 5: Spectral Power Distribution of a Typical Metal Halide Lamp(2)

Color Rendering Index

The ability to see colors properly is another aspect of lighting quality. Light sources vary in their ability to accurately reflect the true colors of people and objects.

The color rendering index (CRI) scale is used to compare the effect of a light source on the color appearance of its surroundings. A scale of 0 to 100 defines the CRI. A higher CRI means better color rendering, or less color shift. However, the CRI number does not indicate which colors will shift or by how much; it is rather an indication of the average shift of eight standard colors. Two different light sources may have identical CRI values, but colors may appear quite different under these two sources. CRI in the range of 75-100 are considered excellent, while 65-75 are good. The range of 55-65 is fair, and 0-55 is poor.

Under higher CRI sources, surface colors appear brighter, improving the aesthetics of the space. At times, higher CRI sources create the illusion of higher illuminance levels compared to the number of watts required by the lamp (and ballast). Sources with higher efficacy require less electrical energy to light a space. Table 1 illustrates CRI values for different light sources; and accordingly, Figure 6 exemplifies mesopic vision of color rendering under aforementioned light sources (HPS and white light source).

Table 1: CRI values for selected light sources[4]

Source	**Typical CRI Value**
Incandescent/Halogen	100
Fluorescent	
Cool White T12	62
Warm White T12	53
High Lumen T12	73-85
T8	75-85
T10	80-85
Compact	80-85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low Pressure Sodium	0
QL	80
Icetron	80

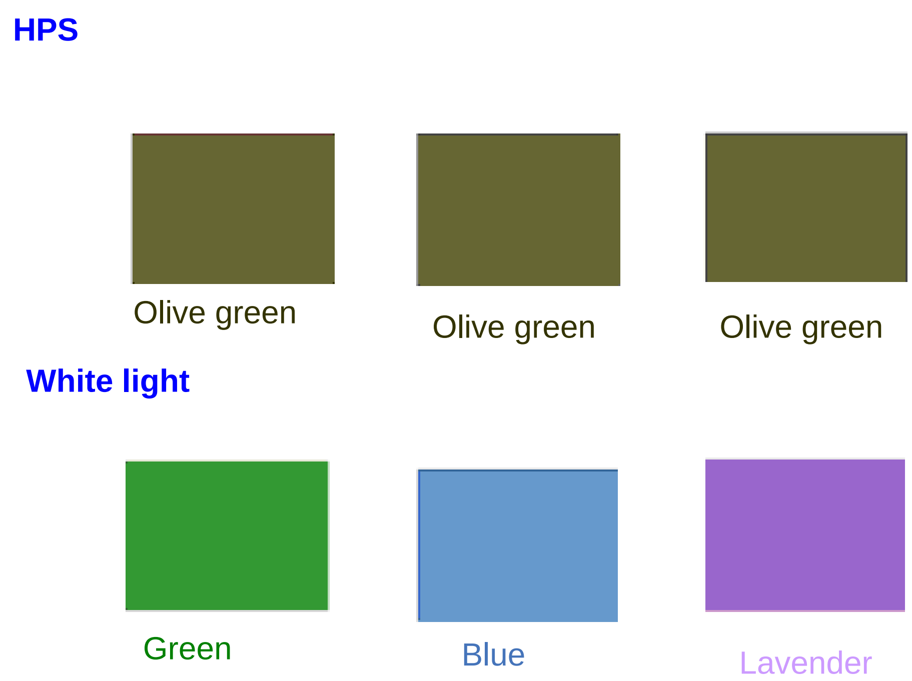


Figure 6: Color rendering demonstration, exaggerated comparison for HPS and White Light[2]

Lighting Level

In order to investigate light level, sensitivity to contrast, and reaction time for several light source types, Dr. Alan Lewis, President of the New England School of Optometry, directed some laboratory studies. In this experiment, observers were asked to detect the appearance of a person standing at the curb and to determine whether the person constituted a possible hazard (pedestrian facing the roadway) or not (facing away). Figure 7 graphs the time taken by the observers to make this determination versus luminance level, for the various sources. At moderately high lighting levels of 3 cd/sq.m. and over, light source type has no effect. However, as lighting levels become progressively lower, the sodium sources require increasingly longer reaction times, versus the white Metal Halide source. At very low levels, the difference is very significant.

Also, Figure 7 illustrates that a given visibility, as measured in terms of reaction time, is achievable using all three light sources (LPS , HPS, white LS), at least over a limited range. The horizontal line representing a 775 msec reaction time intersects all three curves. Dropping vertical lines from each curve to the X-axis provides the luminance level needed to produce that reaction time in this experiment for each source. This visibility can be produced by a much lower level of MH than HPS. For LPS, a higher lighting level is needed to produce the illustrated reaction time.

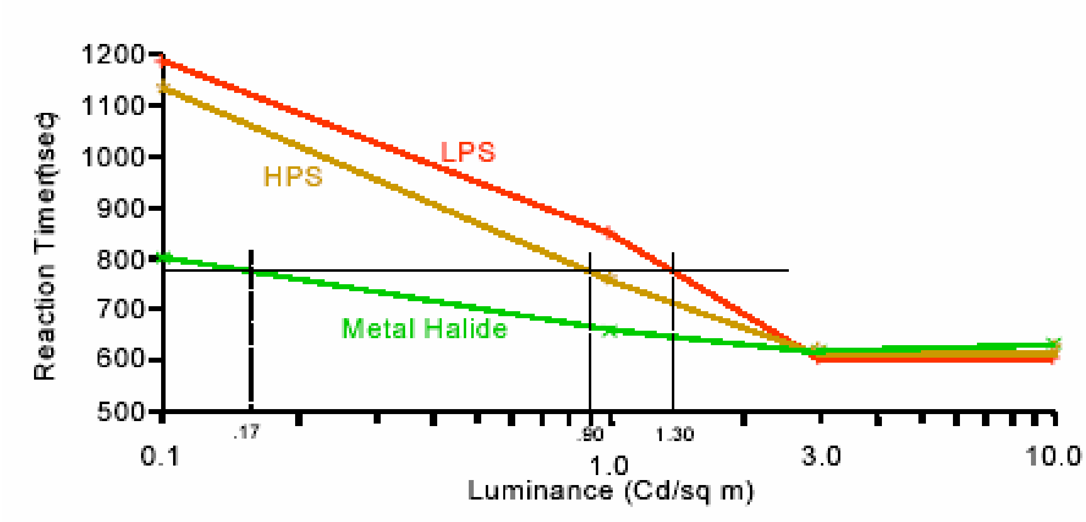


Figure 7: Luminance level for a Fixed Reaction Time[2]

There is a trade-off between lighting level, visibility, and lamp type. To the extent that data similar to those shown in Figure 7 are applicable in the real-world situation, it appears that use of Metal Halide sources could allow a reduction in lighting levels. Based on identical photopically measured luminance, a Metal Halide source is 30 times more effective than a High Pressure Sodium source.

On the contrary, if LPS is used to provide similar lighting levels, as are typically designed today, evidence suggests that roadway visual tasks that are affected by mesopic vision characteristics will have reduced visibility, and that a decrease in safety is a possible result.

Brightness Matching

Considerable research has been conducted under the auspices of the CIE (International Commission on Illumination- abbreviated as CIE from its French title Commission Internationale de l'Eclairage). The data was produced primarily by Kinney and has been analyzed by Adrian. The primary goal of this study was "brightness matching" and to find a procedure where the evident brightness of various color are produced.

Professor Junjian He and his associates have also derived mesopic response functions. Although their work was based on reaction times of subjects under different light sources at different luminances, the results show similar conclusions to the CIE data. Therefore, at this time, the CIE data appears to be useful for comparing relative light levels between sources for equal visual results.

The concepts of "Spectral Correction Factors", (SCF), and "Lumen Effectiveness Multipliers", (LEM), developed are described in detail in the following section. In brief, these factors are dependent upon light level and the spectral power distribution of the source which therefore can be used to correct a calculated photopic or conventional lighting level to an equivalent level, based on the visibility or brightness produced.

Average roadway lighting levels generally fall in the range of 0.3 to 1.2 cd/sq.m. The curve in Figure 8 shows that at 0.75 cd/sq.m. (midpoint of average roadway lighting range) the correction factor is 1.4. This factor is the ratio of Metal Halide to HPS equivalent luminance. This indicates that, on this basis, roughly half the lighting level of Metal Halide, versus HPS, can be used to produce equivalent visibility. This is intended to be illustrative only; the actual factor for any given location will be dependent upon the lighting level at that point. Note that minimum levels may fall as low as 0.03 cd/sq.m.

The multipliers will show a less dramatic effect at “high” roadway lighting levels, and a greater effect at “lower” levels. As a further consideration, it may be argued that under a given lighting system, accidents are more likely to occur in dark areas. For example, a pedestrian is less likely to be detected if silhouetted against an area where the lighting level is lowest.

That is why lighting standards address uniformity, to ensure that levels in a certain part of the roadway do not fall too far below the average. At locations of low lighting levels, the Metal Halide multiplier versus that for HPS is at its greatest, and therefore the increased safety created by the white source is highest at just the point where it is needed the most.

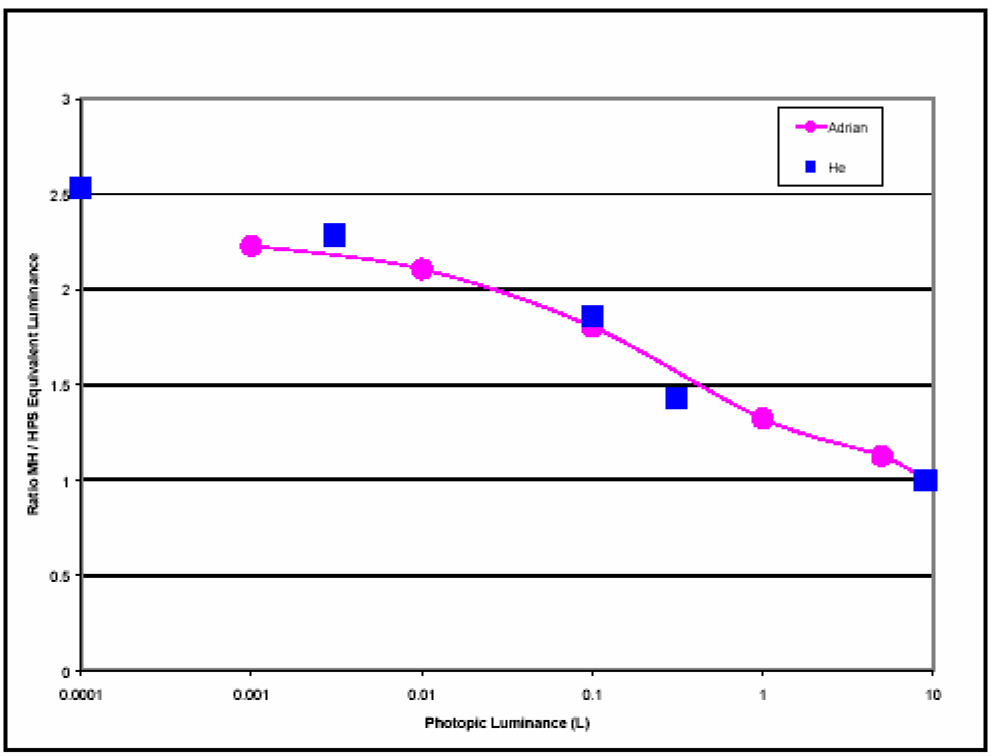


Figure 8: Comparison of Professor Adrian and Professor He Data(2)

Lighting Design and Lumen Effectiveness Multiplier

Luminance contrast and color are important determinants of performance in a range of visual tasks which can be used in light designing. For instance, as luminance contrast is increased, an improvement is observed in both visual acuity and reading speed.

Unfortunately, as described before, there is not an internationally accepted model that demonstrates all the variances of a lamp's spectral distribution accurately and no standard method for computing lamp lumens in the mesopic region.

Professor Adrian proposed "Lumen Effectiveness Multiplier" (LEM) for computing lamp lumens. This factor is the comparison between two different light sources and simply defined and used as a ratio of effectiveness between two spectral distributions, for chosen conditions and one of them is a base case for comparison. Professor He stated LEM as:

$$LEM = \frac{\text{Visual effectiveness of the light source}}{\text{Visual effectiveness of a standard light source}} \qquad \text{Equation(2)}$$

Professor He adopted LEM as a primary factor in the calculation of lamp lumens in outdoor lighting and introduced High Pressure Sodium as a standard light source. Since there are numerous factors which effect lamp spectral distribution, different approaches can be applied for developing actual LEM values. One of them is mesopic response function based on brightness matching data, which Professor Adrian proposed, and another is mesopic response function based on visual performance data described by Professor He.

In brief, the LEM value proposed by Professor Adrian (based on brightness) may be calculated by the following relation:

$$LEM = \frac{\text{Mesopic lumens for source}}{\text{Rated lumens for source}} * \frac{\text{Rated lumens for HPS}}{\text{Mesopic lumens for HPS}} \qquad \text{Equation (3)}$$

Table 2 provides LEM values calculated from the work of Professor Adrian and the researchers who contributed to the development of the response functions based on brightness matching.

Table 2: LEM calculated from empirical data developed by Professor Adrian work[3]

High Pressure Sodium = 1.00

From Brightness Matching Mesopic Functions

Luminance (cd/Sq.m.)	**0.001**	**0.01**	**0.1**	**1**	**3**	**10**
Metal Halide	2.25	2.11	1.82	1.35	1.13	1
High Pressure Sodium	1	1	1	1	1	1
Clear Mercury	1.48	1.43	1.38	1.22	1.09	1
Low Pressure Sodium	0.47	0.51	0.61	0.82	0.95	1

Another approach, which is based on Professor He's research, described previously, is based on the true measure of visual performance. Professor He's functions can be applied in an identical manner to that described for brightness matching functions in developing values for LEM for any spectral distribution. This is a major advantage of this research and the data it has produced. Table 3 illustrates this data and Figure 9 shows the Lumens Effective Multiplier for different light sources.

Table 3 : LEM calculated from data developed By Professor He[3]

(High Pressure Sodium = 1)

From Reaction Time Mesopic Functions

Luminance (cd/Sq.m.)	**Scotopic**	**0.03**	**0.1**	**0.3**	**Photopic**
Metal Halide	2.58	2.3	1.88	1.4	1
High Pressure Sodium	1	1	1	1	1
Clear Mercury	1.98	1.79	1.53	1.22	1
Low Pressure Sodium	0.35	0.46	0.64	0.83	1

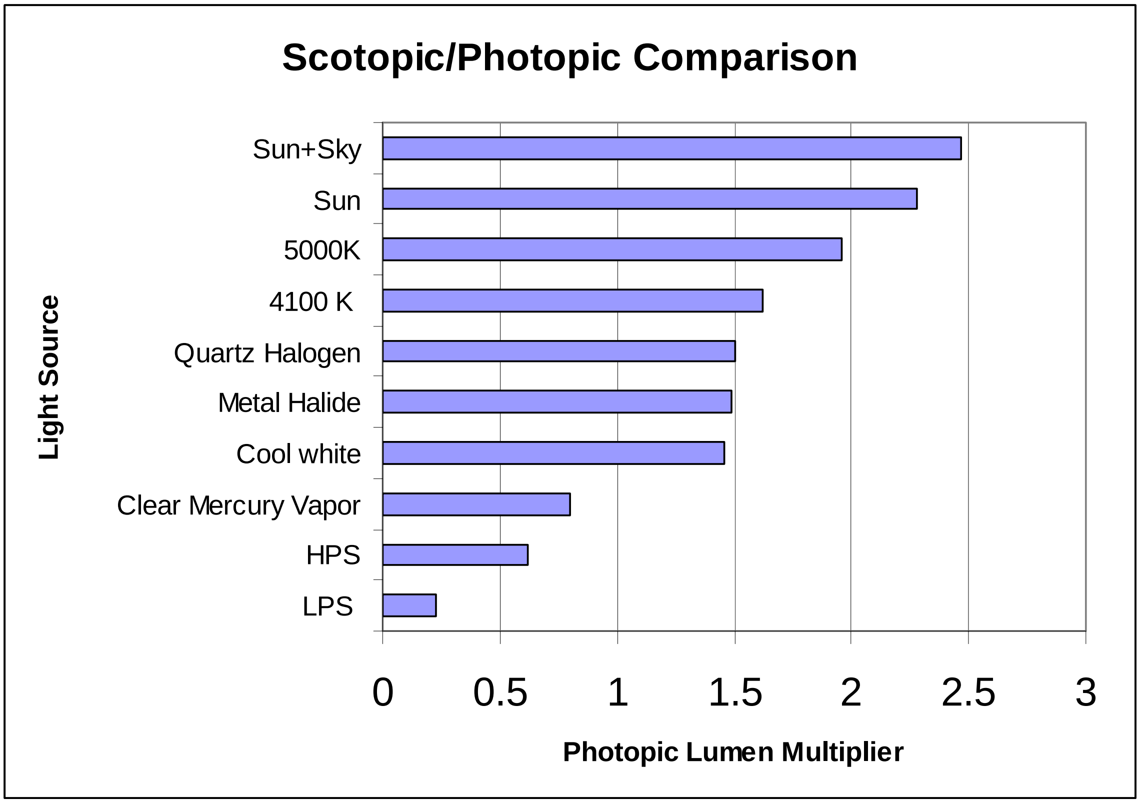


Figure 9: Lumen Effective Multiplier for different light sources

Correlated Color Temperature (CCT)

A description of the color appearance of a light source is measured in Kelvin. Lamps with a Correlated Color Temperature (CCT) below 3500K are considered "warm", and are more reddish in color. Lamps above 4000K are considered "cool" sources, and more bluish in color. In spaces with considerable daylight, lamps with a high color temperature (4100K or higher) will match the color of the light from the sun.

Incandescent lamps are usually "warm" in color. In rooms with both incandescent and fluorescent luminaires, "warm" fluorescent lamps with a low color temperature (3500K or lower) will match the color of the incandescent lamps. Figure 10 illustrates CCT values along the color appearances for different lamps.

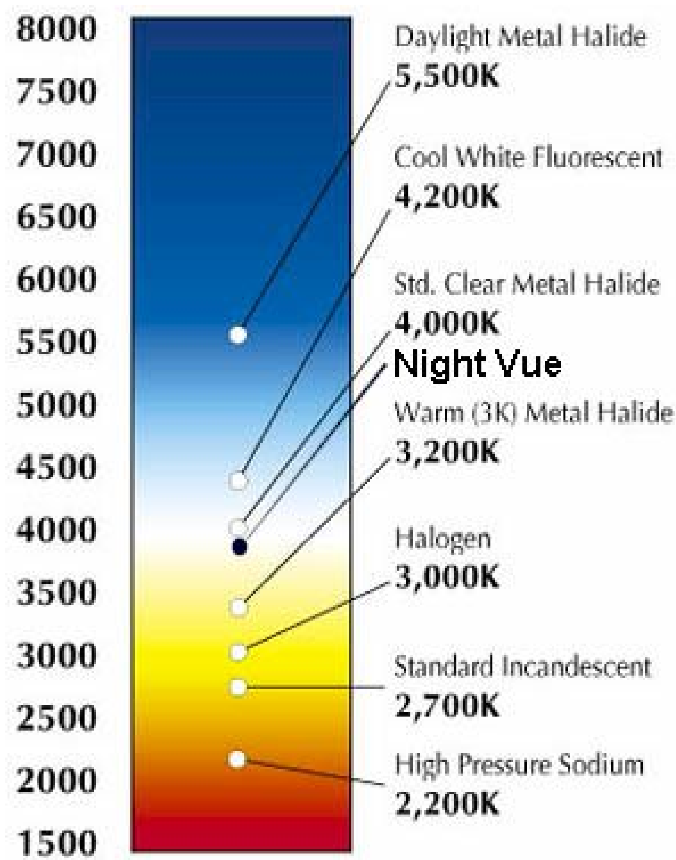


Figure 10: CCT for different lamps[6]

PHASE I : LITERATURE SEARCH

This section discusses the literature on the existing lamps' technology. For each cited lamp, a brief discussion regarding the lamp's infrastructure, its performance and application, lumen depreciation curve, and spectral power distribution is also provided.

Mercury Vapor (MV)

Introduced in the 1930's, the Mercury Vapor (MV) lamp was a revolutionary event in the history of lamps and a pioneer in High-Intensity Discharge (HID) light sources. MV lamps were initiated as a direct replacement for the Edison incandescent lamp. The lamp is able to function without external ballast through applying the length of tungsten filament within the lamp structure to provide current regulation (see Figure 11). The pressure at which a mercury lamp operates has a significant impact on its characteristic of spectral power distribution. In general, higher operating pressure tends to shift a larger proportion of emitted radiation into longer wavelengths. At extremely high pressure, there is also a tendency to spread the line spectrum into wider bands. Within the visible region, the mercury spectrum consists of five principal lines

(404.7, 435.8, 546.1, 577, and 579 nm), which result in greenish-blue light. While the light source itself appears to be bluish-white, there is a deficiency of long wavelength radiation and most objects appear to have distorted colors. Blue, green, and yellow are emphasized; orange and red appear brownish. The spectral power distribution can be observed in Figure 13.

Since MV primarily has not significantly changed since its initiation, MV is being gradually replaced by better-performing lamps, such as MH and HPS, with better CRI and mean lumens. Currently, MV lamps are used primarily in spaces that are not frequently occupied by people, because of color distortion. A phosphor coating is added to get better CRI, but the improvement is small in comparison to HPS. Outdoor security, street lighting, and landscape lighting are some of the applications for MV lamps; however, as mentioned previously, these MV applications appear to be losing ground to new technology. The MV lamps are available in wattages from 50 to 1000 watts. The most common wattage is the 175-watt lamp, followed by the 400-watt lamp, and then the 100-watt lamp. Mercury Vapor has a mean life from 12,000 to 24,000 hours. Figure 12 exhibits lumen depreciation curve for Mercury Vapor.

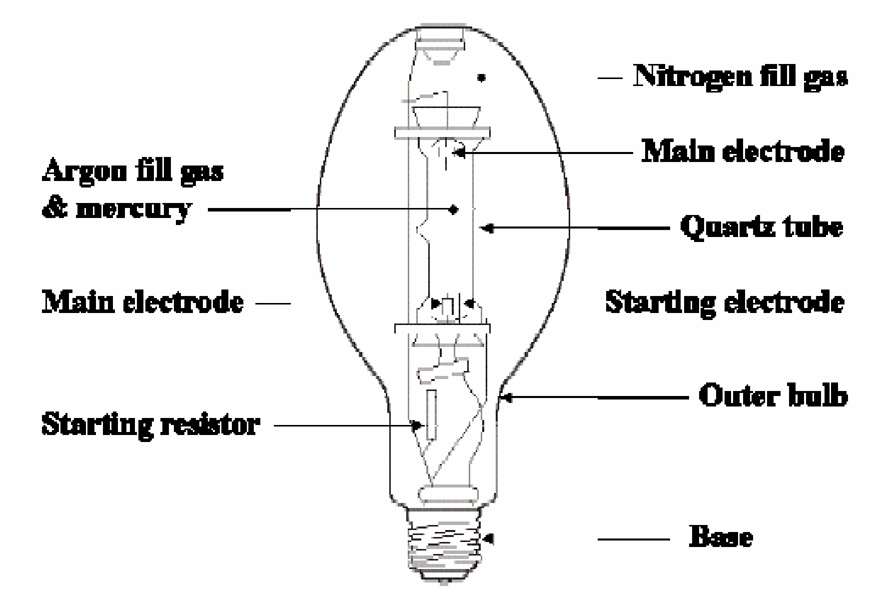


Figure 11: Construction of Mercury Vapor (MV) lamps[8]

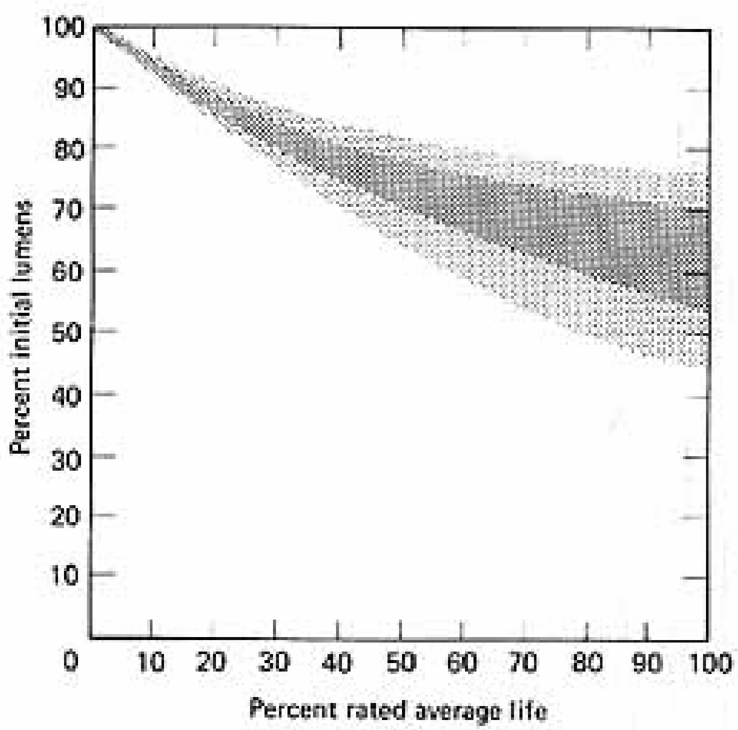


Figure 12: Lumen depreciation curve

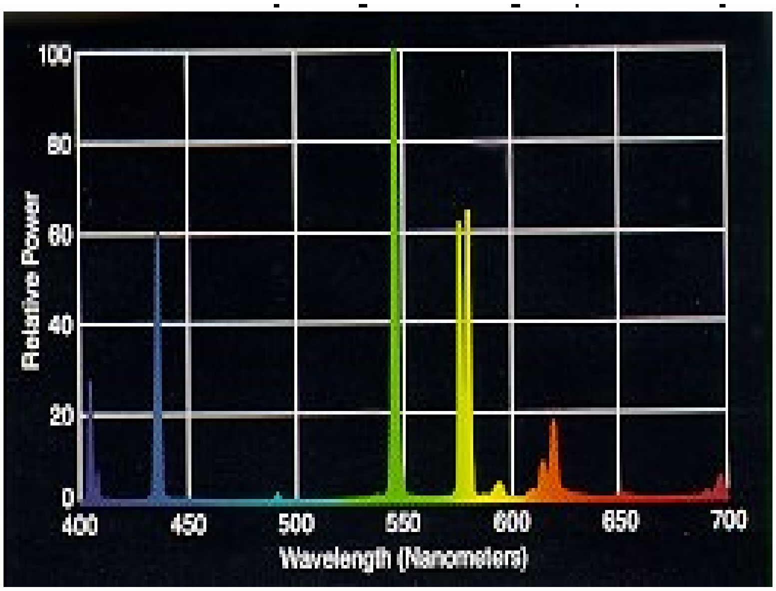


Figure 13: Spectral power distribution

Metal Halide (MH)

Developed in the 1960's, just after the HPS lamp, the standard MH lamp is similar to its mercury lamp predecessor, with significant advancements. The major benefits of this change is an increase in efficacy to between 60 and 120 lumens per watt and an improvement in color rendition to the degree that this source is suitable for commercial areas.

The Metal Halide arc tube contains various Metal Halides, in addition to the mercury and argon (see Figure 14). When the lamp attains full operating temperature, the Metal Halides in the arc tube are partially vaporized. As the halide vapors approach the high-temperature central core of the discharge, they are disassociated into the halogen and the metals, with the metals radiating their light spectrum. As the halogen and metal atoms move near the cooler arc tube wall by diffusion and convection, they recombine, and the cycle repeats. The use of Metal Halides inside the arc tube presents two advantages. First, Metal Halides are more volatile at arc tube operating temperatures than pure metals. This allows the introduction of metals with desirable emission properties into the arc at normal arc tube temperatures. Second, those metals that react chemically with the arc tube can be used in the form of a halide, which does not readily react with fused silica.

The MH lamps are available in low (less than 175 watts), medium (from 175 to 400 watts) and high (greater than 400 watts) wattages. A disadvantage of the Metal Halide lamp is its shorter life (7,500 to 20,000 hrs) as compared to mercury and High Pressure Sodium lamps. The lumen depreciation curves displays in Figure 15. Starting time of the Metal Halide lamp is approximately the same as for mercury lamps. Restrike delay after a voltage dip has extinguished the lamp, however, can be substantially longer, ranging from 4 to 12 minutes depending on the time required for the lamp to cool. Figure 16 illustrates spectral power distribution for Metal Halide (MH).

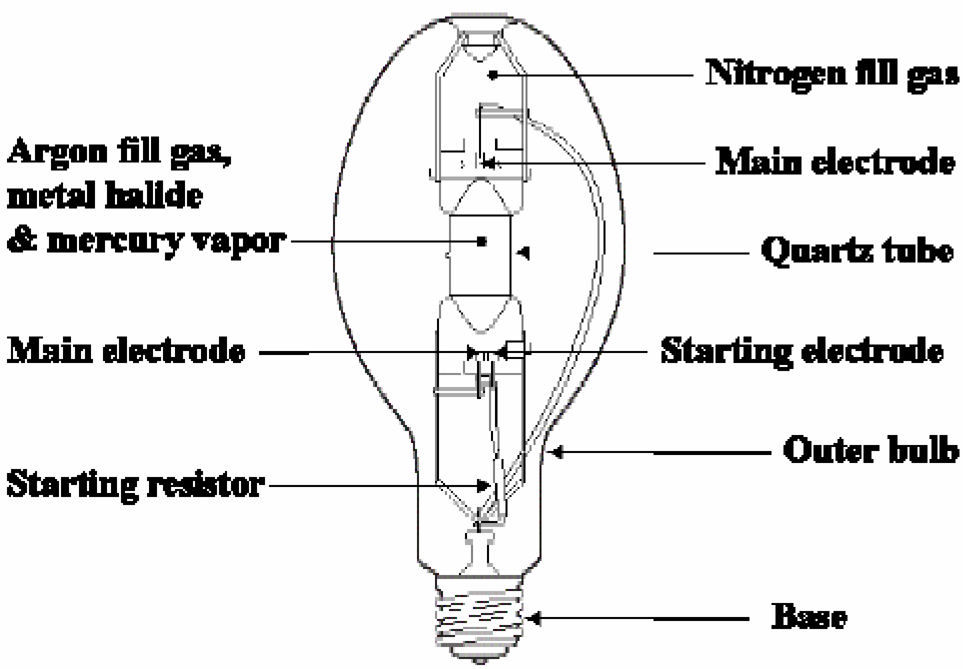


Figure 14: Construction of Metal Halide (MH) Lamps[8]

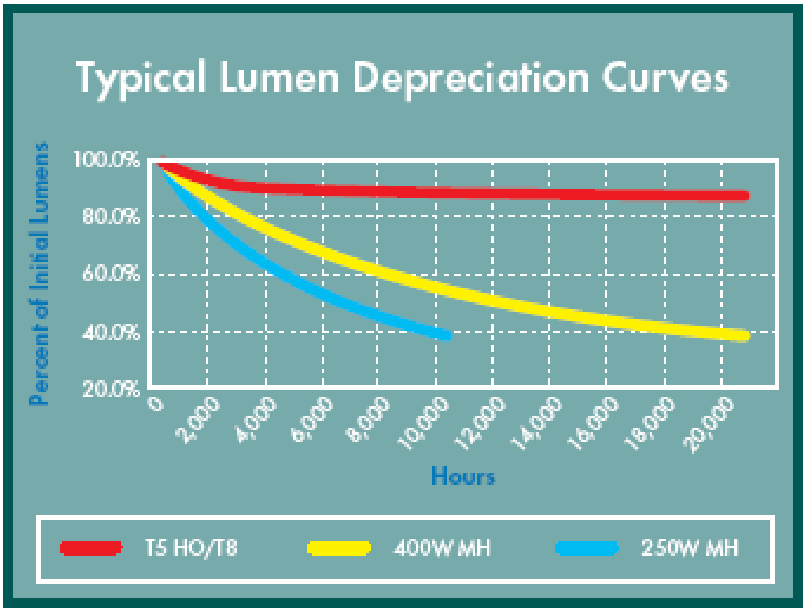


Figure 15: Lumen depreciation curve

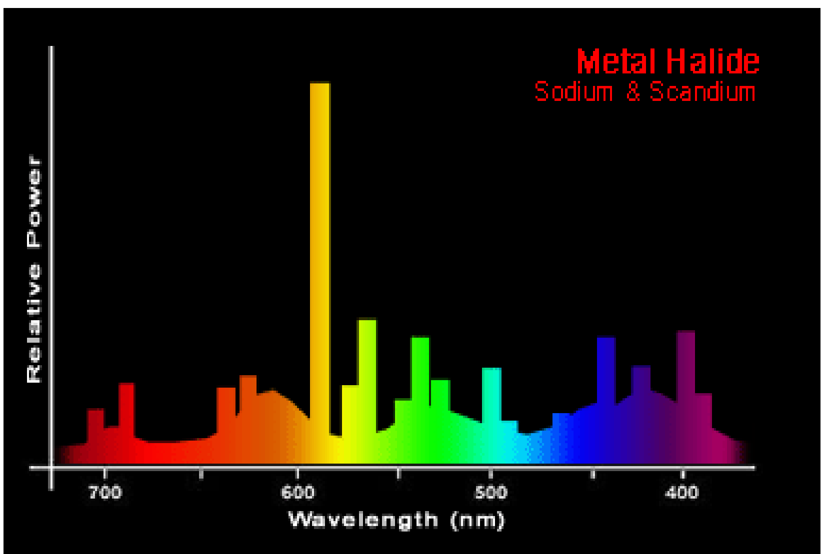


Figure 16: Spectral power distribution[10]

Low Pressure Sodium (LPS)

Since its commercial introduction in 1932, the Low Pressure Sodium lamp has consistently maintained its enviable position as the most efficient light source available. Present-style LPS lamps are known as the Sodium OXide (SOX) type. The construction of a typical SOX lamp is illustrated in Figure 17.

SOX lamps are generally employed in street lighting applications, primarily because they deliver more lumens of light for each watt of power and are more efficient than any other type of lamp. This fact is illustrated in Figure 18. SOX installations therefore have the lowest energy consumption costs, which is critically important when thousands of miles of roads must be lit and the electricity bills must be kept as low as possible. The principal reason for the high efficacy is because the color of the light is close to the maximum sensitivity of the human eye in normal viewing conditions. (See Figure 19).

LPS is the favoured light source for tunnel illumination, particularly in Japan and Korea where underground roads extending 10 miles or more are not unusual. The lamp is relatively inexpensive and can be operated on low cost electrical control gear. Furthermore, LPS contains zero mercury and can be easily disposed as non-toxic waste without incurring extra expense at its end of life. Most High Pressure Sodium, and all other light sources employed in street lighting, contain poisonous mercury and special restrictions apply to the disposal of used lamps. A final advantage is that being a low pressure discharge lamp, its striking voltage is not sensitive to temperature, as is the case for other discharge lamps. Thus in the case of a momentary power supply interruption, the lamp will restrike as soon as the power is restored and no cooling down time is required.

In addition to these advantages, SOX does have two major drawbacks. No color rendering is possible under this light source and its rated life is shorter than other types of discharge lamps. Typical installations have to be re-lamped every two or three years, whereas the expensive maintenance schedule can be extended to five or six years with High Pressure Sodium. This reduced maintenance cost can offset the energy savings of Low Pressure Sodium for certain installations.

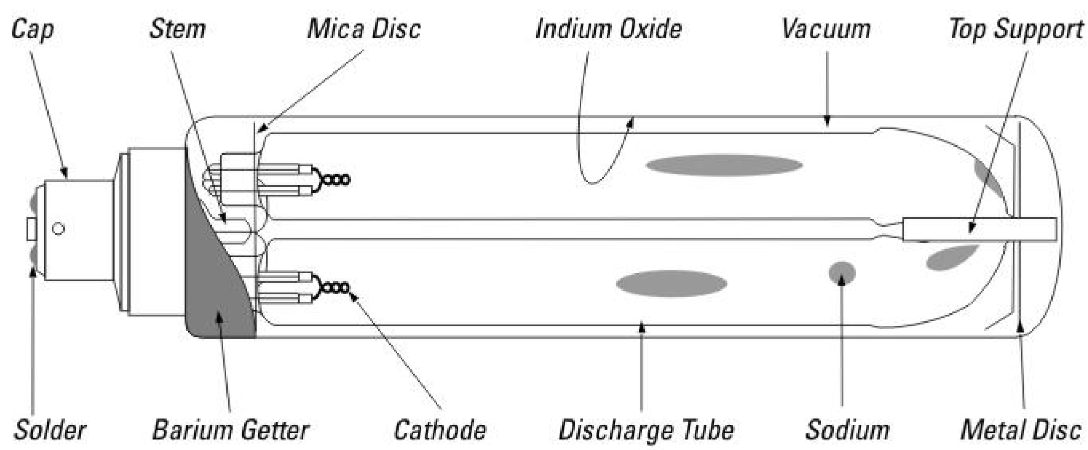


Figure 17: Typical Sodium OXide (SOX) lamp

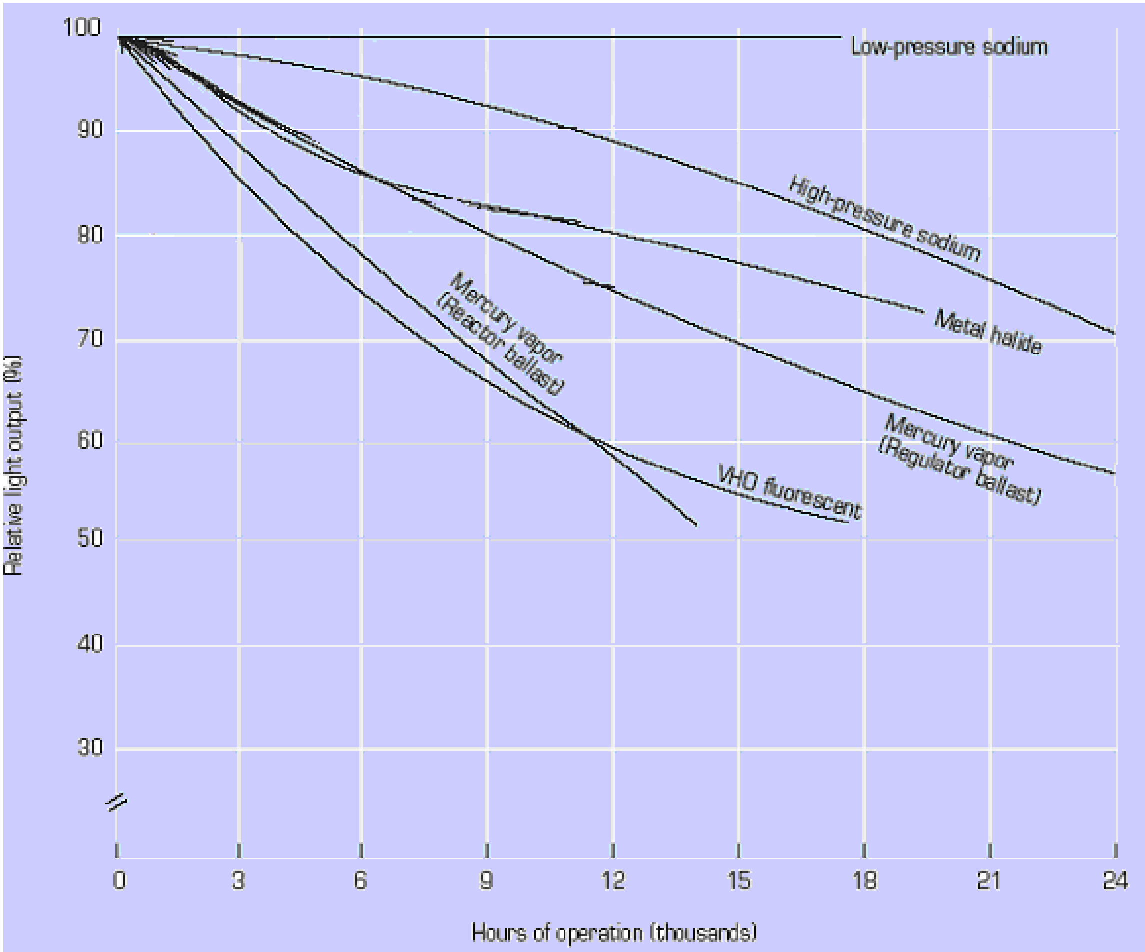


Figure 18: Lumen depreciation curve for LPS and other competitive lamps

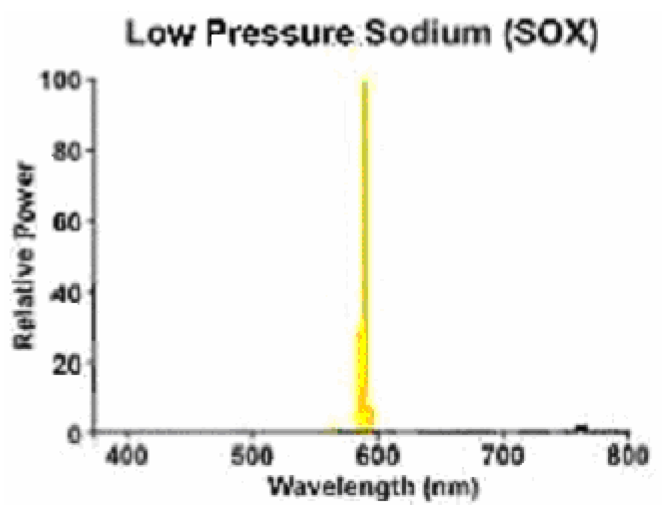


Figure 19: The spectral power distribution of the Low Pressure Sodium lamp

High Pressure Sodium (HPS)

Introduced in the 1960's, High Pressure Sodium (HPS) currently is the most appropriate, efficacious, and inexpensive lamp, which is being used in road lighting, although new technology is coming to take its place rapidly.

HPS lamps have a two-bulb construction (see Figure 20). The arc tube is made of a ceramic material that contains the electrodes, sodium, and mercury amalgam, and a small amount of xenon. No starter probe is present in the HPS arc tube. The tube is long and slender and is made of polycrystalline aluminum oxide ceramic. The high temperatures needed to vaporize sodium dictate the geometry and material. Furthermore, the highly corrosive nature of sodium, especially at elevated temperatures, precludes the use of certain materials such as quartz. Therefore, the arc tube is manufactured from a ceramic material.

The outer envelope is elliptical in shape and is made of a hard glass that primarily acts to protect the arc tube from damage. Usually, it contains a vacuum, which acts to reduce convection and heat losses from the arc tube to maintain high efficiency.

HPS lamps are used in applications where energy efficiency and long life are the primary concern, with little regard to color rendering. Figure 21 and Figure 22 illustrate the lumen depreciation curves and the spectral power distribution respectively. Although HPS lamps are available in wattages from 35 watts up to 1000 watts, typical wattages for these applications range from 50 to 400 watts. In addition, the limited color temperatures and low color rendering results in the lamp's inherent lack of variety in available product packages. Applications include outdoor stationary, commercial, and industrial sectors. Commonly used as street and parking lights, HPS lamps also provide visibility and a sense of security by illuminating public access areas, subways, parks and other pedestrian areas.

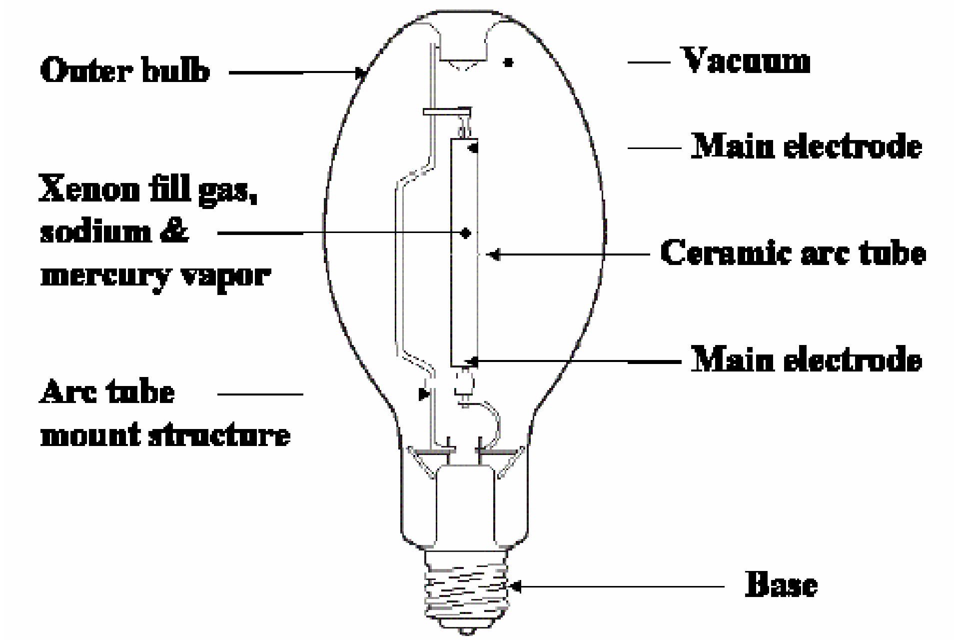


Figure 20: Construction of High Pressure Sodium (HPS)[8]

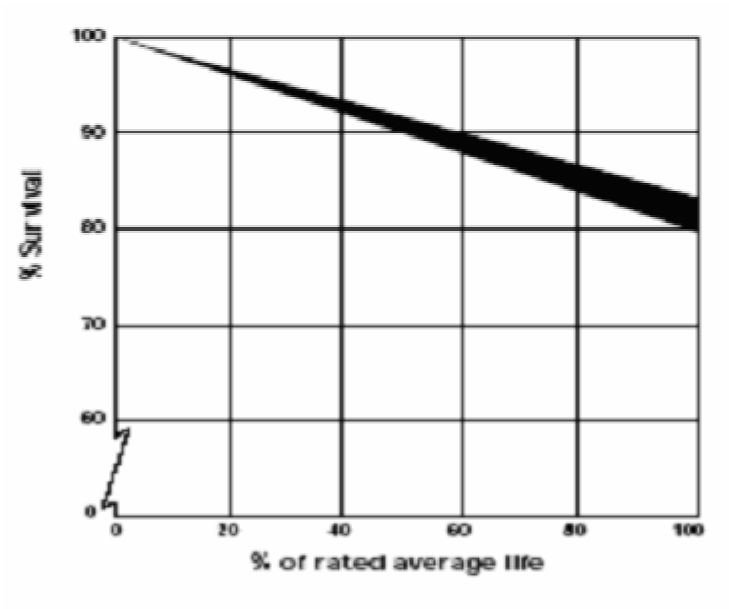


Figure 21: HPS lamp with 24,000 hr, mean life

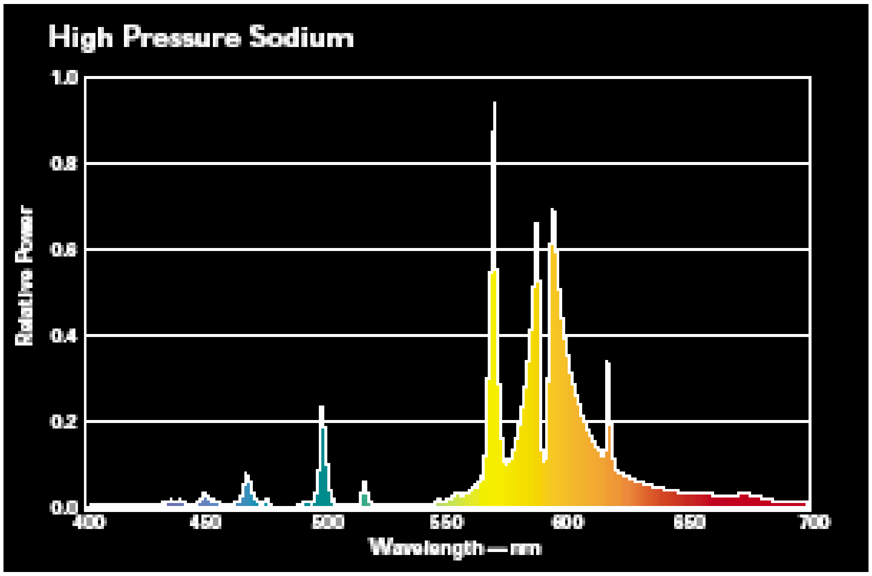


Figure 22: Power Distribution Curves in relation to mesopic vision

HPS Retro White

Philips Electronics introduced HPS retro-white to replace yellow light with crisp, bright white light (significantly better CRI) by compensating 17% reduction in footcandles, as it is illustrated in Figure 24. This lamp is ideal for indoor application, such as industrials, warehouses and parking lots, and locations which require working operation 24 hr/7 days a week.

The patent-pending coil design, applied in retro white construction, offers protection for open fixture rating, as it can be observed in Figure 23. Furthermore, it uses ALTO lamp technology to pass the EPA test for non-hazardous waste. Therefore, it offers reduced cost for hazardous waste disposal. For the sake of readers' knowledge, Alto means that the lamps pass the US government's TCLP (Toxicity Characteristic Leaching Procedure).

The rated life of this lamp is about 15,000 hours, compared to HPS with 24,000. It is as energy and cost efficient as the current HPS lamps and is a direct replacement for the currently used HPS lamps. HPS- Retro-white lamp is available in both 250W and 400W and as mentioned before, it does not require periodic shut-off like Metal Halide. The proper operation position of this lamp is vertical, based up or down, and it is not appropriate for horizontal position.

The most commonly used fixture for the state roadway system is the cobrahead, which operates in the horizontal position. Therefore, the HPS retro white cannot be used in these fixtures currently. The HPS Retro white can be used in an Expressway Fixture which operates in the vertical position. Philips engineering is currently working to redesign the lamp for universal operation, but the revised lamps are not yet commercially available.

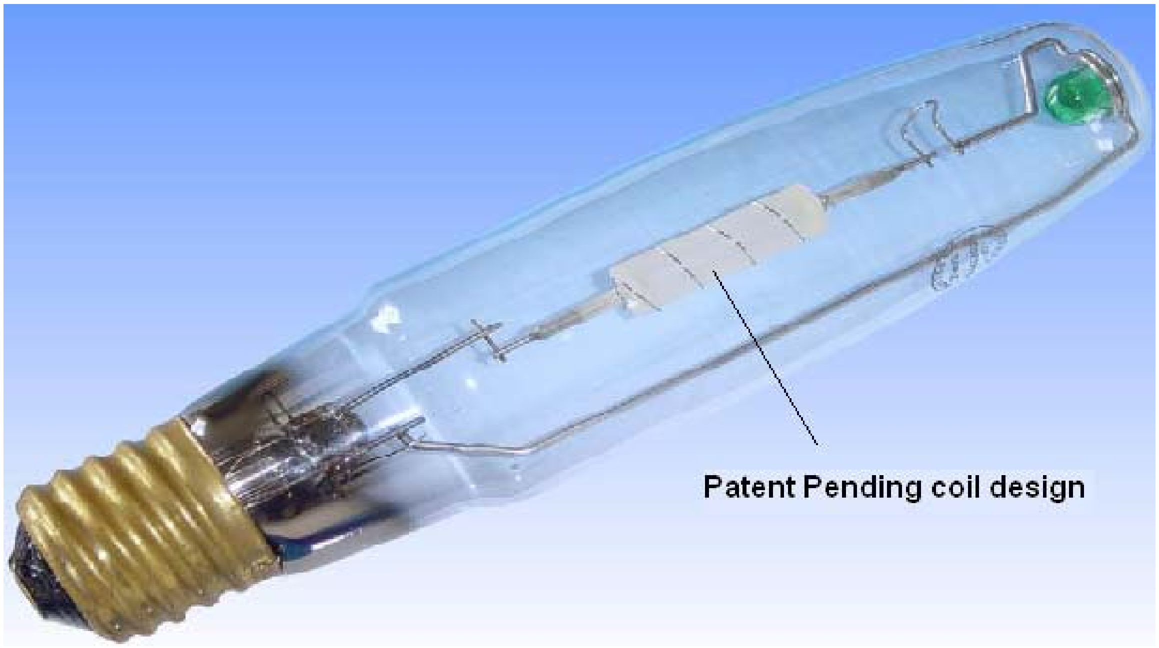


Figure 23: HPS retro- white

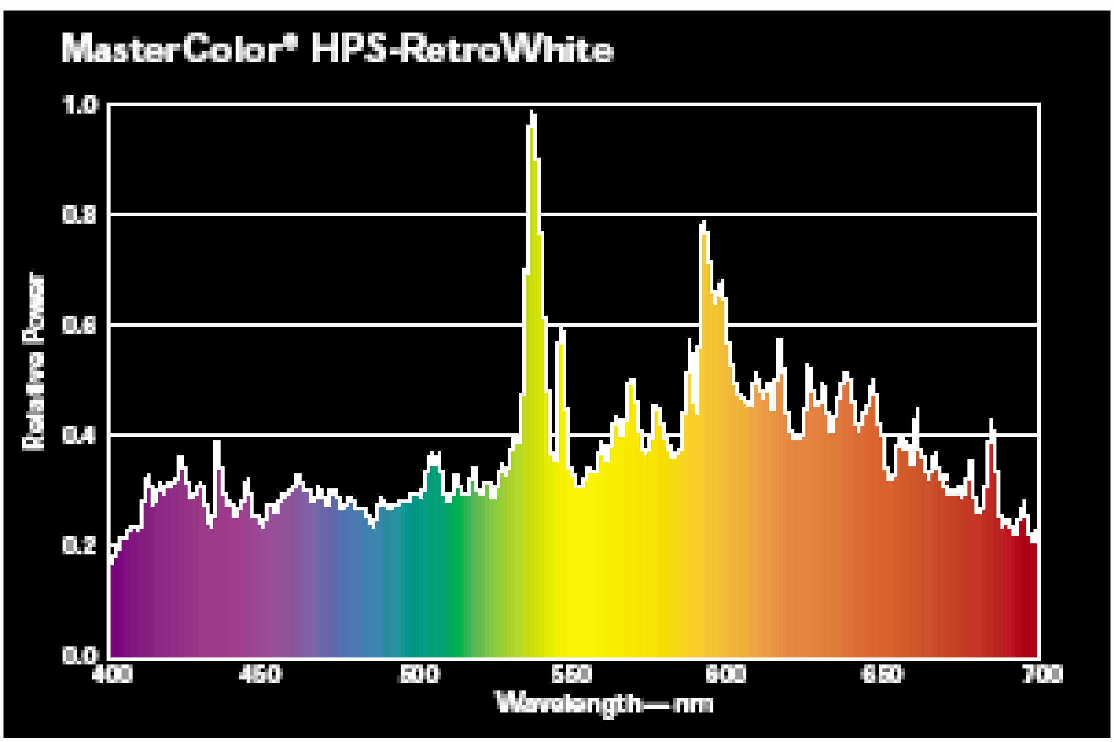


Figure 24: The spectral Power Distribution Curves in relation to mesopic vision

Instant Restrike High Pressure Sodium

The rated life of this lamp is 24,000 hours when used with the instant restrike for power interruptions. This lamp has two filaments (see Figure 25) mounted in parallel, and is designed to utilize the second filament to expedite the start-up process, thus avoiding the delay caused by the cool-start-up cycle normally experience by HPS lamps. Only one filament is lighted at a time. When this lamp is used in a more traditional application, the rated average life is 40,000, thus, a significant increase in life with fewer relampings. The estimated cost per restrike lamp is just a little less than two traditional HPS lamps. The advantage of these lamps is that the replacement cycle is cut in half, thus reducing maintenance costs while maintaining existing electrical and lamp costs. These lamps may be suitable for use in areas, which are difficult to mobilize in or in areas that are hazardous/difficult for maintenance personal to access.

It is as energy efficient as the current HPS lamps and is a direct replacement for the currently used lamps. The Spectral Power Distribution of this lamp is the same as HPS lamps

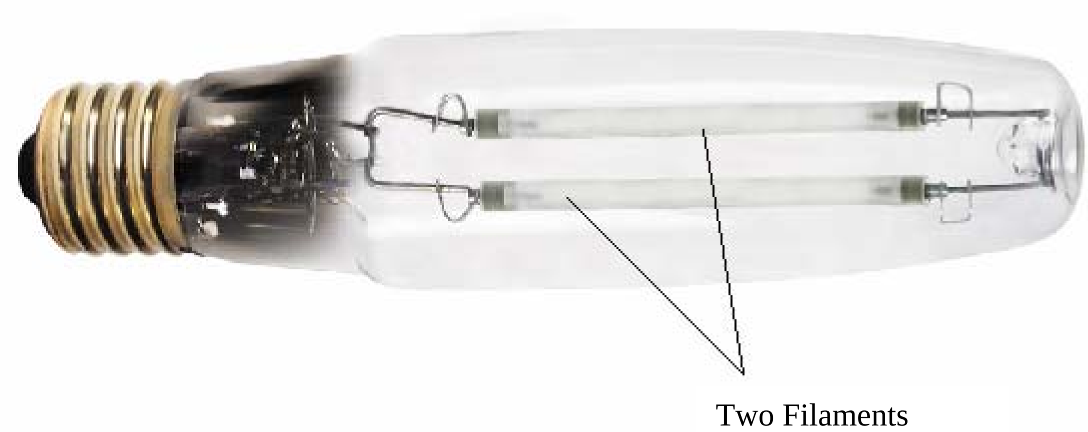


Figure 25: Instant Restrike HPS

QL Induction Lighting

QL induction lighting is manufactured by Philips Electronics. According to Philips, the QL is a completely different structure to generate light. QL does not use the glowing filaments of incandescent lamps, or the electrodes used in conventional gas discharge lamps. QL transmits the energy via a magnetic field combined with gas release in order to generate light by means of induction.

The QL System has three major components (see Figure 26), which Philips claims each of them can be exchanged independently if service is required:

- The vessel or discharge bulb is a closed glass bulb containing a low-pressure inert gas filling with a small amount of Mercury Vapor. The walls of the vessel are coated on the inside with a fluorescent powder of any of the modern three-line phosphor types, providing a choice of color temperatures. Currently, two different CCT for QL exist: 830 (3000K) and /840 (4000K). Each of them has different power distribution, which is illustrated in Figure 28. The discharge vessel is fixed to the power coupler by the plastic lamp cap with a click system. These two components normally never need to be disassembled, due to the ultra-long lifetime of the system.

- The power coupler transfers energy from the HF generator to the discharge inside the glass lamp, using an antenna that comprises the primary induction coil and its ferrite core. Other parts of the power coupler are a plastic support for the antenna, a 40 cm coaxial connecting cable carrying current from the HF generator and a heat conducting rod with mounting flange. The mounting flange allows the QL lamp system to be mechanically attached to the luminaire and removes waste heat to a heat sink which forms part of the luminaire.

- The HF generator produces the 2.65 MHz alternating current supply to the antenna.

In QL, the process of generating light initiates from a primary coil (induction coil), which is powered by the high-frequency electronics in the HF generator. The secondary coil is corresponded to the low-pressure gas and metal vapor inside the lamp. The induced current causes the acceleration of charged particles in the metal vapor. These particles collide, resulting in excitation and ionization of the metal vapor atoms and raises the energy level of the free electrons from these atoms to a higher, unstable state.

As these excited electrons fall back to their stable, lower-energy state, they emit ultraviolet radiation. This falls on the fluorescent coating inside the lamp, causing light to be emitted. One of the best features of this lamp is long mean life by having about 100,000 hours, which is illustrated in Figure 27.

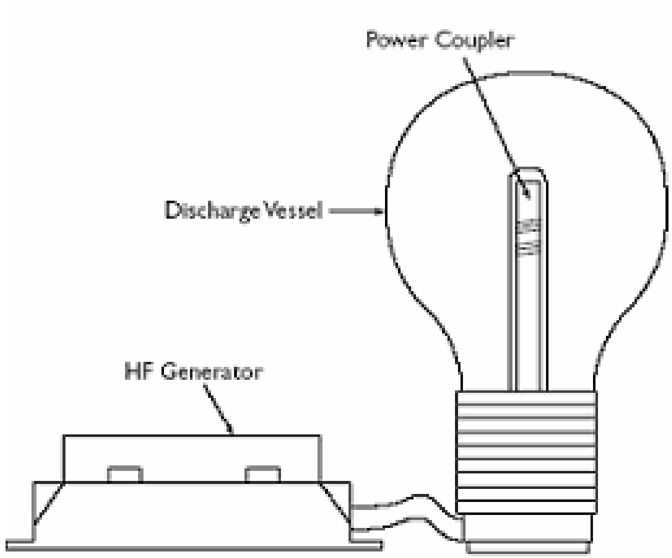


Figure 26: Construction of QL

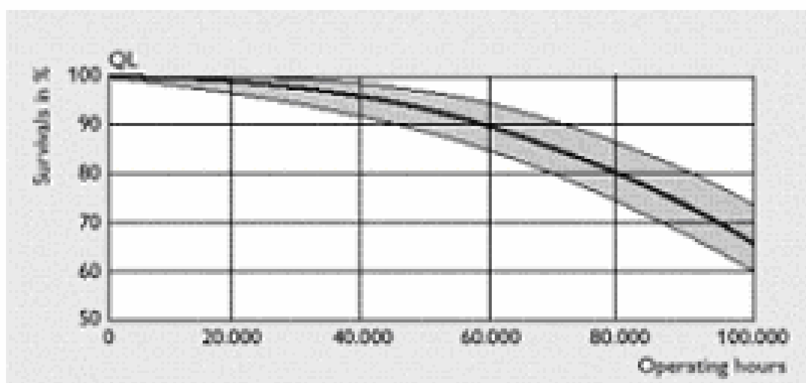


Figure 27: Life expectancy graph

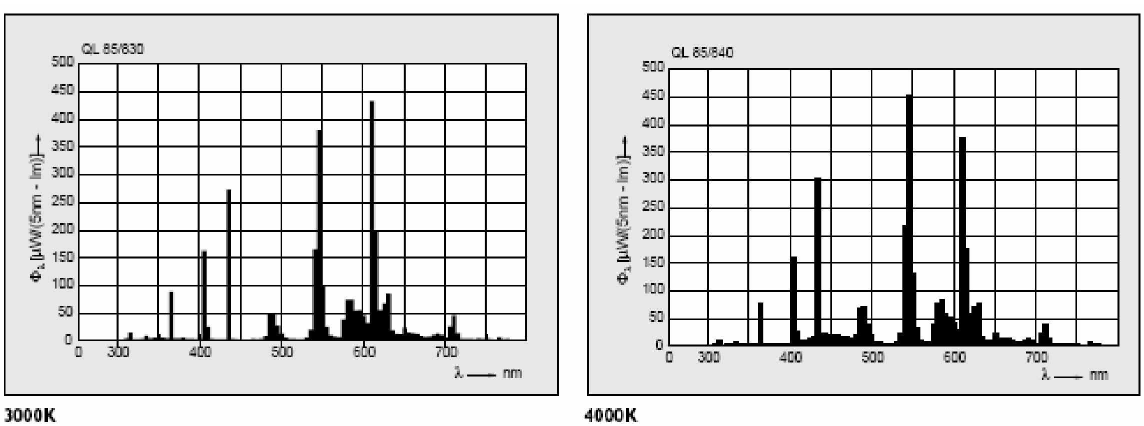


Figure 28: Power Distribution Curves with different CCT (QL 85)

Icetron

This lamp, manufactured by Osram Sylvania, does not have any electrodes and uses magnetic induction, at each end of the fluorescent tube, to produce illumination. The absence of electrodes (or filaments/wires) is a significant factor behind the much longer lamp life. The comparison to a fluorescent system is appropriate, since the operating theories of the induction system and fluorescent lighting are similar. The conventional fluorescent system, with its internal electrodes, utilizes the UV radiation generated by the internal discharge. The radiation is converted to visible light by the phosphor coating on the inner wall of the glass tube. Different phosphors provide for different color temperatures and corresponding CRIs.

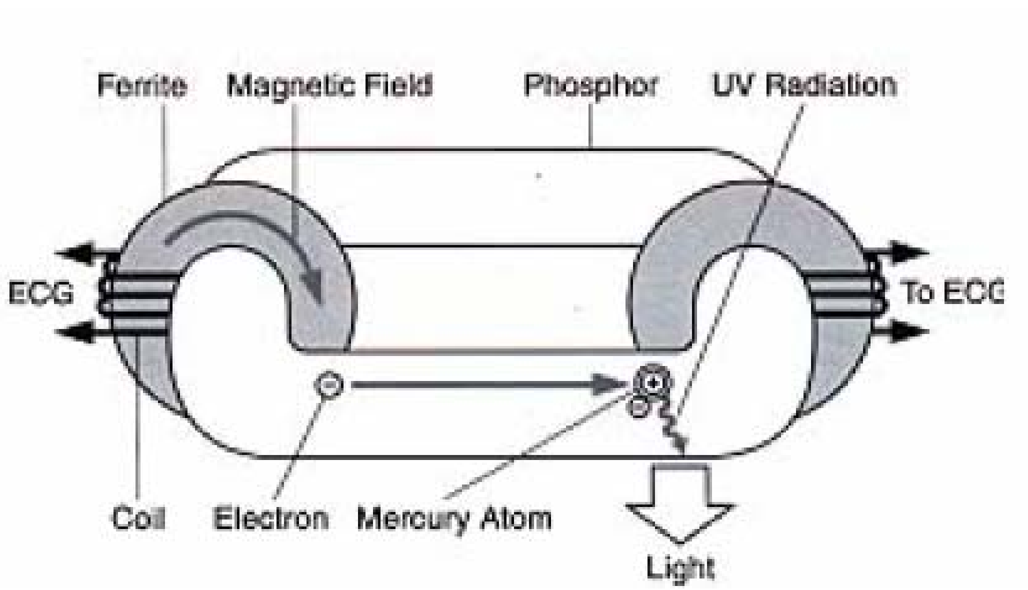


Figure 29: Construction of Icetron

Osram Sylvania's Icetron system incorporates an electrodeless fluorescent lamp that is excited by a radio frequency (RF) magnetic field. The two large ferromagnetic (metal) cores create a magnetic field around the glass tube, using the high frequency generated by the RF power converter (ballast). The discharge path, induced by the ferrite cores, forms a closed loop--it is this inductively coupled field that initiates, excites, and maintains the interaction between the electrons and the phosphor within the tube, converting the UV light to visible light. The Icetron lamp has an unusual shape (as illustrated in Figure 29).

The choice of phosphors is directly related to the need to be consistent with conventionally used lamps, as well as to ensure the longevity of the 100,000-hour product and to decrease the amount of lumen fall-off that can occur over time which is illustrated in Figure 30. Its frequency is 250kHz, which is considered very safe, and meets the more stringent European standards besides all applicable Federal Communications Commission EMI (electromagnetic interference) regulations.

The Icetron is available in 3500K and 4100K color temperature versions and in three model types: the 100/QT100 at 100W, with 8,000 lumens; a 100/QT150 at 150W, with 11,000 lumens, and the 150/QT150 at 150W, with 12,000 lumens. The spectral power distribution of Osram 830 (3500 K) is illustrated in Figure 31.

There are now over two dozen fixture manufacturers certified by Osram Sylvania to offer complete lighting systems based on Icetron technology.

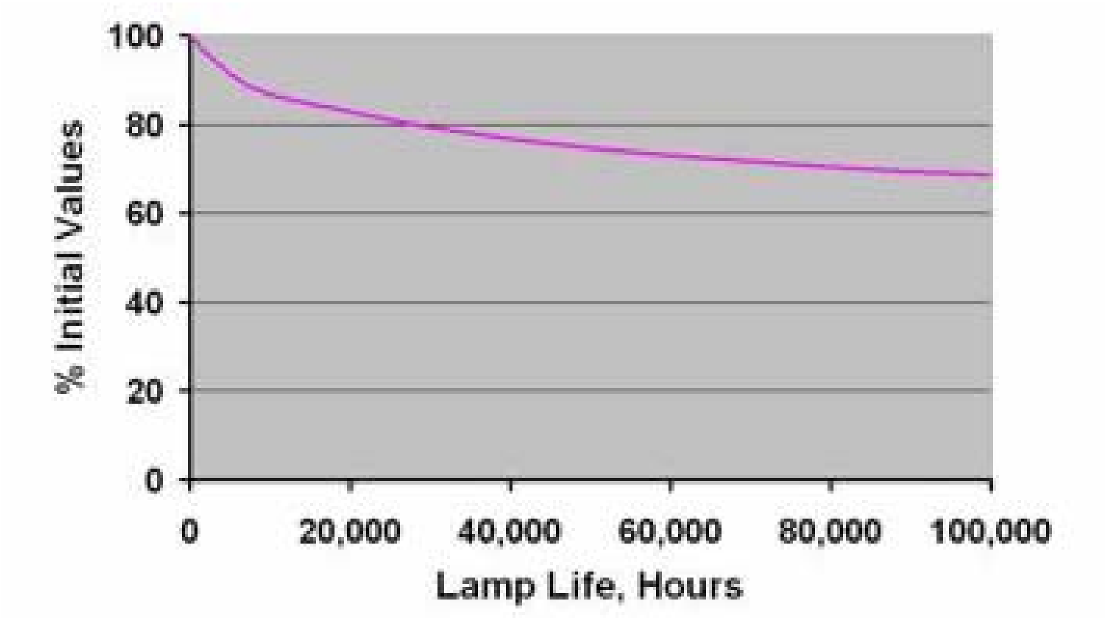


Figure 30 : Life expectancy graph

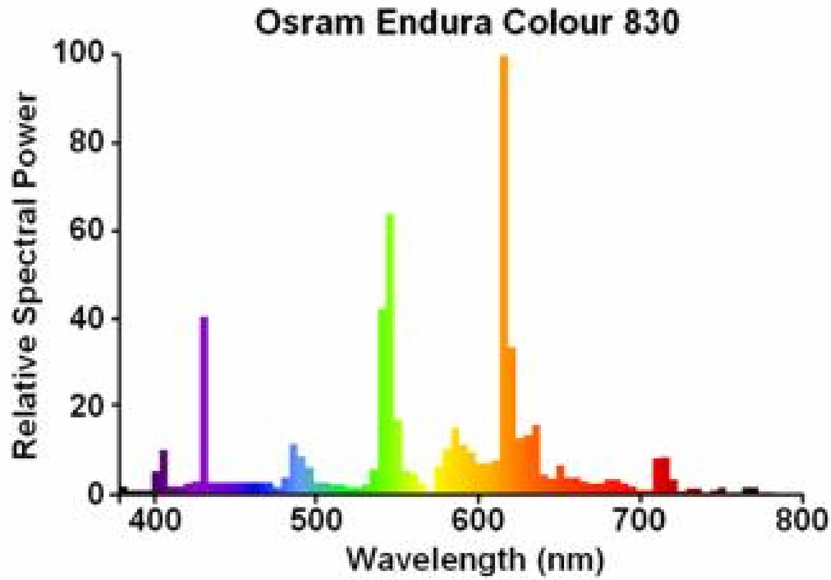


Figure 31: Power Distribution Curves in relation to mesopic vision

Fluorescent and Compact Fluorescent

These lamps are gaining popularity in residential usage. They are more efficient than standard incandescent and make good sense for residential indoor usage. From the initial literature review it was found that fluorescent lighting may not be appropriate for full scale highway usage. Temperature, and its affects on start-up, (as well as vibration), may make fluorescent impractical at this time. In discussions with NJDOT there was a general consensus that only fluorescent lamps with medium or mogul bases would be considered due to past problems with pin alignments and breaking, thus creating safety hazards and difficulty in handling. Also, considerable literature indicates that the rated life of fluorescent is significantly less than the HPS. The life expectancy graph is demonstrated in Figure 32. Initial literature also indicates that fluorescents are considerably more energy efficient than incandescent but less than HPS. For example, 150W incandescent, fluorescent and HPS produce about 17, 60, 107 lumens per watt respectively[9]. Thus, between the re-lamping, lamps costs, and energy efficiency, these lamps will not yield a cost savings.

Fluorescent lamps have a cool white light source with high CRI factor as it is illustrated in Figure 33.

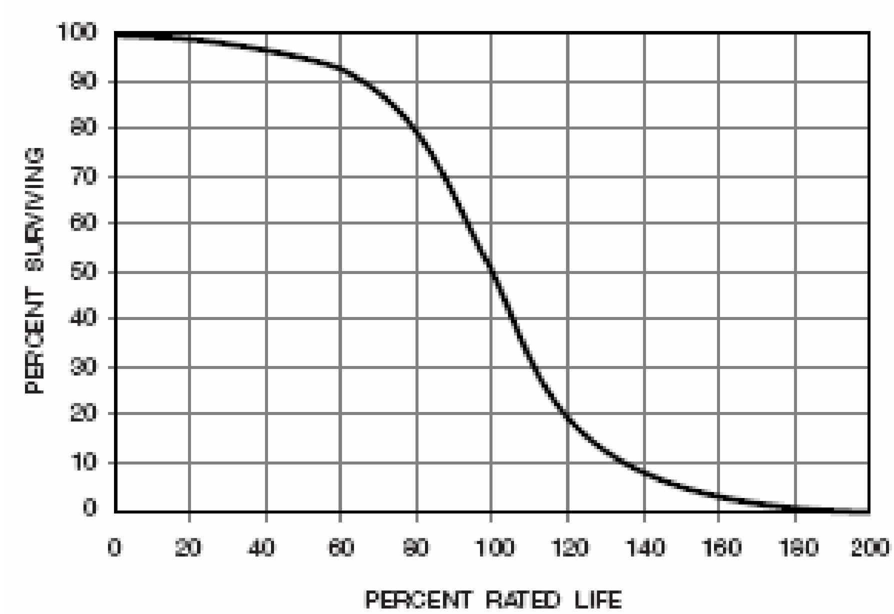


Figure 32: Life expectancy graph

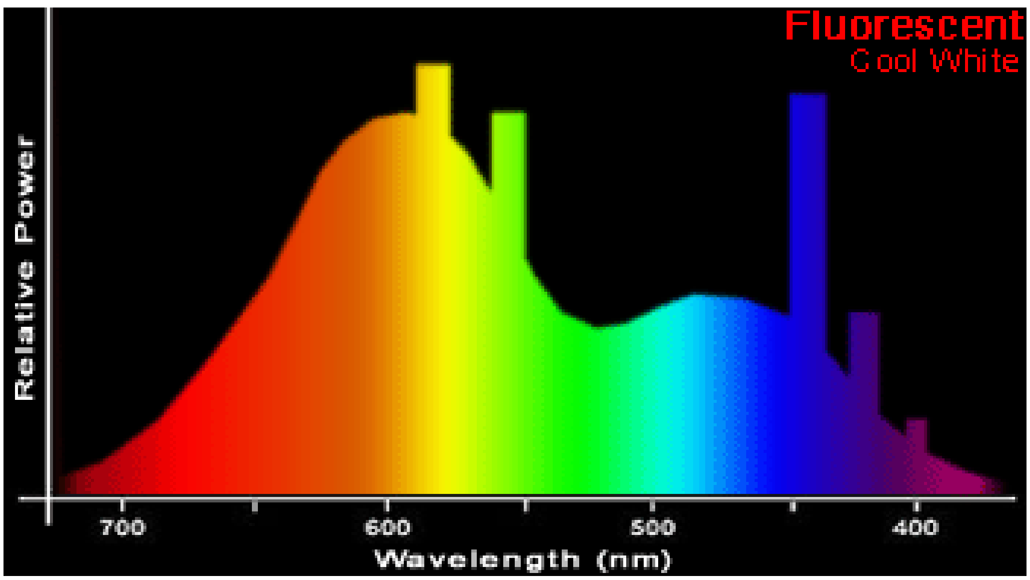


Figure 33: Power distribution in Cool white FL[10]

LED Clusters

Currently, several companies have LED clusters that will fit into standard overhead lighting Cobraheads (see Figure 34). However, there are several potential problems with full scale commercialization. The distribution of light (isofootcandle /utilization curves) is extremely uniform and narrowly focus (minimal light scatter).

Figure 34: Complete fixture with Night Vue (42W)

LED has a white light source with CCT about 4000K and relatively high CRI value as it appears in Figure 36. The ultra-white LEDs typically used in these clusters have significant epoxy degradation due to UV light discoloring the individual epoxy lens, thus diminishing the light. LED companies are currently researching this issue and seeking alternatives to correct this problem.

LEDs are extremely energy efficient and have long lives (see Figure 35). These two factors make LEDs a front runner for future investigation. One of these studies has developed a method known as Scattered Photons Extraction (SPE) by Nadarajah Narendran, Ph.D., director of research at the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, in April 2005. This new technology speeds up the progress of solid-state lighting and saving the energy.

Commercially available white LEDs combine a light-emitting semiconductor with a phosphor to produce visible white light. However, more than half of the light, or photons, produced by the phosphor are diverted back toward the LED where much of it is lost due to absorption. This reduces the LEDs overall light output.

The research team compared the commercially available white LED SPE prototypes to the current LEDs, and found that they produced 30-60 percent more light output and luminous efficacy-light output (lumens per watt). This means more visible light is produced without increasing energy consumption. Further research into the SPE technology could result in even higher levels of light output and greater luminous efficacy. This industry has set a target for white LEDs to reach 150 lumens per watt (lm/w) by the year 2012. The new SPE LEDs, under certain operating conditions, are able to achieve more than 80 lm/w.

This new outcome definitely can impact future applications of LED in road lighting. As a result, the research team still evaluated several LED prototypes and commercially available LED clusters; however, the LED cluster does not meet the NJDOT lighting requirements and Lumens.

The NJDOT Specification is based on mean lumens and also isofootcandle/utilization curves; simply comparing lumens to lumens is not going to adequately evaluate LEDs. LEDs do not operate like HPS, MV, Incandescent, etc. Therefore, the evaluation of the LEDs must be conducted differently. The LEDs will not produce an isofootcandle line, but rather a plane/region of uniform focused light.

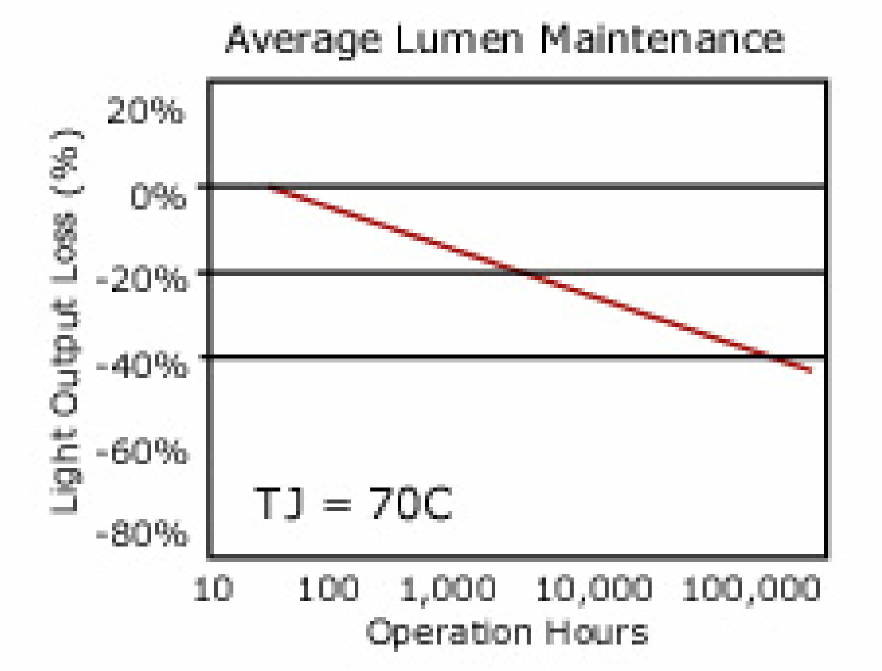


Figure 35 : Lumen life expectancy

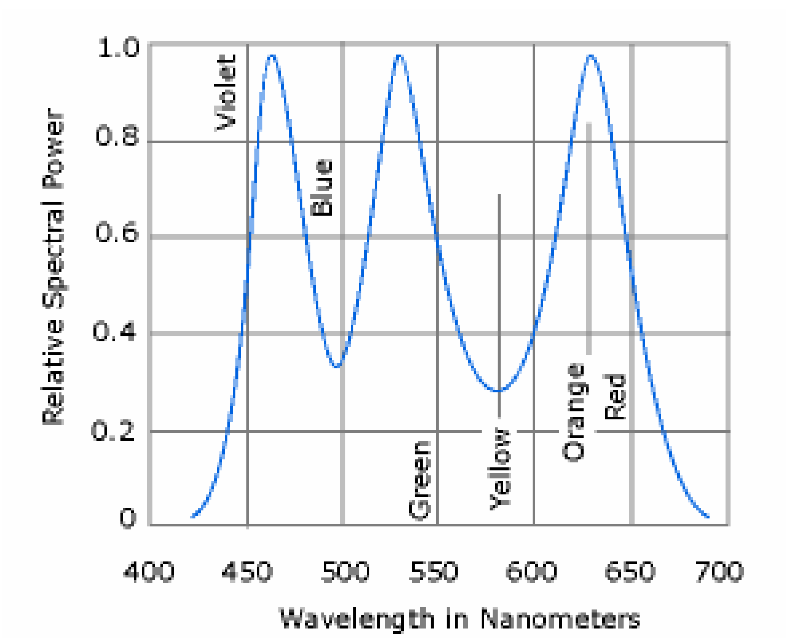


Figure 36: Night Nue Spectral output[10]

Solar

Solar does not have any electrical or grid connection costs unless it is used as backup or supplemental power. In principle, a solar panel converts light to electricity. During daylight, even on cloudy days, this solar generator (solar panel) charges long-life batteries, which store energy until it is needed. Thus, the energy of the sun is harnessed to produce power.

Of course, in practice, solar outdoor lighting is a bit more complex. In addition to large-capacity batteries and solar panels (see Figure 37), the system also incorporates sophisticated proprietary charge regulators, which stop the flow of solar generated electricity when the batteries are fully charged and then resume charging when more power is needed.

Figure 37: Solar panel mounting system

This is very significant from a 'security' perspective by providing uninterrupted power in critical infrastructure areas. Such areas include emergency evacuation routes, airports, power plants, bridges, tunnels etc. The current renewable energy program in New Jersey will cover 70% of the cost of the solar portion of the installation; in addition, it will also provide energy credits for each KW of renewable energy generated at the current rate $0.15/KW-hr. Thus, based on the number of KW-hrs generated by the panels, the State Renewable Energy fund will pay the owner a credit, an incentive to offset the purchase cost.

Solar Lighting companies typically produce a system utilizing compact florescent lamps, typical clusters of two or three CFL at 36-42 Watts. They all share the common mean life of roughly 12,000 hours, which is half the life of the standards HPS or Mercury Vapor that are used today.

In general, the fact that the solar systems use the comparatively short life CFL's is a maintenance disadvantage. However, several companies are currently developing upgraded systems to include HPS and QL technologies. With the addition of these lamps to the solar system, the systems will require significantly less energy and maintenance costs. Minimum battery life is estimated about five (5) years and, typical, life expectancy is about eight (8) to ten (10) years[17] at which time the batteries need to be replaced. In the case of the QL technology, the maintenance would be battery replacement every five (5) years as opposed to the lamps itself, and there would be all the other benefits of using a solar system (no grid connection no power interruption, no monthly electric bill, etc).

There are clear advantages of utilizing a solar system in limited access areas, critical areas, and areas that have a lack of existing infrastructure.

Summary

In conclusion, Table 4 identifies the advantages and disadvantages of each lamp briefly and Table 5 provides the technical specification.

Table 4: Summary of Pros and Cons for each mentioned lamp

Lamp	Pros	Cons
Mercury Vapor	Inexpensive to install and purchase Medium life Dimmable Good color rendering due to white light	Expensive to operate due to inefficiency tend to be glary due to intense light Dramatic lumen depreciation over time Use hazardous material (mercury)
Metal Halide	Good color rendering More efficient than Mercury Vapor Widely used	Short life , high maintenance Less efficient than HPS, LPS High temperatures burn out ballasts
Low Pressure Sodium	Very energy efficient, medium life minimum glare Able to restrike immediately Minimal or no lamp depreciation over life	Orange-yellow color Safety Concern due to color rendition Expensive fixtures
High Pressure Sodium	Energy efficient Widely used, reliable Medium Life	Orange-yellow light Safety Concern due to color rendition Cannot restrike immediately
HPS Retro White	Good color rendering Operates 24/7 Less cost for hazardous waste disposal	Short life , high maintenance Less efficient than HPS, LPS and Metal Halide Needs vertical position to operate

HPS Restrike	Longer life if the second filament is not utilized Energy efficient Instant restrike	Orange-yellow light Safety Concern due to color rendition Use hazardous material (mercury, sodium)
Induction Lighting **(Icetron, QL)**	Energy efficient Low maintenance costs due to long life Good color rendering due to white light immediate ignition & re-ignition No flickering	High initial cost Difficult to retrofit existing fixtures Use small hazardous material (Mercury) Not dimmable Need a high-frequency generator
Fluorescent	Good for residential usage More energy efficient than MV and incandescent Good color rendering	Not appropriate for roadway lighting Short life , high maintenance Cannot restrike immediately Use hazardous material (mercury, sodium)
LED	Low maintenance costs due to long life Minimal Light pollution Energy efficient	Low lumens/watt Expensive fixtures Extremely uniform light with minimal light scatter
Solar	Less energy and maintenance by using QL and LED lamp No power interruption No electricity bill	Expensive fixtures New Technology

Table 5 : Lamps technical specifications

Lamp Type	Mean life hour	Lumens Per Watt	CCT	CRI
Mercury Vapor	12,000-24000	Up to 63	3200-6800	20-50
Metal Halide	4,500-20,000	Up to 120	3000-5600	62-96
Low Pressure Sodium (LPS)	18,000	Up to 180	1700	0
High Pressure Sodium(HPS)	24,000	Up to 140	2100	21
HPS Retro white	15,000	Up to 90	4000	85
Instant restrike HPS	40,000	Up to 140	2100	21
QL	100,000	Up to 72	3000-4000	80
Icetron	100,000	Up to 76	3500-4000	80
LED(42 W)	100,000	Up to 26	4000	63
Solar	Battery (8-10 yr), Solar collector 20 yr			
Fluorescent	6000-25000	Up to 95	3000-7500	85

TUNNEL LIGHTING

The goal of a quality tunnel lighting system is to "ensure that traffic, both during day and nighttime, can approach, pass through, and leave a tunnel, at the designated speed, with a degree of safety and comfort not less than that along adjacent stretches of open road"[(12)].

During daytime hours, this means ensuring that a driver's eyes can safely adapt from brightness conditions just outside the tunnel portal to a practical illumination level inside. Once the driver's eyes have adjusted, illumination levels can be further reduced in an effort to minimize energy use, while continuing to ensure that eye adaptation is not adversely affected. The initial adjustment takes place through a "threshold" zone as it appears in the Figure 38. This is followed by a "transition" zone, which facilitates safe adaptation to a minimum acceptable level in what is referred to as the "interior" zone. Lighting levels for the threshold and interior zones are determined based on a variety of factors including:

- Traffic speed
- Traffic volume
- Tunnel length
- Geographic orientation
- Approach characteristics

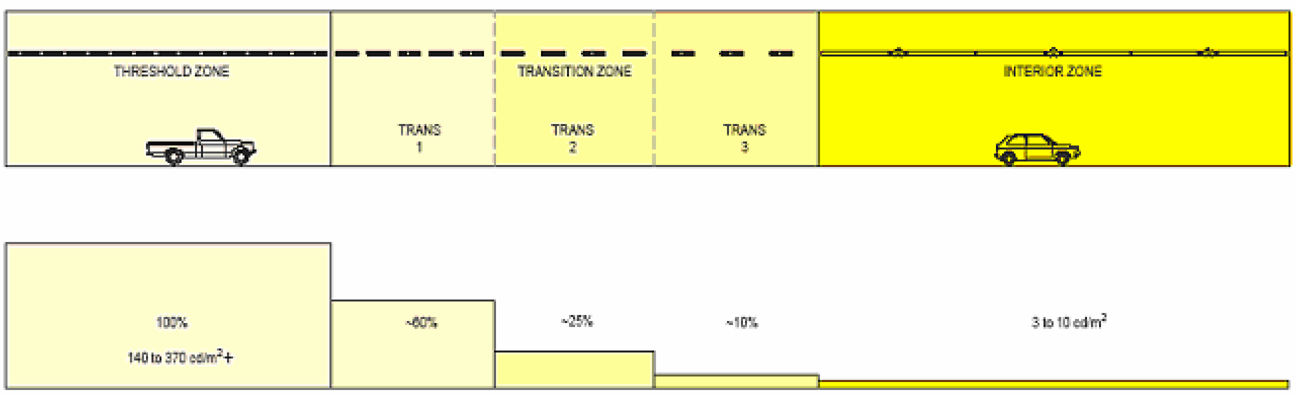


Figure 38 : Day time lighting

The transition zone is split into three or more reduction steps, each with typically no less than one third the roadway luminance of the previous step (see Figure 38). Threshold and transition zone lengths are determined based on traffic speed.

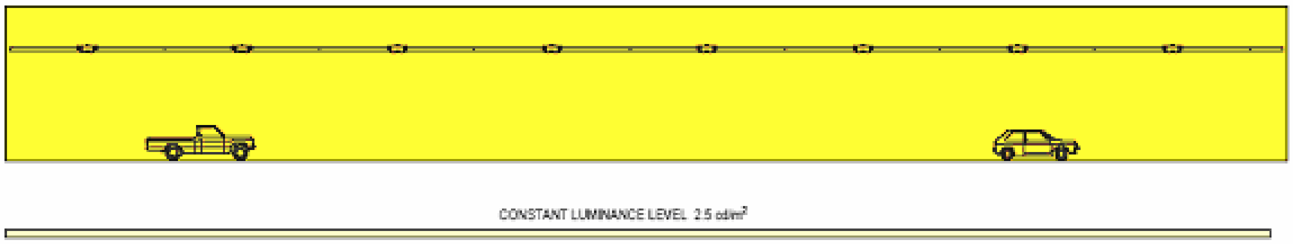


Figure 39 : Night time lighting

During nighttime hours, the eye is adapted to low roadway luminance levels (see Figure 39). Based on the consensus of experts, a minimum value of 2.5 cd/m^2 should be maintained throughout a tunnel at night.

By this consideration, four important technologies for tunnel lighting are presented briefly, each of them has pros and cons. However, this topic is not the primary objective of this project; the authors believe that a glimpse at this issue may interest the readers for future consideration.

Tunnel Light Pipe

Figure 40 illustrates light pipe in tunnel and has the following specification:

Figure 40 : Tunnel light pipe

- 250/400W Metal Halide or High Pressure Sodium luminaire
- 6" (150mm) diameter light guide
- Standard system lengths of 16', 24', 32' and 40' (4.8m, 7.3m, 9.7m and 12.2m) with a single luminaire

- 250/400W mogul base ET18 Metal Halide or High Pressure Sodium lamp
- 15,000 (MH)/24,000 (HPS)/40,000 (HPS standby) hour lamp life
- 2100K (HPS)/4000K (MH) color temperature
- Remote outdoor enclosed ballast (S51/M59 type), quad tap voltage
- Polished stainless steel luminaire and mounting bracket finish
- Need Routine maintenance
- Linear lighting quality

Tunnel Dual Beam

Figure 41 illustrates dual beams in a tunnel and has the following specification:

Figure 41 : Tunnel Dual beam

- 250/400W mogul base ET18 Metal Halide or High Pressure Sodium lamp
- 15,000 (MH)/24,000 (HPS) hour lamp life
- 2100K (HPS)/4000K (MH) color temperature
- Symmetric linear-like distribution
- Polished stainless steel finish
- Remote outdoor enclosed ballast (M59/S51 type), quad tap voltage
- Need Routine maintenance

Tunnel LED Lighting

Figure 42 illustrates a LED fixture in a tunnel and has the following specification:

Figure 42 : Tunnel LED lighting

- 130,000 hours lamps life
- 40% to 80% saving energy, depending on the configuration; virtually maintenance-free; and no need for huge emergency backup systems (UPS)
- Quick and easy installation
- Environment-friendly
- Instant re-strike capability for optimum backup in case of power failure
- Low voltage: 24 VDC, 40 watts maximum per fixture
- Luminous distributed evenly
- Durable and resistance to corrosion
- Intelligent operation based on a computer program that provides self diagnostic capabilities, easy remote management and bidirectional communications

Tunnel Induction Lighting

Figure 43 illustrates the fixture that easily can be replaced by QL lamp in a tunnel and has the following specifications:

Figure 43 : Tunnel Induction Lighting

- Lamp type can be (70W, 100W Icetron or 55W, 85W QL)
- Symmetrical for center rows
- Asymmetrical for side rows
- Low glare
- Ceiling Mounting

Tunnel Fluorescent Lighting

The research team believes Fluorescent (FL) lamps are not a suitable option for tunnels, because of lamp's short life and harsh conditions for re-lamping and maintenance in tunnels.

Tunnel LPS lighting

The large physical size of the LPS lamp means that it has a low luminance so it is less likely to give rise to glare and the low operating temperature permits the use of compact optical systems and lightweight plastic lanterns. These features made the LPS lamp to be the favoured light sources for tunnel illumination.

However, the two major drawbacks of this lamp (no CRI and short life) limit its usage on tunnel lighting particularly in comparison to new replacement technology, such as LED.

BRIDGE LIGHTING

Due to extremes in weather and vibration, successful lighting on bridges is challenging to both apply and maintain. Longer maintenance cycles and remote luminaire access provide benefits to the operator. Currently, HPS and MH lamps are used widely for bridge lighting; however, any technology which can extend operating life and reduced maintenance can result in significant cost saving.

As discussed previously, LED and inductive systems (QL, ICETRON) both are new technologies which can replace HPS and MH in road and bridge lighting.

ISO-FOOTCANDLE CHART

Iso-footcandle charts are often used to describe the light pattern when a fixture produces a distribution other than symmetric. These charts are derived from the candlepower data and show exact plots or lines of equal footcandle levels on the work plane when the fixture is at a designated mounting height (see Figure 44).

For computation, illuminance (the quantity of light reaching a unit area of surface), measured in footcandles or lux is defined by intensity (Î), directed toward point P divided by the square of the distance (D) from the source to the surface.

$$E = \frac{I}{D^\wedge 2} \quad \text{Equation (4)}$$

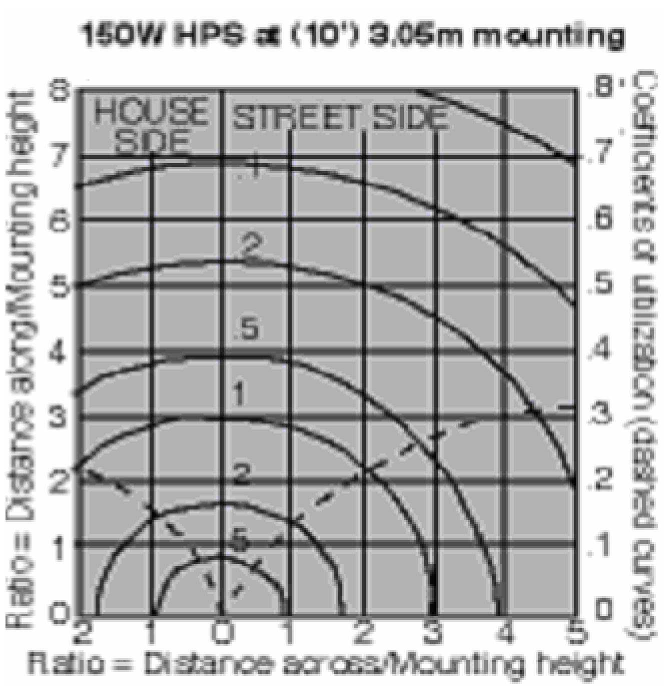
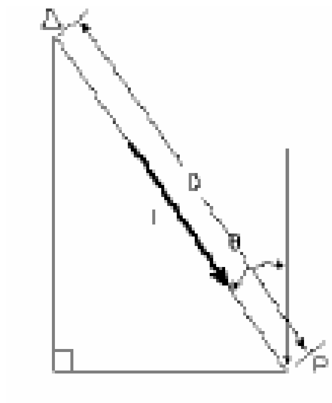


Figure 44 : Isofootcandle chart for HPS 150 W

As the area covered by a given solid angle becomes larger with distance from the source, the included light flux remains the same. The illumination density of light on the surface decreases as the inverse square of the distance increases. This formula holds only if the receiving surface is perpendicular to the source direction. If light is incident at some other angle, the formula becomes:

$$E = \frac{I \cos\theta}{D^2}$$ Equation (5)



Where:
E = illumination in footcandles (fC) or lux
I = intensity in candela (cd) toward point P
D = distance in feet or meters
θ = angle of incidence

For deriving Iso-footcandle curves; the lamp's intensity, height and shape of fixture are all important factors. This study included a simplified analysis; a more detailed analysis would need to derive data based on lamps by specific wattage and fixture. An Iso-foot candle curve for a typical cobrahead HPS luminaire, highly used by NJDOT, is illustrated in Figure 45.

Also, three iso-foot candle curves with shoebox style luminaries for 1000-watt High Pressure Sodium, 1000-watt Metal Halide and 1000-watt Mercury Vapor are demonstrated in Figure 46, Figure 47, and Figure 48. Figure 49 illustrates iso-footcandle from a height of 25 feet for LED 42W with cobrahead style.

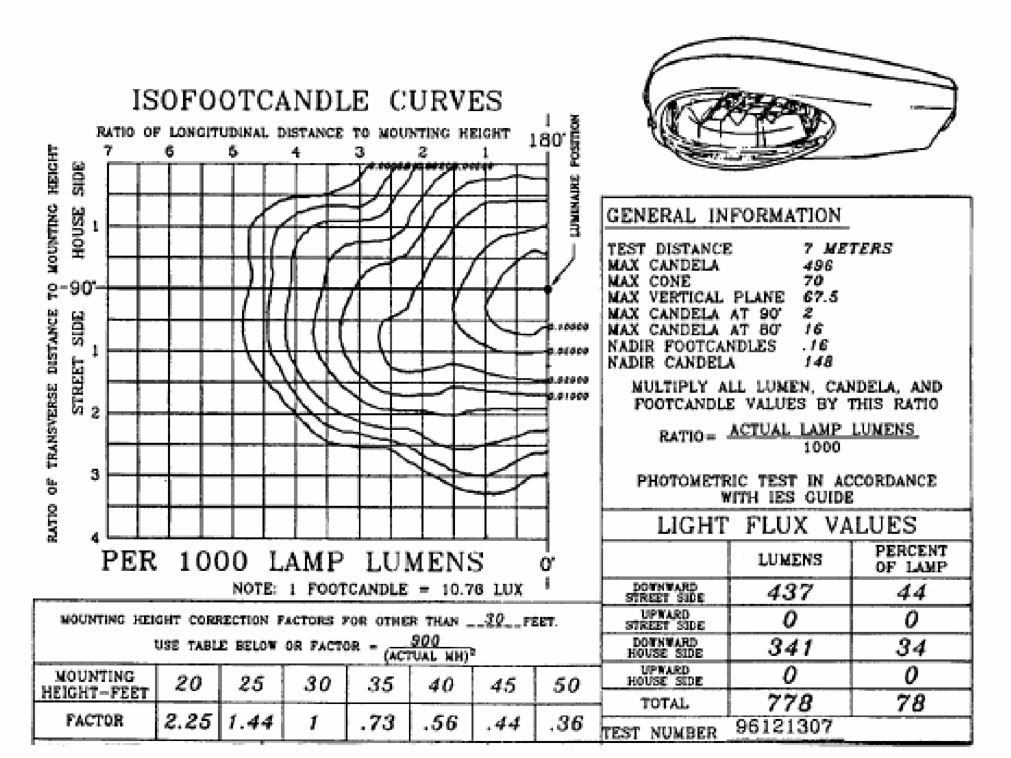


Figure 45: Foot candle curves per 1000 lamp lumens(15)

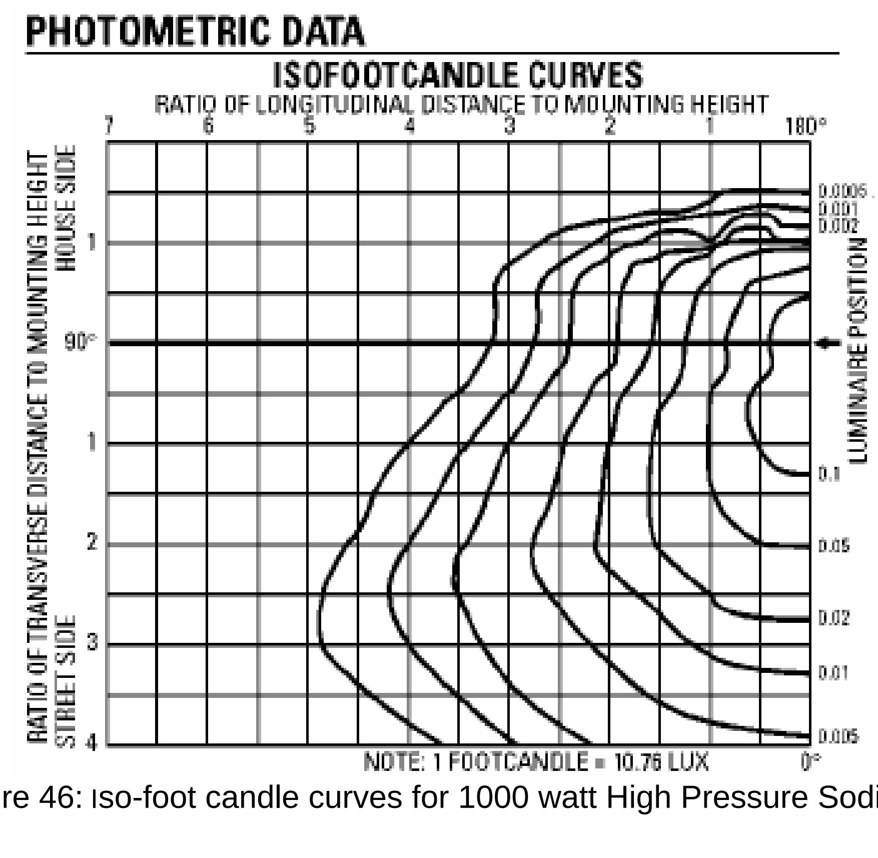


Figure 46: Iso-foot candle curves for 1000 watt High Pressure Sodium(6)

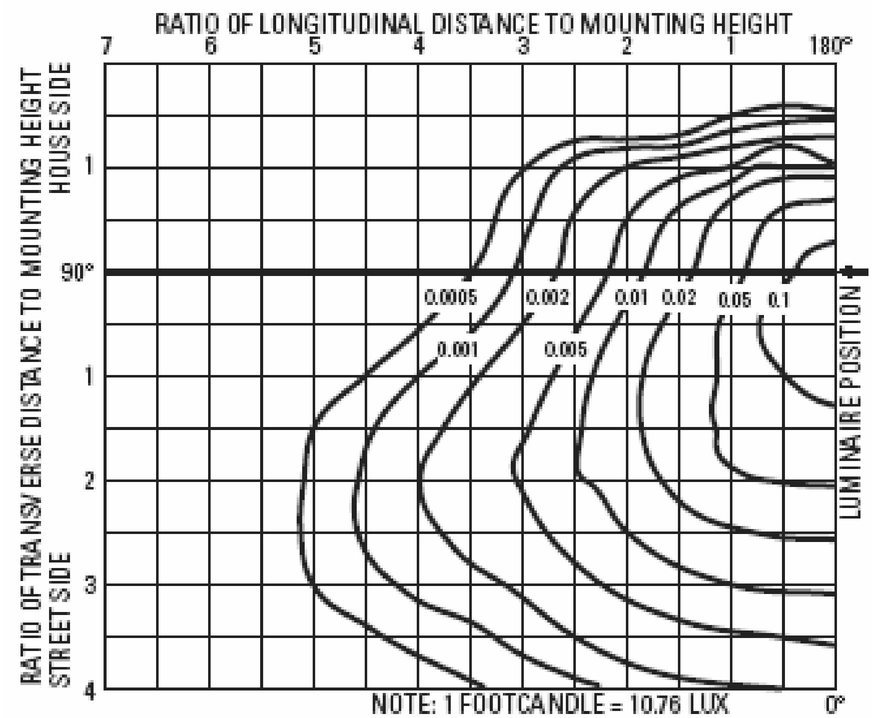


Figure 47: Iso-foot candle curves for 1000 watt Mercury lamp(6)

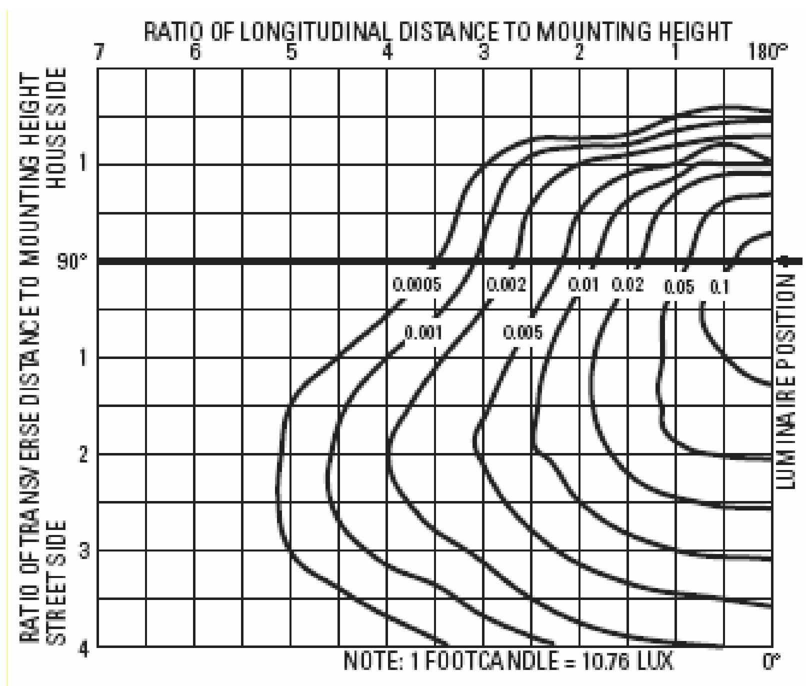


Figure 48: Iso-foot candle curves for 1000 watt Metal Halide(6)

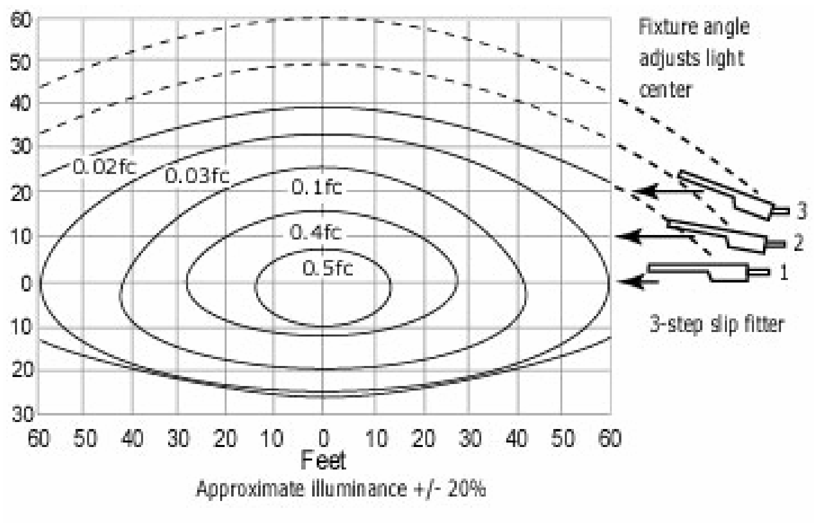


Figure 49: Iso-footcandle chart from a height of 25 feet for LED 42W[20]

For Iso-foot candle example purposes, Table 6 demonstrates the recommended minimum average maintained illuminance for roadway and it can be compared with a foot candle for familiar light level, demonstrated in succeeding table (Table 7).

Table 6: Minimum Average Maintained Illuminance (Eh) and Maximum Uniformity Ratios by Facility Classification and Pavement Classification[15]

Roadway and Walkway Classification		R1		R2 & R3		R4		Uniformity avg/min
		Foot-candles	Lux	Foot-candles	Lux	Foot-candles	Lux	
Freeway		0.6 - 0.8	6 - 9	0.6 - 0.8	6 - 9	0.6 - 0.8	6 - 9	3:1 to 4:1
Expressway	Commercial	0.9	10	1.3	14	1.2	13	3:1
	Intermediate	0.7	8	1.1	12	0.9	10	
	Residential	0.6	6	0.8	9	0.7	8	
Major	Commercial	1.1	12	1.6	17	1.4	15	3:1
	Intermediate	0.8	9	1.2	13	1.0	11	
	Residential	0.6	6	0.8	9	0.7	8	
Collector	Commercial	0.7	8	1.1	12	0.9	10	4:1
	Intermediate	0.6	6	0.8	9	0.7	8	
	Residential	0.4	4	0.6	6	0.5	5	
Local	Commercial	0.6	6	0.8	9	0.7	8	6:1
	Intermediate	0.5	5	0.7	7	0.6	6	
	Residential	0.4	3	0.4	4	0.4	4	
Alleys	Commercial	0.4	4	0.6	6	0.5	5	6:1
	Intermediate	0.3	3	0.4	4	0.4	4	
	Residential	0.2	2	0.3	3	0.3	3	
Sidewalks	Commercial	0.9	10	1.3	14	1.2	13	3:1
	Intermediate	0.6	6	0.8	9	0.7	8	4:1
	Residential	0.3	3	0.4	4	0.4	4	6:1
Pedestrian Ways and Bicycle Lanes		1.4	15	2.0	22	1.8	19	3:1
Rest Areas	Entr and Exit Gores Interior Roadways	--	--	0.6 - 0.8	6 - 9	--	--	3:1 to 4:1
	Parking Areas	--	--	1.0	11	--	--	3:1 to 4:1

R1 = cement/concrete, R2 = asphalt/gravel, R3 = asphalt/rough texture (typical highway), R4 = asphalt/smooth texture

Table 7 : Light levels of familiar times

Time	Avg. Maintained Foot-candles
Full Moonlight	.01 - 0.1
Pre-dawn	.01 - 1.0
Windowed room, cloudy day	6.0 - 8.0
Bright sunlight on the beach	30,000

PHASE II : EXPERIMENTAL APPROACH

The research team believes that the experimental approach, Phase II, should focus on two imperative lamp technologies, HPS and QL. Based on the Literature Search, Phase I, and the following section, LCCA, QL has a distinguished mean life compared to other lamp technologies (MV, LPS, HPS, HPS restrike , HPS retro white). Also, QL has a high mean lumen compared to a LED lamp, and has reasonable shape compared to another induction lighting lamps (Icetron). Finally, it has a best cost effectiveness among other proposed alternatives (Figure 66, Figure 67, Figure 68, and Figure 69).

This section consists of a discussion with brief reviews on basic factors on designing roadway lighting to give the required background to the readers for calculating luminaries spacing and uniformity ratio on the two aforementioned lamp technologies: HPS and QL. Conclusively, calculation results will be compared with the American Association of State Highway and Transportation Officials (AASHTO) recommendation for luminaries spacing and uniformity ratio.

The next step is field verification. Various tests are implemented based on visibility calculations noted in the Federal Highway Administration (FHWA) manual report by the research team[20]. This verification is based on two essential issues: effect of CRI on mean lumen and mesopic vision, and visibility comparison between two lamp technologies: HPS and QL.

Luminaire Spacing

Luminance refers to the light that is reflected toward the eye after having struck the pavement. On the other hand, illuminance refers to the light falling onto the pavement. Luminance is a primary factor in determining pole spacing and in designing roadway lighting. Luminaire spacing is as follows:

$$\text{Luminaire Spacing} = \frac{LL * CU * LLD * LDD}{Eh * W} \qquad \text{Equation (6)}$$

Where:
LL = Initial lamp lumens
CU = Coefficient of utilization

LLD = Lamp lumen depreciation factor (0.8)
LDD = Luminaire dirt depreciation factor (0.9)
Eh = Average maintained level of illumination
W = Width of lighted roadway

The research team discussed each factor briefly and calculated luminaire spacing for two lamps (HPS, and QL).
Note : For all estimates, luminaires style for roadway lighting are assumed to be the 25 feet shallow glass "cobrahead" style (see Figure 50).

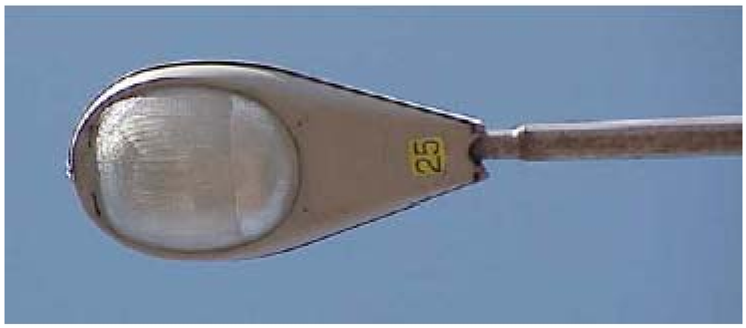


Figure 50: Cobrahead luminaries style

Initial Lamp Lumens

Initial lamp lumen can be obtained from manufacture's catalogue. The present analysis of pole spacing is accomplished for two different wattages of HPS (250W, and 150W) and QL (165, and 85). HPS 250W has 27,000 initial lumen, and HPS 150W has 15,500 initial lumens. QL 165W (840) has 12,000 initial lumen and QL 85 W(840) has 6,000 initial lumens with CCT 4,000K. As mentioned before, initial lamp lumen is not efficient for estimation of LL value. Therefore, Lumen Effectiveness Multiplier (LEM) should be included in calculations for obtaining real lumens in mesopic sight. Based on Figure 9, LEM factors for 4,100k and HPS light source is 1.62, and one (1) respectively, thus:

LL for HPS (250W) = 27,000 * 1 (HPS LEM) = 27,000
LL for HPS (150W) = 15,500 * 1 (HPS LEM) = 15,500
LL for QL(165W) = 12,000 * 1.62(QL LEM) = 19440
LL for QL(85W) = 6,000 * 1.62(QL LEM) = 9720

Coefficient Of Utilization

The Coefficient of Utilization (CU) is an indication of a fixture's efficiency. In other words, a coefficient of utilization (CU) refers to the ratio of lumens which ultimately reach the work plane to the total lumens generated by the lamp. A coefficient of utilization curve is provided for luminaires intended for outdoor use.

The CU can be read directly from the curve and inserted into the standard spacing formula (Luminaire Spacing = $\frac{LL * CU * LLD * LDD}{Eh * W}$ Equation (6).

For directional flood-type fixtures, the CU ranges from about 65% to 90%. For non-directional fixtures, most manufacturers provide utilization curves. In general, the larger the area to be lit, the higher the utilization beam is going to be. Since most fixture catalogs do not have this data, the CU factor for QL lamp is extracted from HPS 250W curves (see Figure 51).

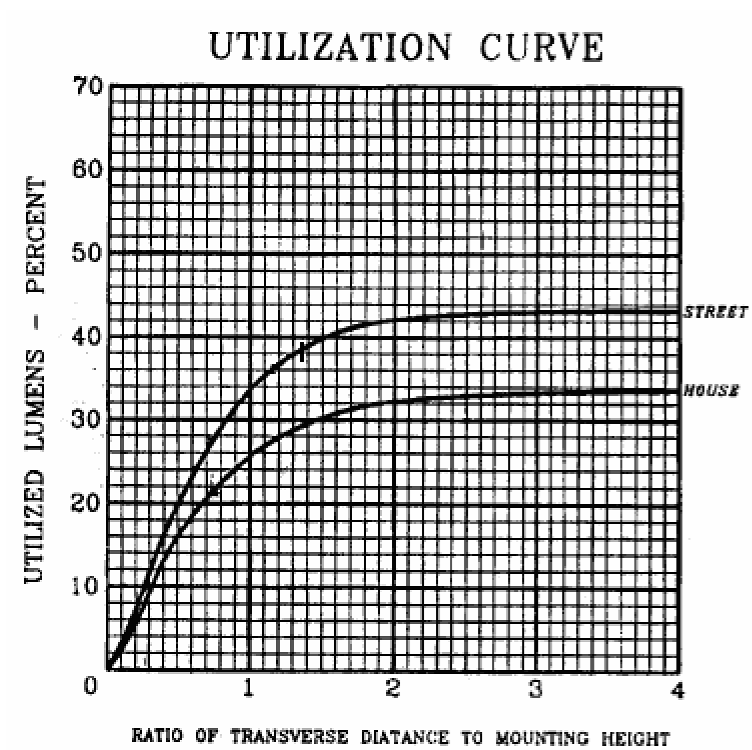


Figure 51: Utilization Curve for HPS 250W(15)

Two curves are shown in the Figure 51, one for the street side (normally the desired area to be lit) and one for the house side (or the direction away from the primary lit direction). The street curve represents the utilization of the bare lamp, in percent, as the ratio of lateral distance to mounting height increases.
The CU is computed as follows:

1. To obtain the pavement area CU, enter the CU curve for the Street Side at the correct transverse distance to mounting height ratio. In this case, the pole height is 25 feet and the transverse distance is 34 feet (10+24) (see Figure 52), thus, the ratio would be 34/25 or 1.36. Follow the chart up until it reaches the Street Side curve and read the Utilized Lumens (in percent). This results in 38 percent.

2. To obtain the shoulder area CU, enter the CU curve for the Street Side at the correct transverse distance to mounting height ratio. In this case, the ratio would be 10/25 or 0.4. Follow the chart up until it reaches the Street Side curve and reads the Utilized Lumens (in percent). This results in 14 percent.

3. The CU from the "triangle" that forms from the luminaire to the near pavement edge is subtracted from the "triangle" that forms from the luminaire to the far side pavement edge. This results in a CU of approximately 24 percent.

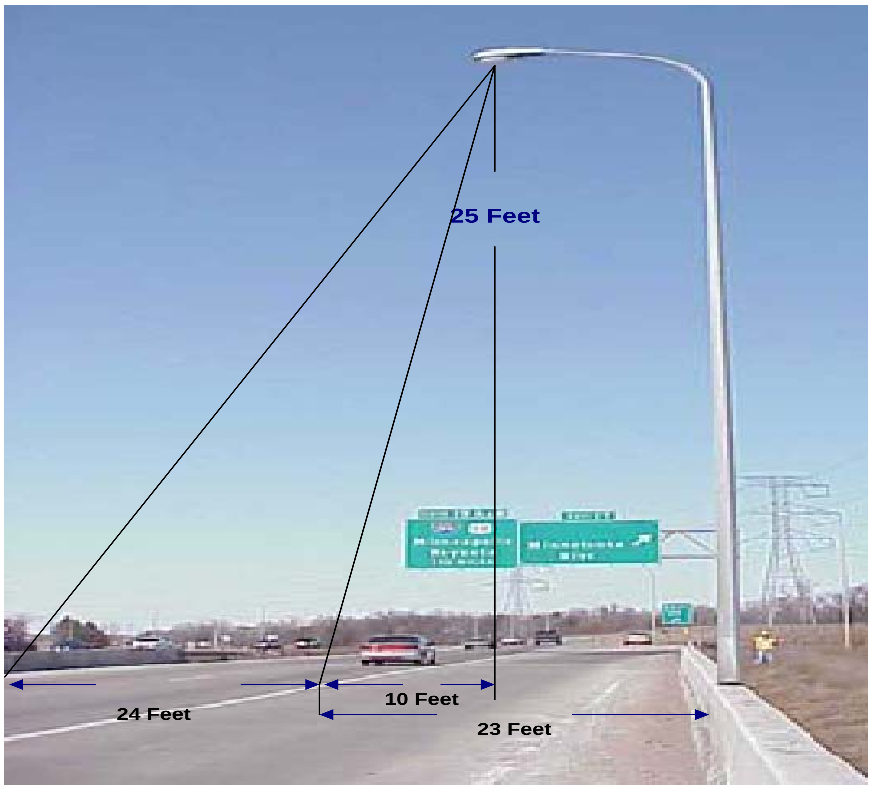


Figure 52: Case study for calculation of pole spacing

Lamp and Luminaire Depreciation Factors (LLD)

In determining the light output for a luminaire, the lighting system designer must consider the luminaire light loss factor. The luminaire light loss factor is a combination of several factors including the Lamp Lumen Depreciation (LLD) factor and the Lamp Dirt Depreciation (LDD) factor (discussed later). LLD is the fractional remainder of lamp lumens lost, at rated operating conditions, due to lamp degradation. The loss factor is applied to the light output of a new luminaire (initial light output) to determine the light output of the luminaire after a fixed period of time (maintained light output). LLD is estimated by dividing mean lumen divided by initial output.
For HPS (250W): LLD = 24300/27000 = 0.9
For HPS (150W): LLD = 14000/15500 = 0.9

For QL(165W): LLD = 9600/12000 = 0.8
For QL(85W): LLD = 4800/6000 = 0.8

Lamp Dirt Depreciation (LDD)

Dirt and dust present in all ambient environments are ultimately attracted to and trapped in electrical equipment. The extent of dust collecting on the lamps depends on the environment, what type of fixture is in use, whether it is ventilated or not, and the type of work performed in the area. The extent of LDD depends on these conditions and also how often the fixtures will be cleaned. To determine this factor, the appropriate curve can be selected from Figure 53 in accordance with the type of ambient as described by the following examples:

Very Clean – No nearby smoke or dust generating activities and low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more that 150 micrograms per cubic meter.

Clean – No nearby smoke or dust generating activities. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per cubic meter.

Moderate – Moderate smoke or dust generating activities nearby. The ambient particulate level is no more than 600 micrograms per cubic meter.

Dirty – Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.

Very Dirty – As above but the luminaires are commonly enveloped by smoke or dust plumes

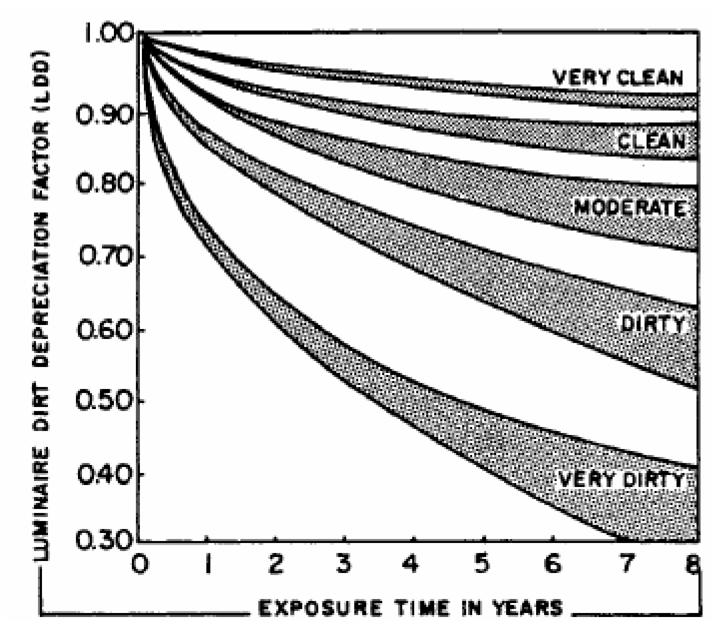


Figure 53: LDD nomograph

Average Maintained Level of Illumination

Minimum Average Maintained Illuminance (Eh) and Maximum Uniformity Ratios by Facility Classification and Pavement Classification are illustrated in Table 6.

Uniformity Ratio Background of Theory

Another important issue for designing roadway lighting is uniformity ratio.

The definition for "uniformity ratio" can vary from average-to-minimum to maximum-to-minimum, and can be applied to vertical or horizontal (or even both) values for either illuminance or luminance - initial or maintained - at grade or above - over the entire site or part of it. The possible range of uniformity ratios can make it difficult to understand the implications of uniformity ratios in particular. A ratio of 3:1 for average-to-minimum is roughly the same as a ratio of 10:1 (to 12:1) for maximum-to-minimum. Meeting 3:1 and 10:1 ratios as criteria will be around 50%-100% more expensive than meeting criteria of 6:1 and 20:1 (to 24:1). In present calculation, uniformity ratio refers to the average-level-to-minimum point method uses the average illuminance on the roadway design area divided by the lowest value at any point in the area. Under this method, the average-to-minimum ratio should not exceed 3 to 1 for any roadway except local residential streets, which may have a ratio as high as 6 to 1[15].

$$\text{Uniformity Ratio} = \frac{\text{Average maintained illumination value}}{\text{Minimum maintained illumination value}}$$

As requirements for uniformity increase, almost all of the costs of lighting systems also increase, as do any associated costs with installing and operating the lighting system.

By having this preface for designing pole spacing and uniformity ratio, following calculations are applied for HPS and QL.

Pole Spacing and Uniformity ratio for HPS 250W Lamp:

LL for HPS 250W = 27,000 lumen LEM = 1
LLD = 24300/27000 = 0.9
LDD = 0.90 (based on LDD curve)
W = 24 feet (2 lane roadway)
CU= 0.24
Minimum average maintained illumination (Eh) for major commercial roadways with asphalt/rough texture (typical highway) is 1.6 footcandles. (based on Table 6)

$$\text{Luminaire Spacing} = \frac{27000 * 0.9 * 0.9 * 0.24}{24 * 1.6} = 137 \text{ feet}$$

__**Uniformity ratio :**__
Based on Figure 45, each curve is 1000 lumens, therefore for estimating each curve, total lumen divides by 1000 = 27,000/1000= 27
Pole factor compared to a 30 feet pole is 1.44, based on Figure 45.
Minimum maintained illumination value = (27,000/1000)(0.9)(0.9)(1.44)(0.025)= 0.79 footcandles
Uniformity Ratio: 1.6 / 0.79 = 2.03 (less than 3:1, adequate design)

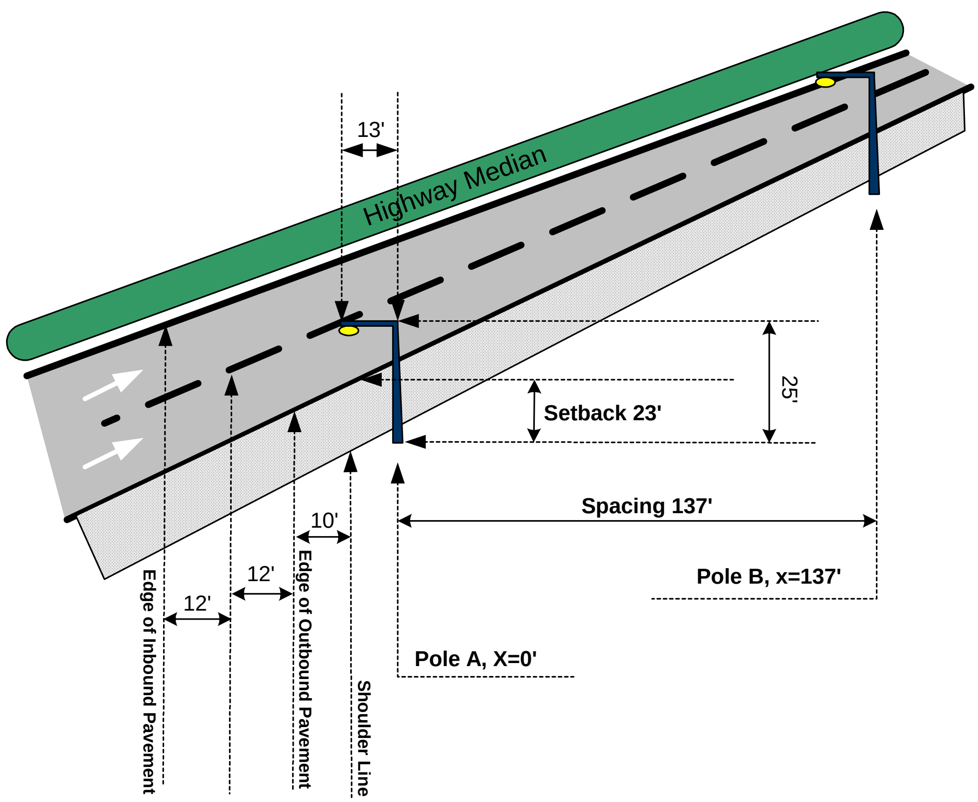


Figure 54: HPS 250W Pole Spacing based on Uniformity Ratio

Pole Spacing and Uniformity ratio for HPS 150W Lamp:

LL for HPs 150W = 15,500 lumen LEM = 1
LLD = 14000/15800 = 0.9
LDD = 0.90 (based on LDD curve)
W = 24 feet (2 lane roadway)
CU= 0.24
Minimum average maintained illumination (Eh) for major commercial roadways with asphalt/rough texture (typical highway) is 1.6 footcandles. (based on Table 6)

Luminaire Spacing = $\dfrac{15500 * 0.9 * 0.9 * 0.24}{24 * 1.6}$ = 78.47 feet

Uniformity ratio :

Based on Figure 45, each curve is 1000 lumens, therefore for estimating each curve, total lumen divides by 1000 = 15,500/1000= 15.5
Pole factor compared to a 30 feet pole is 1.44, based on Figure 45.
Minimum maintained
illumination value = (15,500/1000)(0.9)(0.9)(1.44)(0.025)= 0.45 footcandles
Uniformity Ratio: 1.6 / 0.45 = 3.5

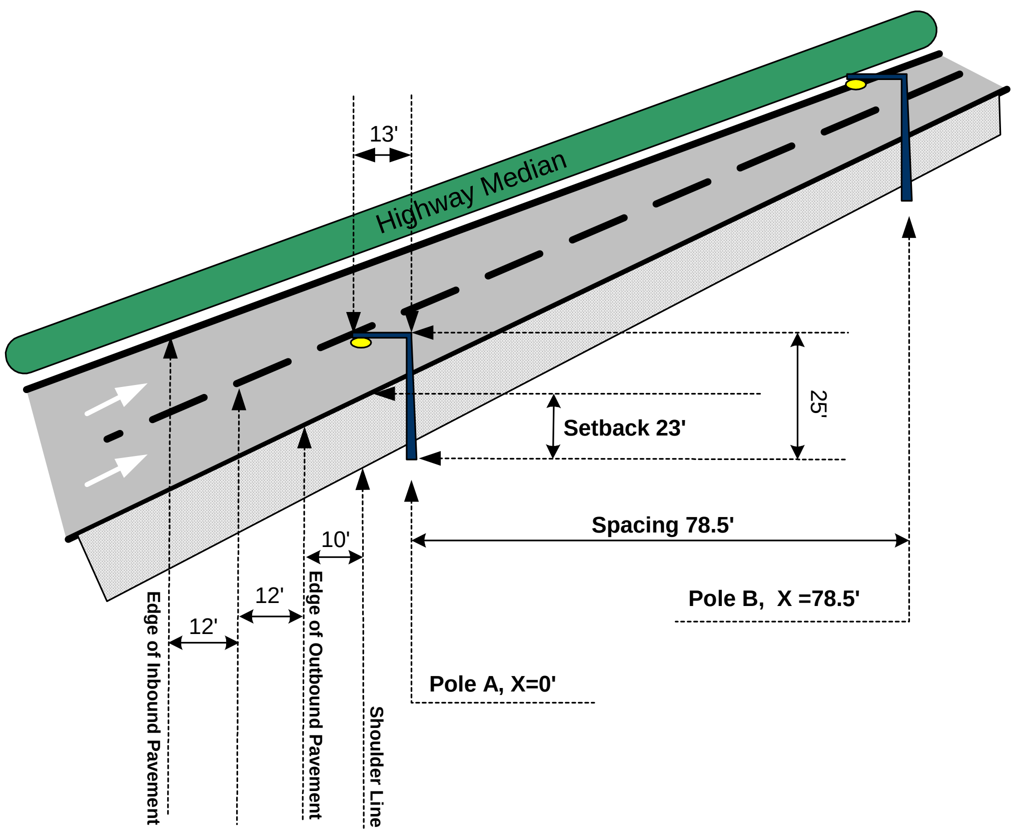


Figure 55: HPS 150W Pole Spacing based on Uniformity Ratio

Pole Spacing and Uniformity ratio for QL 165W Lamp:

LL for QL 165 W/ 840= 12,000 CCT = 4000
LEM = 1.62 => LL = 12,000*1.62 = 19440 lumen
LLD = (9600/12000) = 0.8
LDD = 0.90 (based on LDD curve)
W = 24 feet (2 lane roadway)
CU = 0.24
Minimum average maintained illumination (Eh) for major commercial roadways with asphalt/rough texture (typical highway) is 1.6 footcandles. (based on).

Luminaire Spacing = $\frac{19440 * 0.8 * 0.9 * 0.24}{24 * 1.6}$ = 87 feet

<u>Uniformity ratio :</u>
Based on Figure 45, each curve is 1000 lumens, therefore for estimating each curve, total lumen divides by 1000 = 19,440/1000= 19.44
Pole factor compared to a 30 feet pole is 1.44, based on Figure 45.
Minimum maintained
illumination value =(19,440/1000)(0.9)(0.8)(1.44)(0.025)= 0.503 footcandles
• Uniformity Ratio: 1.6 / 0.503 = 3.18 (more than 3:1, further consideration will be needed)

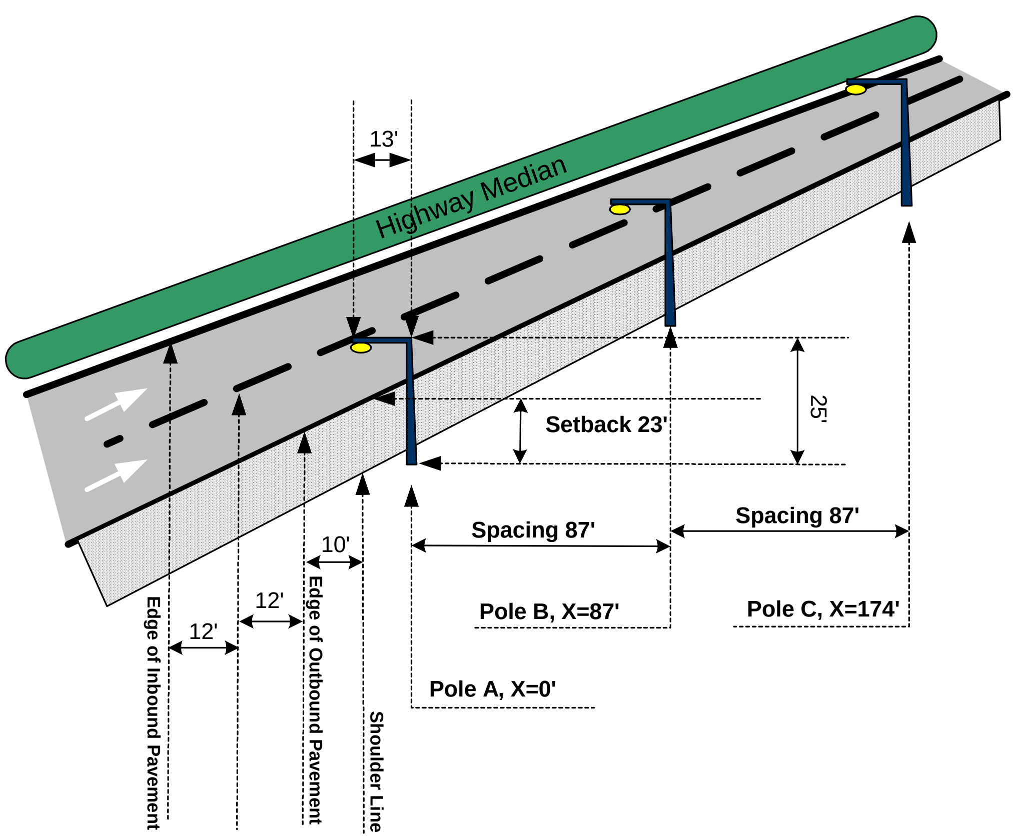


Figure 56: QL 165W Pole Spacing based on Uniformity Ratio

Pole Spacing and Uniformity ratio for QL 85W Lamp:

LL for QL 85 W/ 840= 6000 CCT = 4000
LEM = 1.62 => LL = 6000*1.62 = 9720 lumen
LLD = (4800/6000) = 0.8
LDD = 0.90 (based on LDD curve)
W = 24 feet (2 lane roadway)
CU = 0.24
Minimum average maintained illumination (Eh) for major commercial roadways with asphalt/rough texture (typical highway) is 1.6 footcandles. (based on).

Luminaire Spacing = $\frac{9720 * 0.8 * 0.9 * 0.24}{24 * 1.6}$ = 43.74 feet

Uniformity ratio :

Based on Figure 45, each curve is 1000 lumens, therefore for estimating each curve, total lumen divides by 1000 = 9,720/1000= 9.72
Pole factor compared to a 30 feet pole is 1.44, based on Figure 45.
Minimum maintained
illumination value =(9,720/1000)(0.8)(0.9)(1.44)(0.025)= 0.25 footcandles
• Uniformity Ratio: 1.6 / 0.25 = 6.44 (more than 3:1, further consideration will be needed)

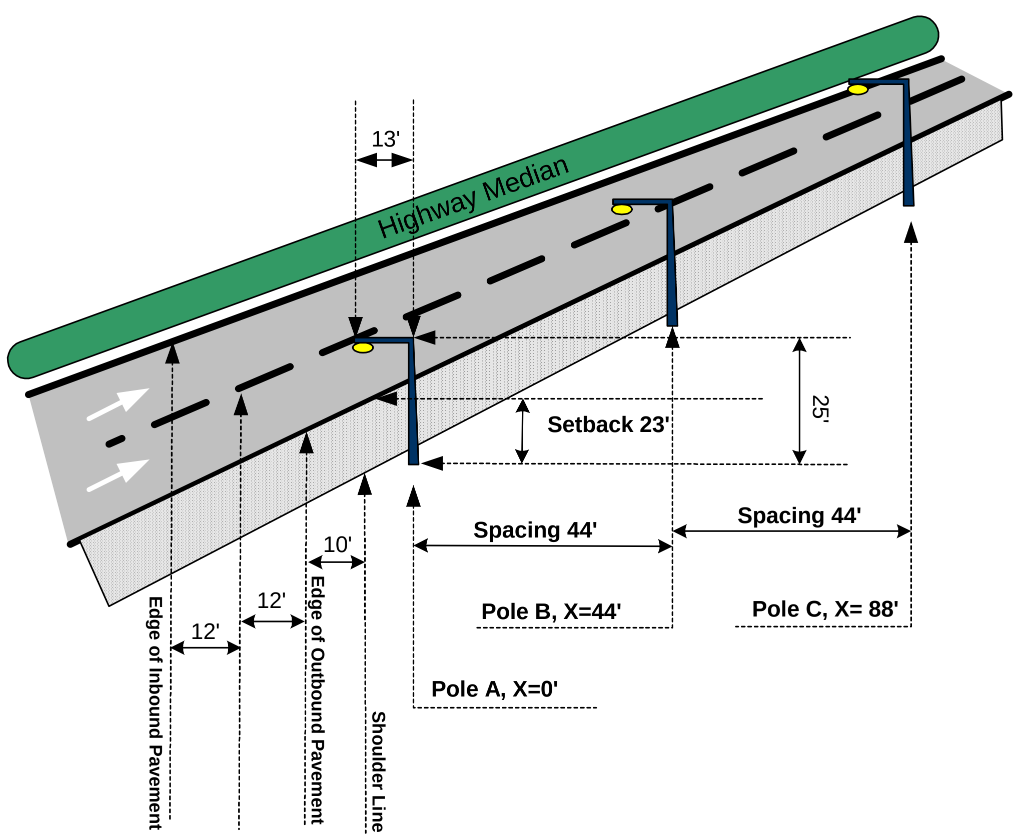


Figure 57: QL 85W Pole Spacing based on Uniformity Ratio

Based on the outcome of preceding calculations, the research team believes, that based on the existing pole spacing, QLs can not meet the DOT standard for pole spacing and uniformity ratio even by considering LEM factor. However, future design on pole spacing for new roads require additional investigation on light quality and distribution of various light technologies such as LED and QL.

Field Verification

The field verification seeks to analyze two primary issues. In the first phase, the research team is investigating the effect of two lamp sources (yellow & white light sources) on color rendering. The second phase is investigating the effect of white and HPS light sources on lumen and visibility. The field testing took place at the NJDOT complex just outside Ewing in Trenton, NJ. The tests were conducted in a parking area of the complex. Ideally, the tests were looking for the comparison of HPS 250W with QL 150W, and HPS 150W with QL 85W.

However, due to time constraints these tests were refined to simply compare yellow and white light sources. The exact lamps and wattages are unknown. The results presented in the following sections are therefore for reference purposes only.

During the field verification and the development of the test protocol, numerous types of observations were used to compare the camera results with the actual observations of the research team. The actual observations made by the research team were used to select the most suitable camera settings. By changing the camera setting the “camera” results can vary greatly. However, through the team observations, the research team chose the best settings, which duplicated actual observations. Also, note that one member was 30 years old, whereas the other member was over 50 years old. Older people take longer to adjust to changes in light level and are more sensitive to glare. The effects are generally noticeable after age forty.

The camera used was an Olympus Stylus 300 Digital 3.2 Mega pixel. The settings were set to “night” scene with the flash turned off. The camera was mounted on a tripod with the center of the lens at 53.5 inches above ground. All overhead lights in the immediate area were disconnected. Numerous images were taken to ensure the level of detail and light appearance was similar to actual visual observations of the research team.

Color Rendering Test

This test was conducted on six different colors (white, red, yellow, green, blue, and black). Six matte poster boards were placed on easels and located on both sides of the two lamp sources.

First step: the CRI investigation was implemented, when two lamp sources were "on" and the camera distance from easels was changed from one pole height (see Figure 58), which is 26 feet to two, three (see Figure 59), four, and five pole heights (see Figure 60).

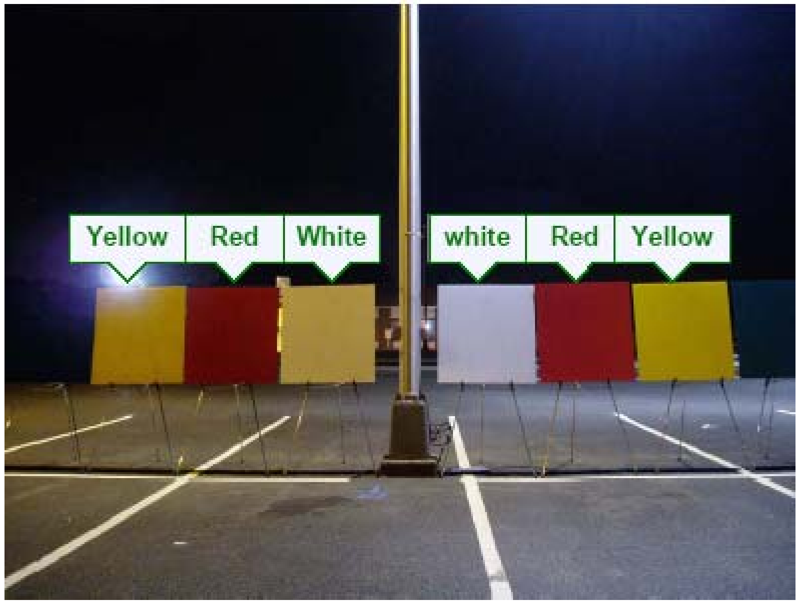


Figure 58: Color rendering test - One pole height spacing

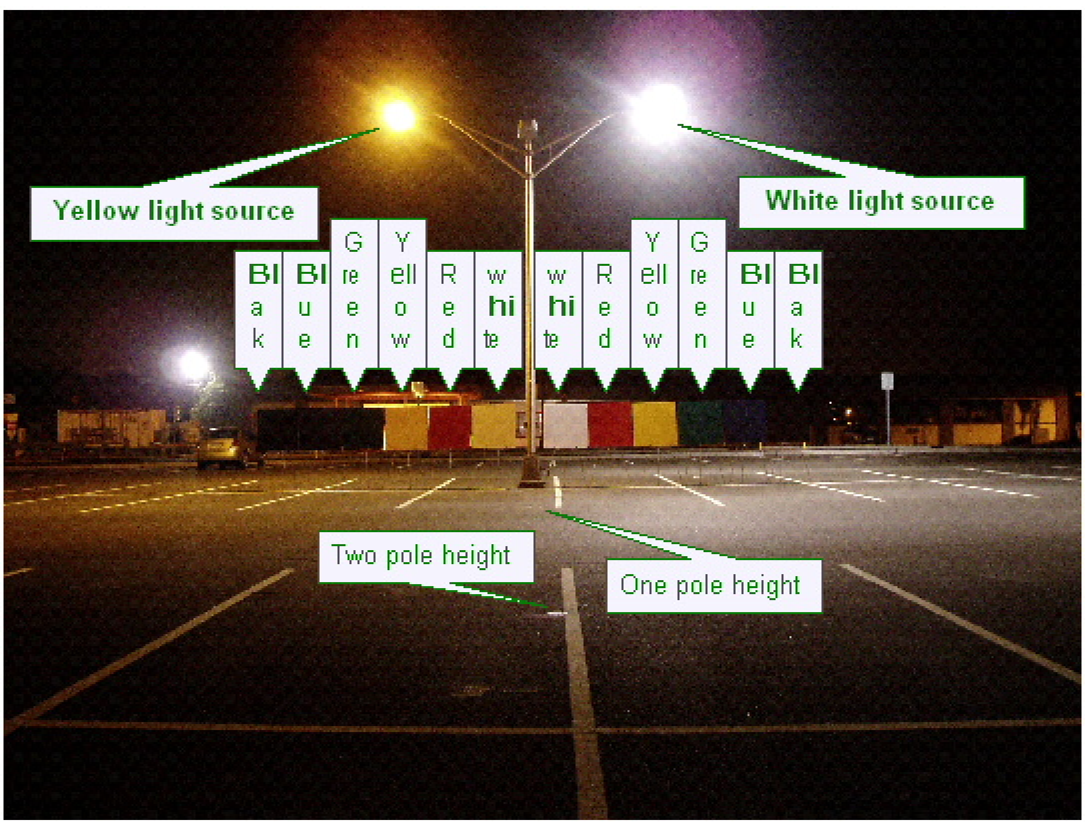


Figure 59: Color rendering test – Three pole heights spacing

Figure 60: Color rendering test - Five pole heights spacing

As it appears from observation, the test confirms that the white light source has better color rendering. If viewing this report in black and white, one might even note that there is even a “shading” distinction on the last 3 panels (green, blue, and black) of the white light source that can not be observed for the yellow light source. These results are highly questionable. Since both light sources were “on”, each lamp may have influenced the observation. The glow and light overlap most definitely re-colored the light augmenting each other. Through the evaluation of each light individually a much better comparison can be made.

Second step: the CRI investigation was conducted, when one lamp was “on”. This test tries to conceal the effect of one lamp’s glare on color rendering of another. Figure 61 illustrates this situation with white light source. As it appears, Figure 61 shows better color rendering with the same distance to the pole compared to Figure 59, when two lights were on. For instance, as it is shown in Figure 59, blue and black targets obscure in white light source area, because of yellow glare. However, Figure 61, with the same distance to the pole, reveals blue and black targets.

Figure 62 illustrates color rendering, when yellow light source are “on”. This figure describes yellow light source poor color rendering.

Figure 61: Color rendering test with white light source - Three-pole spacing

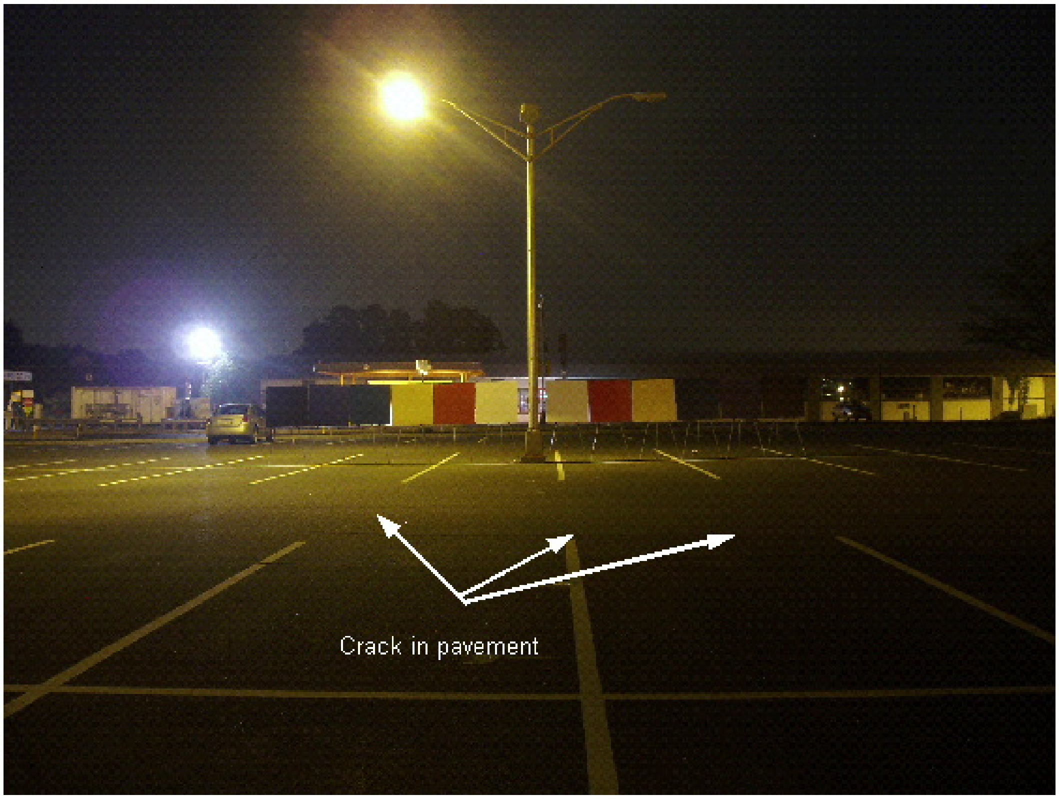


Figure 62: Color rendering test with HPS light source - Three-pole spacing

In reviewing the test results, it was observed that there is a noticeable crack in the pavement between one and two pole spacing. In Figure 61, for the white light source, the crack is distinguished; however, in Figure 62, for the yellow light source, the crack is less noticeable.

Small Target Visibility Test

This test was conducted with glossy black and white buckets as targets. The targets were placed 6 feet from each other in three rows. This test is contrast-based and illustrates the detection of an object based on:

1. contrasting with background
2. luminance of lighting source

Choosing black and white targets was based on the investigation of the distribution of positive null (white targets) and negative contrasts (black targets). This test reveals which light source meets the motorists' need for visual information.

Figure 63 is a direct side by side comparison of the white and yellow light source, which shows that the white light has better visibility than yellow light. On the other hand, white targets, which are not visible clearly and identify null contrast points, are more detectable with luminance of white light source (see Figure 64).

Figure 63: Negative contrast test with HPS and white light source- Three pole spacing

Figure 64: Positive and Null contrast test with HPS and white light source- Three pole spacing

The field testing is seeking two important results. In the first phase, the research team is searching the effect of CRI on visibility and the second phase is stating the effect of different lamp technologies on lumen and visibility. The field testing took place at the NJDOT complex just outside Ewing in Trenton, NJ. The test was conducted in a parking area of the aforementioned complex.

LIFE-CYCLE COST ANALYSIS:

The essential aspects of conducting a Life Cycle Cost Analysis (LCCA) and determining the cost-effectiveness of any given purposed alternative are the identification of all the relevant inputs and outputs and quantification of these factors into costs and benefits to facilitate informed decision making. Costs can be more readily quantified than benefits because they normally have dollar amounts attached. Benefits are qualitative, and thus difficult because they often tend to have more intangibles. In analyses, benefits should be as important as costs and deserve to be brought to the attention of decision makers.

In this study, a LCCA has been conducted for proposed alternatives. Although the research team encourages decision makers to consider extra benefits of lamps with long life besides the result of LCCA. Some of these intangible benefits are: reduced labor, less congestion for relamping, workers' and drivers' safety, less crime, and others.

There is no standard or single method prescribed for benefit analysis information, which the research team conducts in this analysis. What is important is the content; and in the case of benefits, content is critical. No analysis is truly complete unless it addresses benefits attending all the alternatives under consideration. The research team has focused on a quantitative approach; however, employee safety during relamping, or pedestrian safety at dangerous intersections, is too complex to include in this basic LCCA model.

By considering the forgoing discussion, the research team selected 6 lamps for Life Cycle Cost Analysis (LCCA). These selections are based on: a) existing lamp for road lighting and b) proposed alternatives. LCCA for this study is presented for 20 years.

In order to attain our goal, the research team reviewed single and uniform present value for estimating present value cost of each alternative. These costs are as follows:

- Initial lamp or retrofit Cost
- Labor Relamping Cost
- Lamp relamping cost during LCCA
- Electricity cost

For present value of lamp and relamping cost, a single present factor is applied and uniform present factor is utilized for calculation of present value of electricity cost.

The authors believe that a brief discussion regarding these factors is essential to understand how these factors can be applied in LCCA.

Single Present Value and Uniform Present Value Factors for Non-Fuel Costs

Appendix 9 presents the single present value (SPV) factors for finding the present value of future non-fuel, non-annually recurring costs, such as repair and replacement costs and salvage values. The formula for finding the present value (P) of a future cost occurring in year t (C_t) is : (18)

$$P = C_t \times \frac{1}{(1+d)^t} = C_t \times SPV_t$$ Equation (7)

Where:
d = discount rate, and
t = number of time periods (years) between the present time and the time the cost is incurred.

Appendix 10 presents modified uniform present value (UPV*) factors for finding the present value of annually recurring non-fuel costs, such as electricity costs, which are expected to change from year to year at a constant rate of change (or escalation rate) over the study period. The escalation rate can be positive or negative. The formula for finding the present value (P) of an annually recurring cost at base-date prices (A_0) changing at escalation rate e is : (18)

$$P = A_0 \times \left(\frac{1+e}{d-e}\right)\left[1-\left(\frac{1+e}{1+d}\right)^N\right] = A \times UPV_N^* \qquad (d \neq e)$$ Equation (8)

or

$$P = A_0 \times N = A \times UPV_N^* \qquad (d = e)$$ Equation (9)

where
A_0 = annually recurring cost at base-date prices,
d = discount rate,
e = escalation rate, and
N = number of time periods (years) over which A recurs.

For instance, computing present value of electricity cost during LCCA, which is annually recurring costs and expected to increase at 2% faster than the rate of general inflation over 20 years, find the UPV* factor from Appendix 10 that corresponds to 2% escalation and a 20 year study period (18.08). Multiply this factor by the annual electricity cost as computed at base year prices to determine the present value of these electricity costs over the entire 20 years.

To compute the present value of a relamping and the lamp cost expected to occur, for example, every 6 years for road lighting, go to Appendix 9, find the 3.0% SPV factor for year 6 (0.837), and multiply the factor by the replacement cost as of the base date. For our purpose, relamping occurs year 6, 12, 18 for HPS and MV and every 10 years for Restrike HPS.

The aforementioned factors and equations are extracted from 2004 report, published by U.S. Department of Commerce. This data is necessary to develop a LCCA model and determine costs.

System Wide LCCA Approach For One Lamp

According to obtained data from NJDOT, there are an estimated 45,000 lamps in the State roadway system, 15%, 35% and 50% of current lamps are HPS 400W, HPS 250W and HPS 150W, respectively. Therefore, this study has conducted two LCCA for current and proposed alternatives to cover those applications separately. However, this study does not cover LCCA for 400W HPS because of special usage of 400W HPS, which is out of scope of this project. The literature review failed to show any alternatives for 400W HPS. Alternative technologies are as follows:

1. Mercury Vapor
2. High Pressure Sodium
3. High Pressure Sodium Restrike
4. High Pressure Sodium Retro white
5. QL
6. Icetron
7. LED

Before starting LCCA calculation, three notes have to be considered:

- The proposed lamps are being analyzed based on application. For instance, LED technology has not been developed to have an equivalent substitution for HPS 250W, although it can be compared with HPS 150W. Another example, HPS retro white 150W does not exist and cannot be compared along with other alternatives in this category.

- As mentioned before, the appropriate functioning position for HPS retro white is vertical, however, existing head style luminaire (Cobrahead) operate in the horizontal position. Nevertheless, the comparison between retro white and HPS 250W is conducted; because, future advancements in the retro white may allow for its use in the horizontal position.

- In order to make an accurate comparison, the research team has consistently used the Rated Life, as per the manufacture's specification sheets. This was done in order to make an accurate comparison of the LCCA. In real world application the actual life may be significantly less. For instance, HPS Restrike Lamps, the second arc tube can provide lighting rapidly in the event of a power outage/interruption. However, under normal operation where the restrike feature is not utilized, the rated lamp life is 40,000 hours, as per the manufacturer.

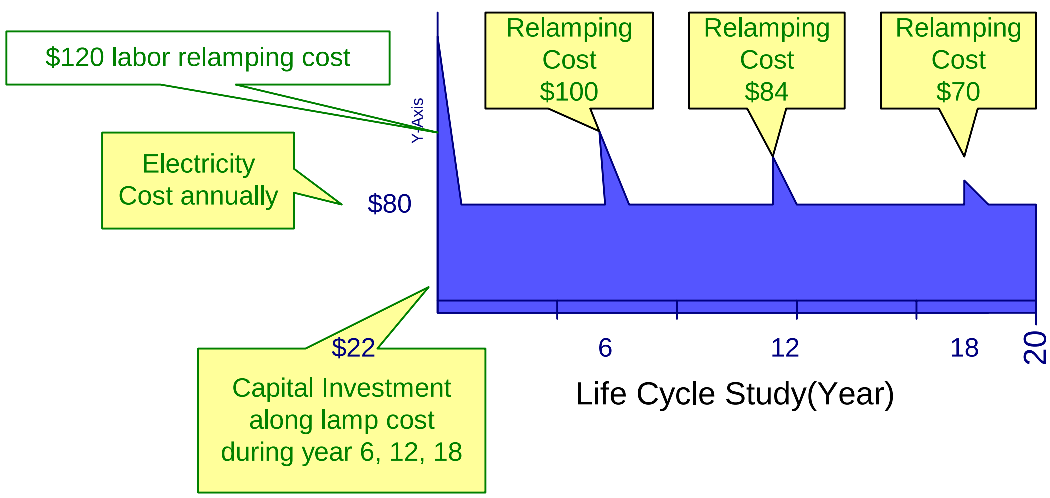
Finally, LCCA will be applied for current and proposed alternatives for two following applications:
Application 1: Usage of HPS 150W (the summary of the LCCA analyze for this application is presented in Figure 65 and Table 8)

Application 2: Usage of HPS 250W (the summary of the LCCA analyze for this application is presented in Figure 66 and Table 9)

In order to develop a better model, a rigorous multiyear field monitoring program would need to be implemented. Simply using purchasing data or relamping contracts does not accurately document mean life. The very nature of developing a LCCA model requires good baseline data, using estimated data would fundamentally create a flawed model.

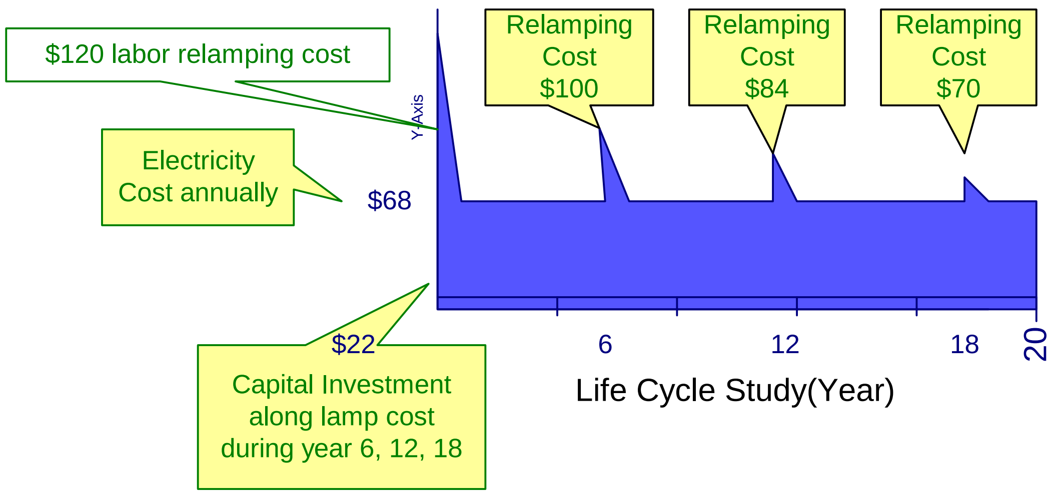
LCCA for Current & Proposed Alternatives for State Roadway Applied HPS 150W

Alternative 1 : MV (175 W)
Initial capital Investment: \$7*
Expected Life: 24,000 Hr 0r 5.8 Yr (4140 hr annually)
Residual Value: \$0
Electricity: (175/1000 (kw) * 0.11 (\$/h) *4140(h/yr) = \$80 kw/yr)
Total Electricity cost during LCCA: 18.08 * \$80 = \$1441
Relamping : NJDOT: \$90 , Contractor \$120 (almost every 6 year)
Total relamping cost during LCCA (NJDOT) : (0.837 * 90)+(0.701*90)+(0.587 * 90) = \$191
Total relamping cost during LCCA (Contractor) :
(0.837 * 120)+(0.701*120)+(0.587 * 120) = \$255
Lamp Cost during LCCA : (0.837 * 7)+(0.701*7)+(0.587 * 7) ≈ \$15
Life cycle study: 20 years



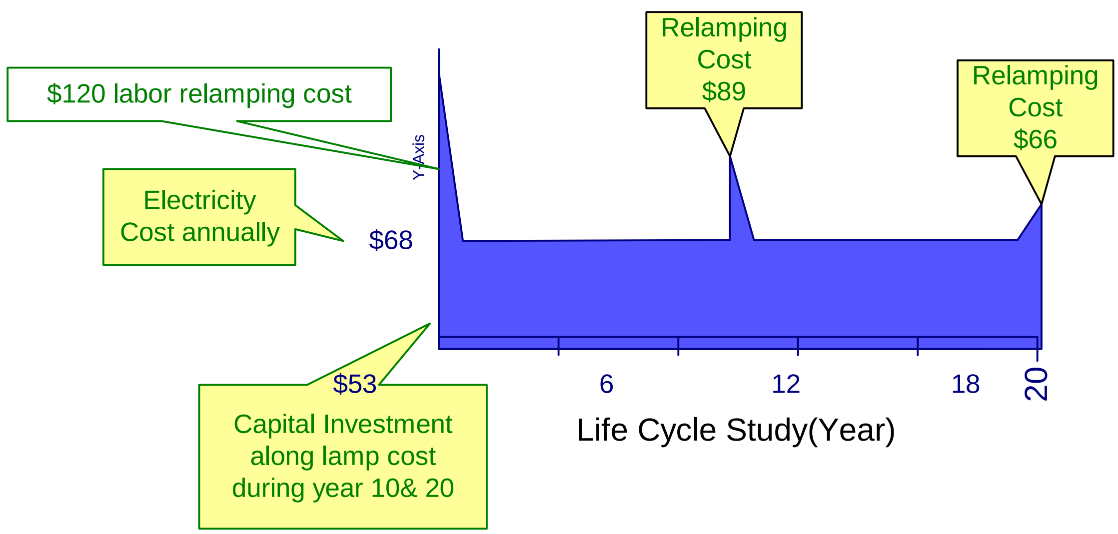
* Requisition for bulk price from "Samson Electrical Supply", which was provided for MV 400W (attached in appendix)

<u>Alternative 2 : HPS (150 W)</u>
Initial capital Investment: $ 7*
Expected Life: 24,000 Hr 0r 5.8 Yr (4140 hr annually)
Residual Value: $0
Electricity: (150/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $68 kw/yr)
Total Electricity cost during LCCA: 18.08 * $68.31 = $1235
Relamping: NJDOT: $90 , Contractor $120 (every 5.8 year)
Total relamping cost during LCCA (NJDOT) : (0.837 * 90)+(0.701*90)+(0.587 * 90) = $191
Total relamping cost during LCCA (Contractor) :
(0.837 * 120) + (0.701*120) + (0.587 * 120) = $255
Lamp Cost during LCCA : (0.837 * 7)+(0.701*7)+(0.587 * 7) ≈ $15
Life cycle study: 20 years



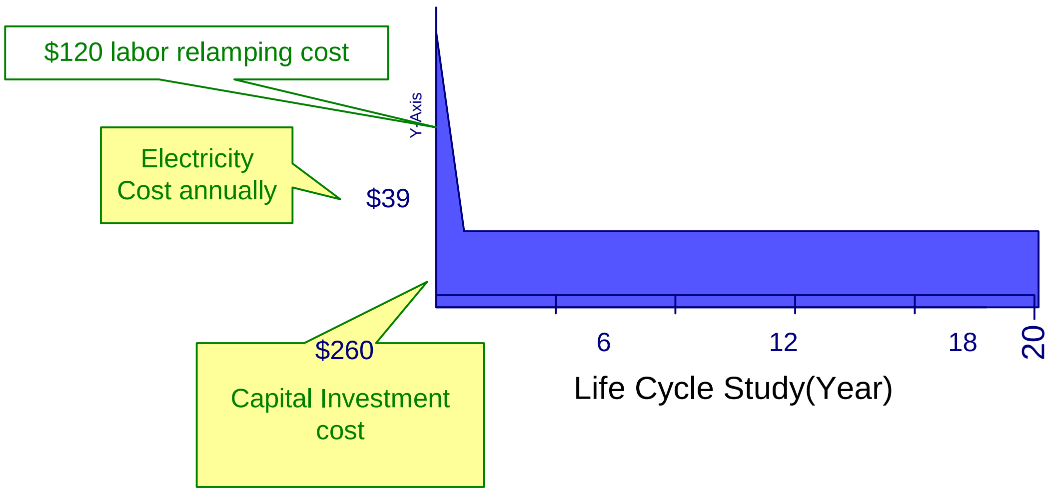
* Requisition for bulk price from NJDOT (Dan Black from Bureau of electrical eng.) on March 24, 2005 (attached in appendix)

<u>Alternative 3 : HPS Restrike (150 W)</u>
Initial capital Investment: $23*
Expected Life: 40,000 Hr 0r 9.7 Yr (4140 hr annually)
Residual Value: $0
Electricity: (150/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $68 kw/yr)
Total Electricity cost during LCCA: 18.08 * $68.31 = $1235
Relamping: NJDOT: $90 , Contractor $120 (every 10 year)
Total relamping cost during LCCA (NJDOT) : (0.744*90)+(0.554 * 90) = $117
Total relamping cost during LCCA (Contractor) :
(0.744*120)+(0.554 * 120) = $ 155
Lamp Cost during LCCA: (0.744 * 23)+(0.554 * 23) ≈ $30
Life cycle study: 20 years



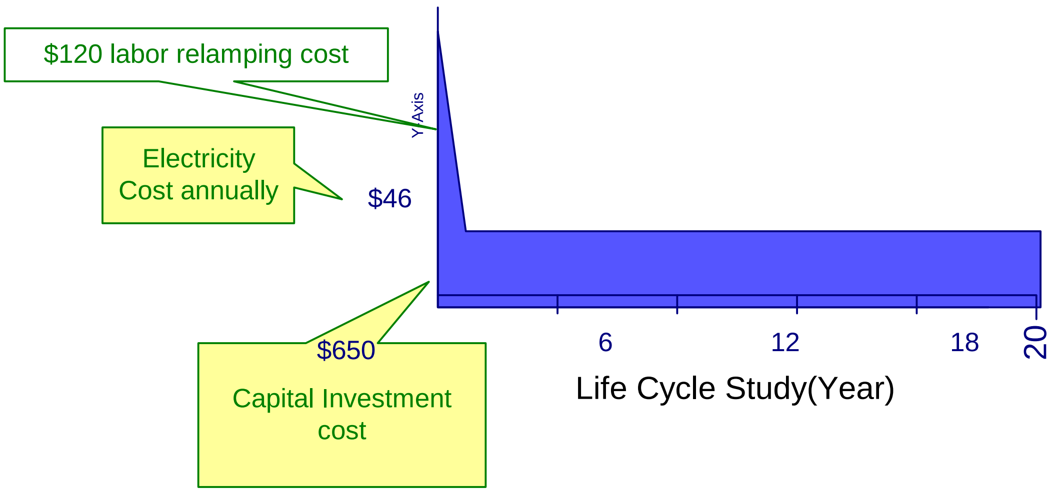
* Requisition for bulk price from "Samson Electrical Supply" attached in appendix

<u>Alternative 4 : QL (85 W)</u>
Initial capital Investment: $260*
Expected Life: 100,000 Hr 0r 24.15 Yr (4140 hr annually)
Residual Value:$0
Electricity: (85/1000 (kw) * 0.11 ($/h) *4140(h/yr) ≈ $ 39 kw/yr)
Total Electricity cost during LCCA: 18.08 * $39 ≈ $700
Relamping: $0
Lamp Cost during LCCA : $0
Life cycle study: 20 years



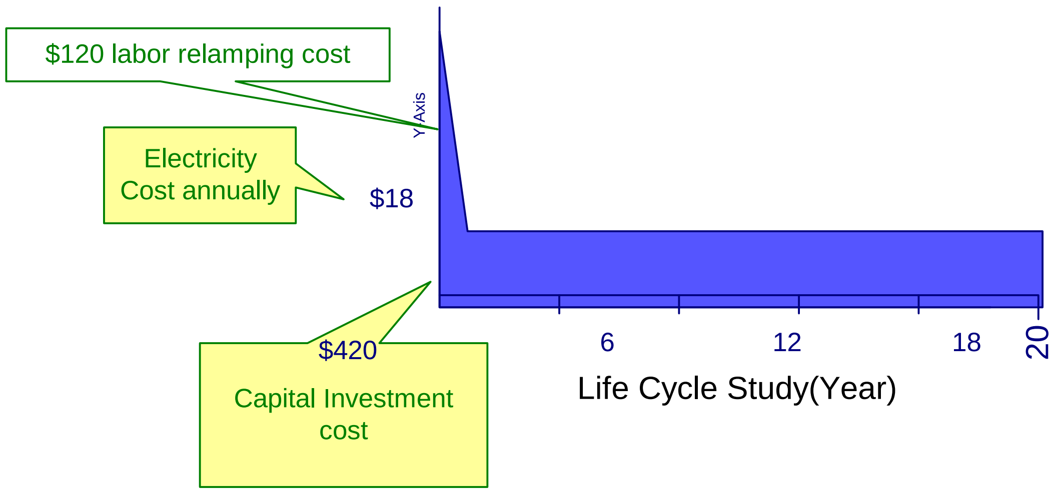
* Requisition for bulk price from Tapnet in March 2005 (attached in appendix)

<u>Alternative 5 : Icetron (100 W)</u>
Initial capital Investment: $ 650*
Expected Life: 100,000 Hr 0r 24.15 Yr (4140 hr annually)
Residual Value:$0
Electricity: (100/1000 (kw) * 0.11 ($/h) *4140(h/yr) ≈ $ 46 kw/yr)
Total Electricity cost during LCCA: 18.08 * $ 46 ≈ $ 823
Relamping: $0
Lamp Cost during LCCA : $0
Life cycle study: 20 years



* Price of one Icetron Cobrahead fixture (100 W) bought in Nov 2004 from GE lighting system

<u>Alternative 6: LED (40 W)</u>
Initial capital Investment: $ 420*
Expected Life: 100,000 Hr 0r 24.15 Yr (4140 hr annually)
Residual Value:$0
Electricity: (40/1000 (kw) * 0.11 ($/h) *4140(h/yr) ≈ $ 18 kw/yr)
Total Electricity cost during LCCA: 18.08 * $ 18 ≈ $ 329
Relamping: $0
Lamp Cost during LCCA : $0
Life cycle study: 20 years



* Requisition for bulk price from Luxbright Inc. in April 2005

Table 8: Summary of alternatives for HPS 150W application (Cost for one lamp during 20 years LCCA)

Alternative	Expected Life(hr)	Initial Capital Investment	Lamp Price During LCCA	Contractor Labor Cost for Relamping	NJDOT Labor Cost for Relamping	Relamping Contractor During LCCA (Labor)	Electricity Cost During LCCA	Total Present Value Cost During LCCA
High Pressure Sodium (150 W)	24,000	$7	$15.00	$120	$90	$255	$1,235	**$1,632**
Mercury Vapor (175 W)	24,000	$7	$15.00	$120	$90	$255	$1,441	**$1,838**
HPS Restrike (150 W)	40,000	$23	$30.00	$120	$90	$155	$1,235	**$1,563**
LED (40W)	100,000	$420	$0	$120	$90	$0	$329	**$869**
Icetron (100W)	100,000	$650	0	$120	$90	0	$823	**$1,593**
QL (85 W)	100,000	$260	0	$120	$90	$0	$700	**$1,080**

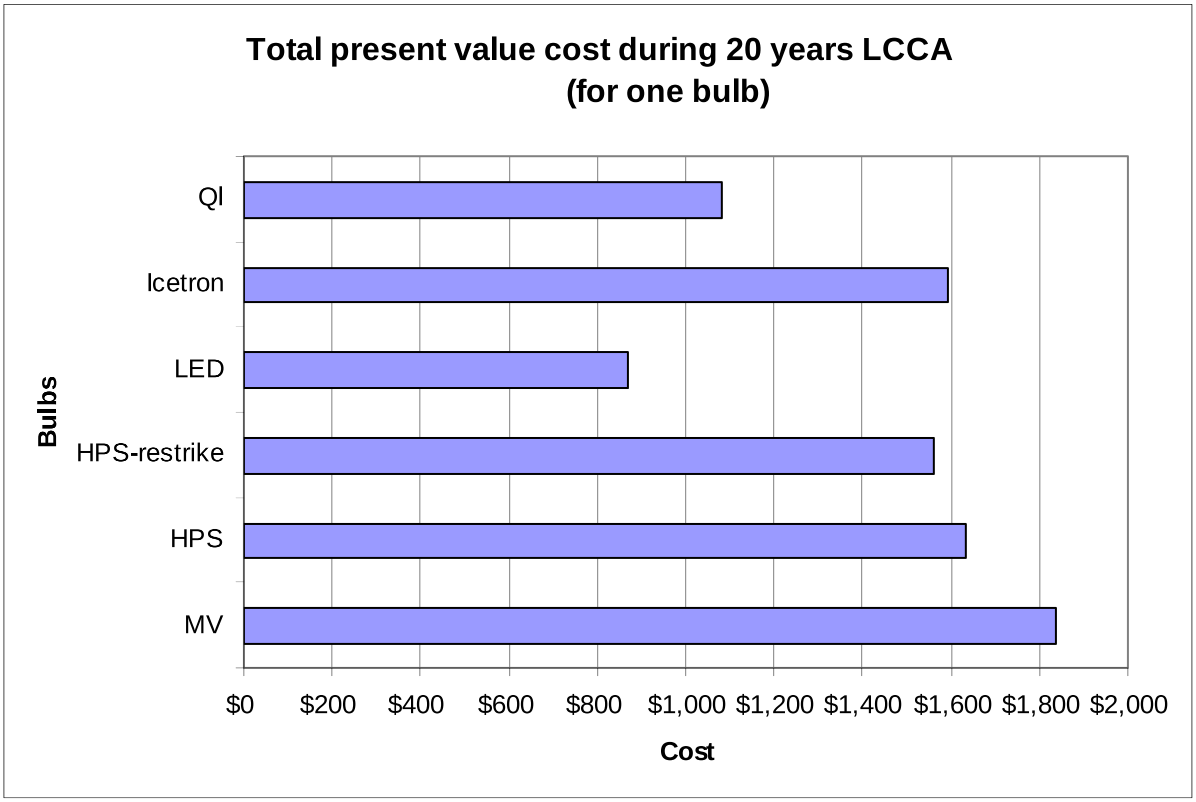
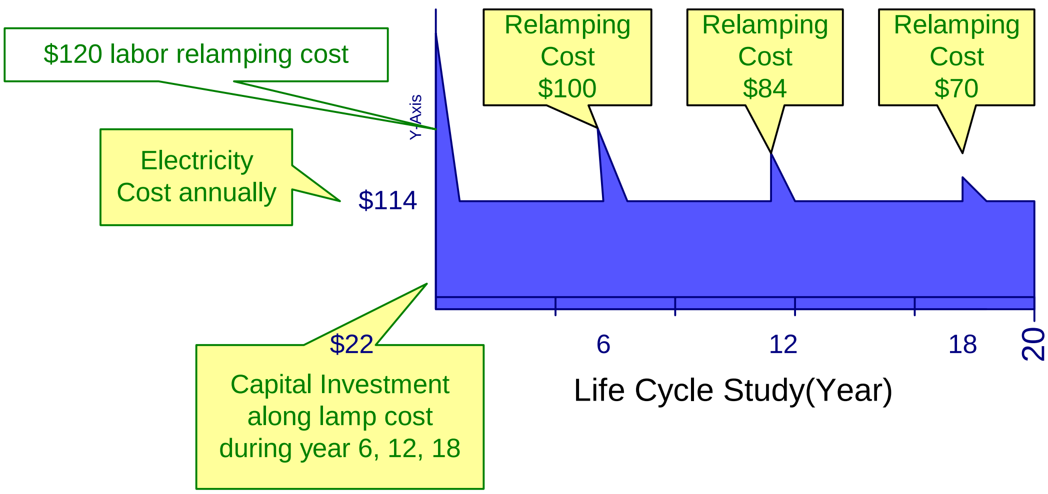


Figure 65: Total cost at the end of LCCA for proposed alternatives of HPS 150W

LCCA for Current & Proposed Alternatives for State Roadway Applied HPS 250W

Alternative 1 : MV (250 W)
Initial capital Investment: $7*
Expected Life: 24,000 Hr 0r 5.8 Yr (4140 hr annually)
Residual Value: $0
Electricity: (250/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $114 kw/yr)
Total Electricity cost during LCCA: 18.08 * $113.85 = $2058
Relamping : NJDOT: $90 , Contractor $120 (almost every 6 year)
Total relamping cost during LCCA (NJDOT) : (0.837 * 90)+(0.701*90)+(0.587 * 90) = $191
Total relamping cost during LCCA (Contractor) :
(0.837 * 120)+(0.701*120)+(0.587 * 120) = $255
Lamp Cost during LCCA : (0.837 * 7)+(0.701*7)+(0.587 * 7) ≈ $15
Life cycle study: 20 years



* Requisition for bulk price from "Samson Electrical Supply" attached in appendix, which was provided for MV 400W

Alternative 2 : HPS (250 W)

Initial capital Investment: $ 7*

Expected Life: 24,000 Hr 0r 5.8 Yr (4140 hr annually)

Residual Value: $0

Electricity: (250/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $114 kw/yr)

Total Electricity cost during LCCA: 18.08 * $113.85 = $2058

Relamping: NJDOT: $90 , Contractor $120 (every 5.8 year)

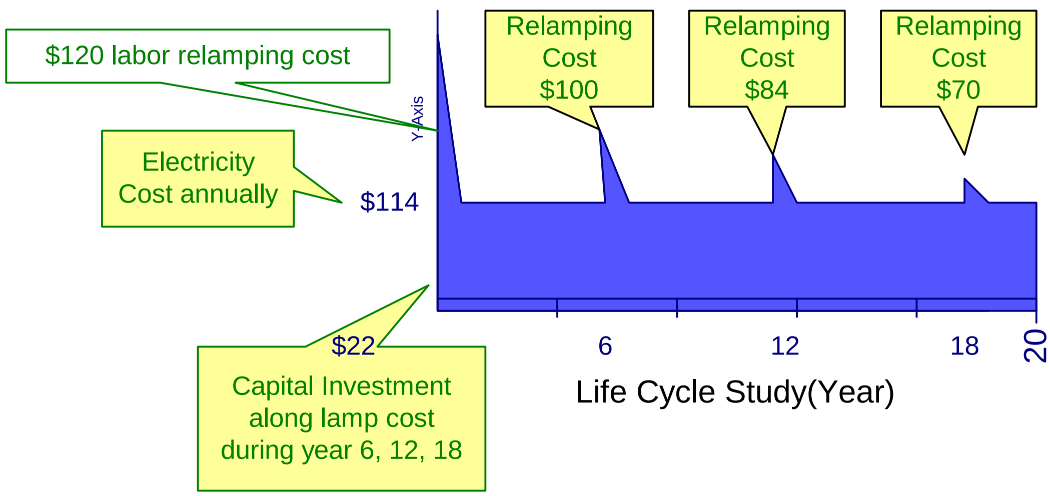
Total relamping cost during LCCA (NJDOT) : (0.837 * 90)+(0.701*90)+(0.587 * 90) = $191

Total relamping cost during LCCA (Contractor) :

(0.837 * 120)+(0.701*120)+(0.587 * 120) = $255

Lamp Cost during LCCA : (0.837 * 7)+(0.701*7)+(0.587 * 7) ≈ $15

Life cycle study: 20 years



* Requisition for bulk price from NJDOT (Dan Black from Bureau of electrical eng.) on March 24, 2005 (attached in appendix)

Alternative 3 : HPS Restrike (250 W)

Initial capital Investment: $12*

Expected Life: 40,000 Hr 0r 9.7 Yr (4140 hr annually)

Residual Value: $0

Electricity: (250/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $114 kw/yr)

Total Electricity cost during LCCA: 18.08 * $113.85 = $2058

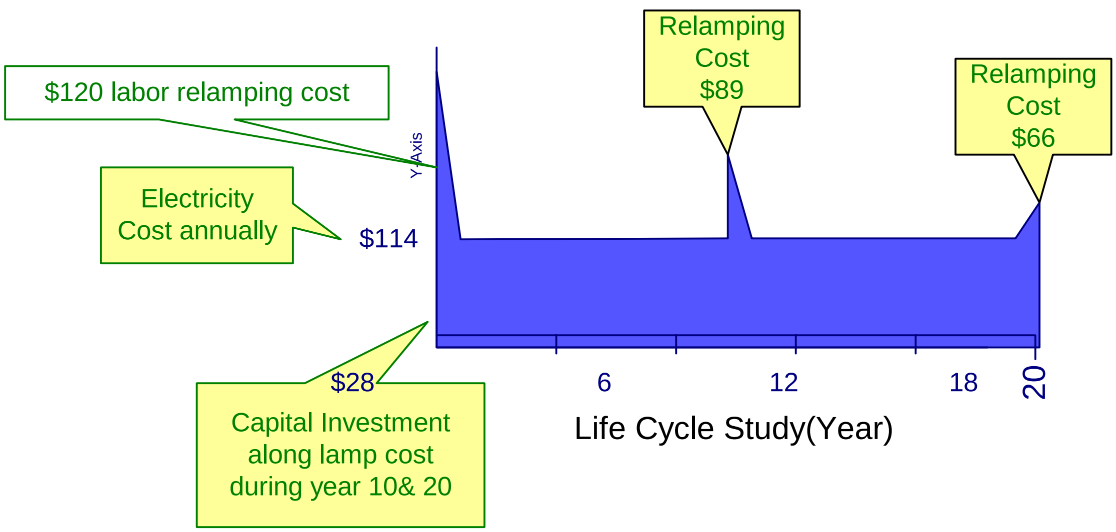
Relamping : NJDOT: $90 , Contractor $120 (every 10 year)

Total relamping cost during LCCA (NJDOT) : (0.744*90)+(0.554 * 90) = $117

Total relamping cost during LCCA (Contractor) :
(0.744*120)+(0.554 * 120) = $ 155

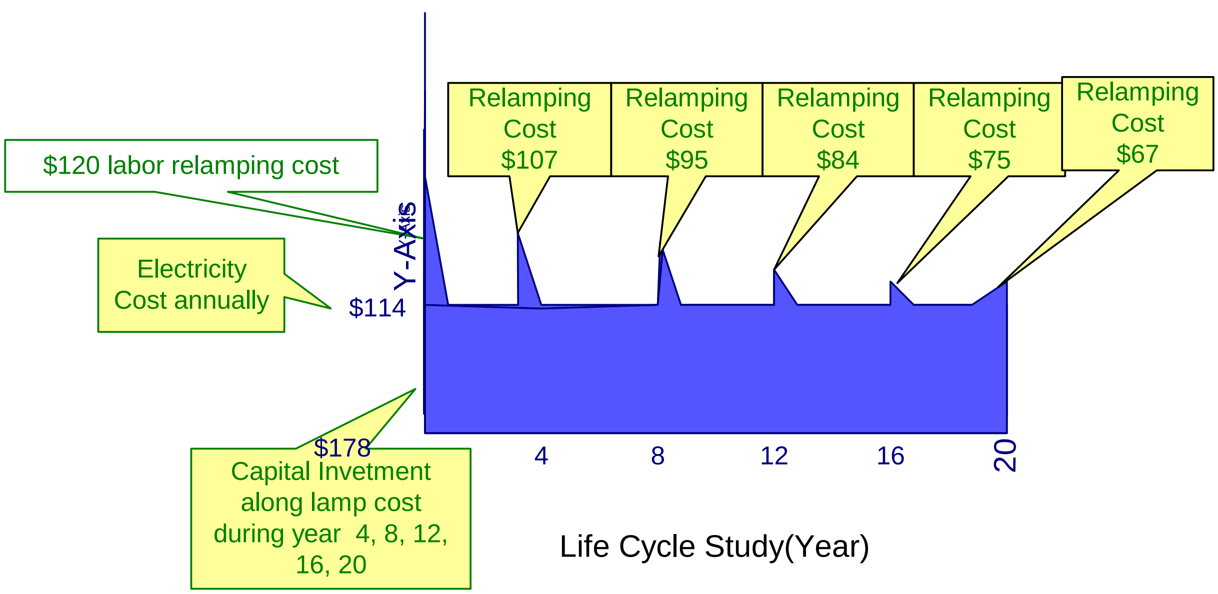
Lamp Cost during LCCA: (0.744 * 12)+(0.554 * 12) = $16

Life cycle study: 20 years



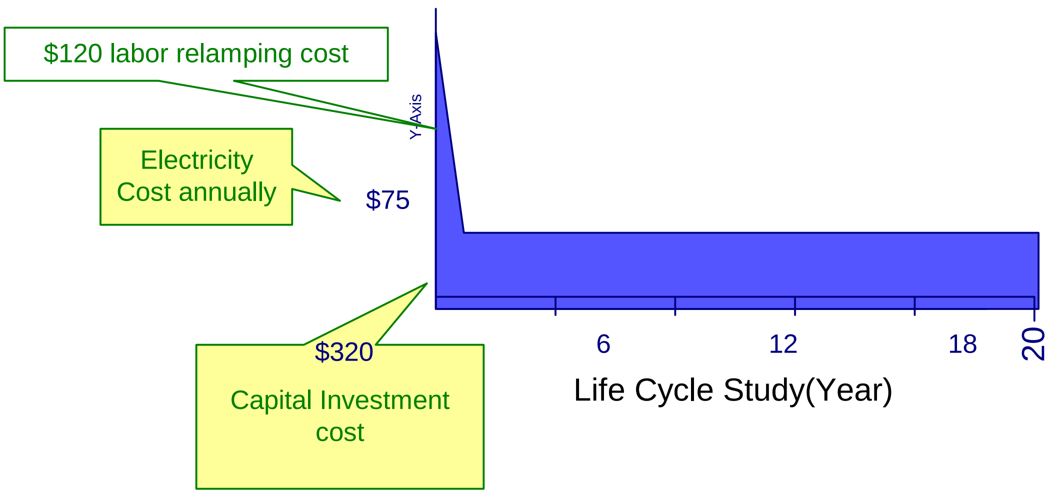
* Requisition for bulk price from "Samson Electrical Supply" attached in appendix

<u>Alternative 4 : HPS Retro white (250 W)</u>
Initial capital Investment: $39*
Expected Life: 15,000 or 3.62 Yr (4140 hr annually)
Residual Value: $0
Electricity: (250/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $114 kw/yr)
Total Electricity cost during LCCA: 18.08 * $113.85 = $2058
Relamping: NJDOT: $90 , Contractor $120 (every 4 year)
Total relamping cost during LCCA (NJDOT) : (0.888 * 90)+(0.789*90)+(0.701 * 90) + (0.623 *90)) +(0.554 * 90) ≈ $ 320
Total relamping cost during LCCA (Contractor) :
(0.888 * 120)+(0.789*120)+(0.701 *120) + (0.623 *120))+(0.554 * 120) ≈ $ 427
Lamp Cost during LCCA : (0.888 * 39)+(0.789*39)+(0.701 *39) + (0.623 *39))+(0.554 * 39) ≈ $ 139
Life cycle study: 20 years



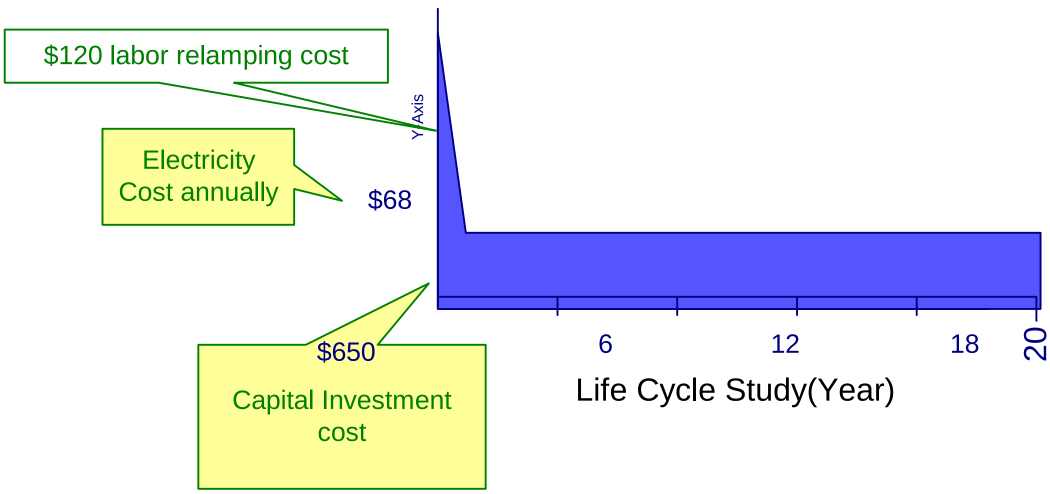
* Requisition for bulk price from "Samson Electrical Supply" attached in appendix

<u>Alternative 5 : QL (165 W)</u>
Initial capital Investment: $320*
Expected Life: 100,000 Hr 0r 24.15 Yr (4140 hr annually)
Residual Value:$0
Electricity: (165/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $ 75 kw/yr)
Total Electricity cost during LCCA: 18.08 * $75.141 = $1359
Relamping: $0
Lamp Cost during LCCA : $0
Life cycle study: 20 years



* Requisition for bulk price from Tapnet in March 2005

Alternative 6 : Icetron (150 W)
Initial capital Investment: $ 650*
Expected Life: 100,000 Hr 0r 24.15 Yr (4140 hr annually)
Residual Value:$0
Electricity: (150/1000 (kw) * 0.11 ($/h) *4140(h/yr) = $ 68 kw/yr)
Total Electricity cost during LCCA: 18.08 * $ 68 = $1235
Relamping: $0
Lamp Cost during LCCA : $0
Life cycle study: 20 years



* Price of one Icetron Cobrahead fixture (100 W) bought in Nov 2004 from GE lighting system

Table 9: Summary of alternatives for HPS 250W applications (Cost for one lamp during 20 years LCCA)

Alternative	Expected Life(hr)	Initial Capital Investment	Lamp Price During LCCA	Contractor labor cost for Relamping	NJDOT Labor Cost for Relamping	Relamping Contractor During LCCA (Labor)	Electricity Cost During LCCA	Total Present Value Cost During LCCA
High Pressure Sodium (250 W)	24,000	$7	$15.00	$120	$90	$255	$2,058	**$2,455**
Mercury Vapor (250 W)	24,000	$7	$15.00	$120	$90	$255	$2,058	**$2,455**
HPS Restrike (250 W)	40,000	$12	$16.00	$120	$90	$155	$2,058	**$2,361**
Retro White(250 W)	15,000	$39	$139	$120	$90	$427	$2,058	**$2,783**
Icetron (150 W)	100,000	$650	0	$120	$90	0	$1,235	**$2,005**
QL (165 W)	100,000	$320	0	$120	$90	$0	$1,359	**$1,799**

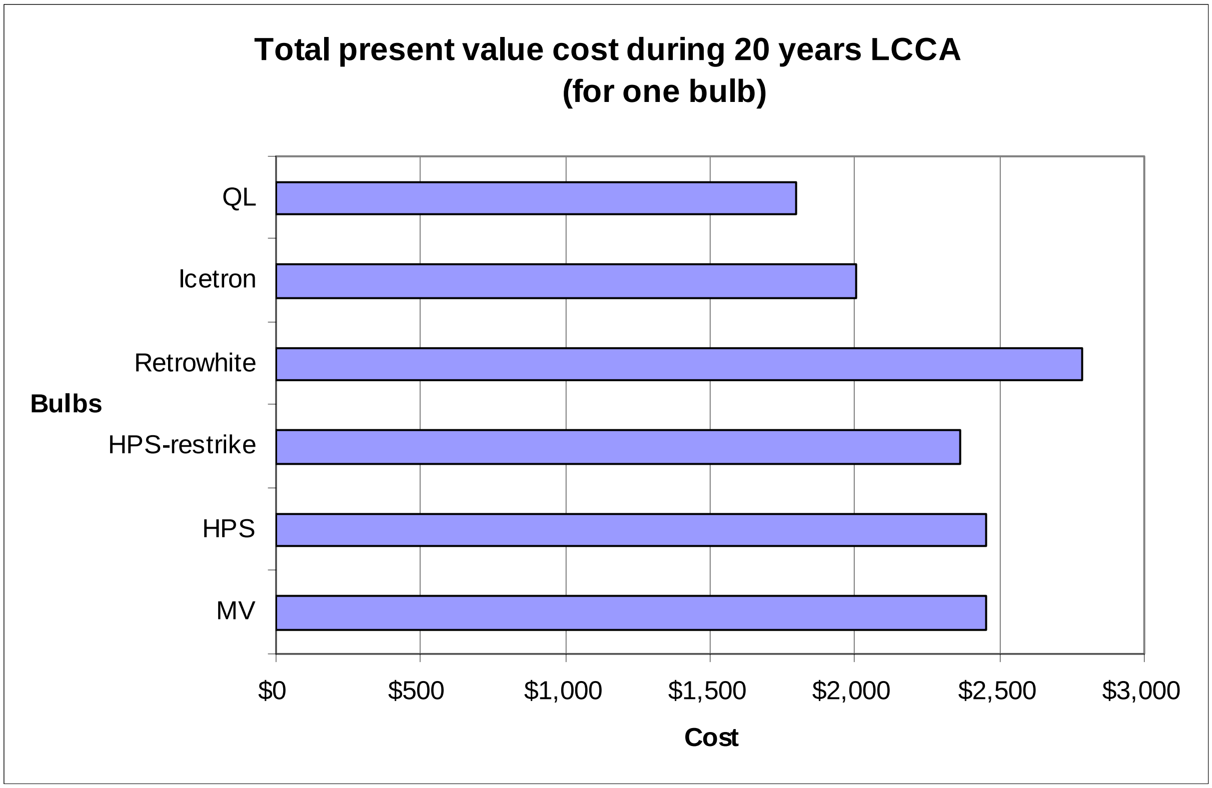


Figure 66: Total cost at the end of LCCA for proposed alternatives of HPS 250W

Cumulative Costs Approach During LCCA

Cumulative costs are an important tool which can assist decision makers in analyzing the cost of different alternatives at any point in time. The previous section covers cumulative cost for one lamp during 20 years of life cycle cost analysis. Because of simplicity, in the following section the current cost is applied for each year, rather than applying costs' present value, which is applied in pervious section.

According to previous classification, the cumulative cost has been applied for two current applications of HPS (150W & 250W). One of the important features, which should be considered before the final decision, is energy consumption for each lamp. The cumulative cost is presented by considering electricity cost, for each alternative. However, for further consideration, this study also covers cumulative cost by excluding electricity cost. As mentioned before, the costs, which are taken into account for this estimation, are: labor relamping, lamp relamping and initial lamp cost. The following graphs (Figure 66 , Figure 67 ,Figure 68 , and Figure 69) have been extracted from tables located in Appendix 11 , Appendix 12, Appendix 13, and Appendix 14 .

As it can be observed from the following graphs, QL and HPS restrike and LED have the better performance than HPS. However, the research team believes LED technology is its still in preliminary stage and can be considered as an option in the near future.

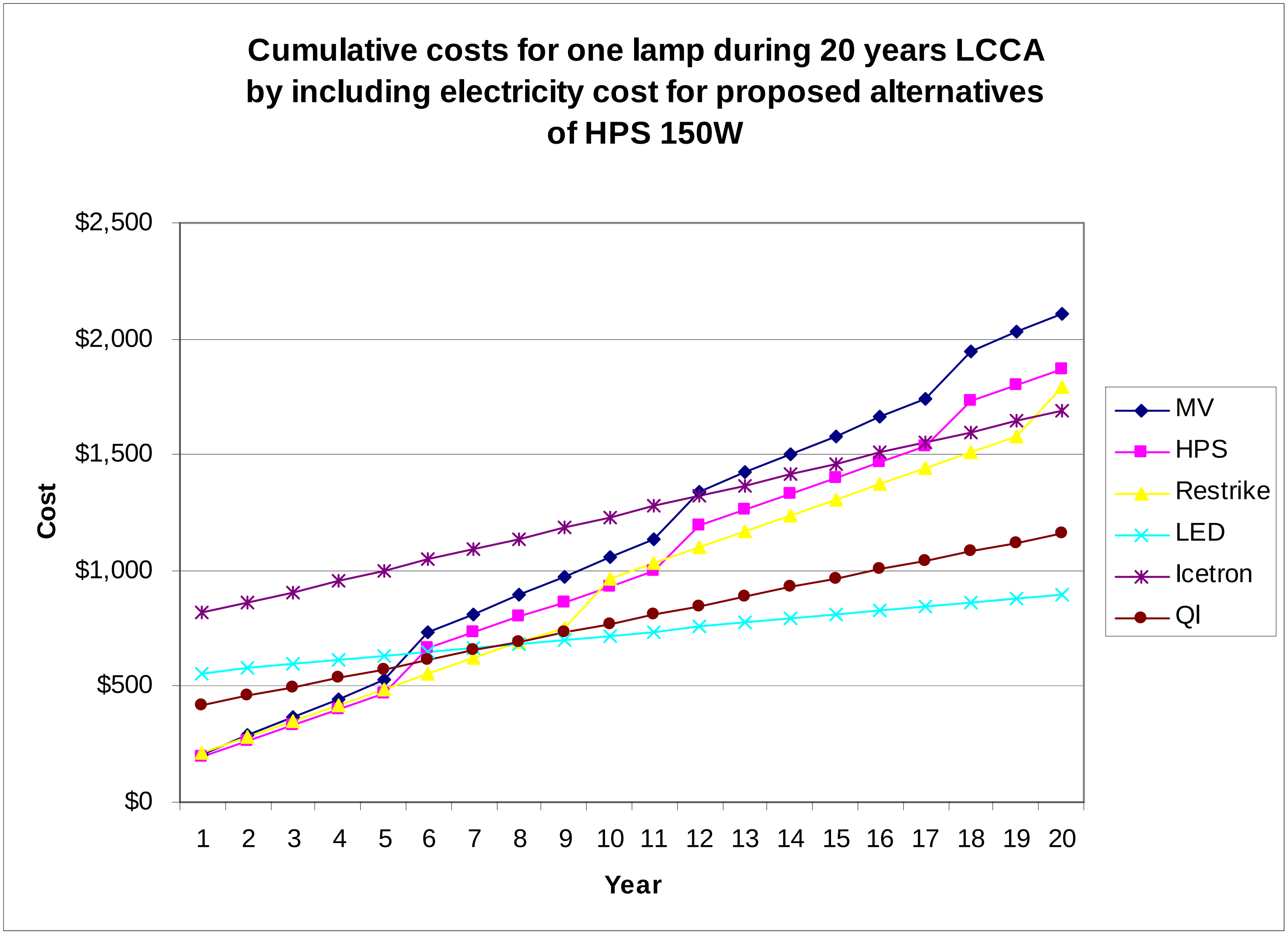


Figure 67: Cumulative costs for one lamp for proposed alternatives of HPS 150W by including electricity

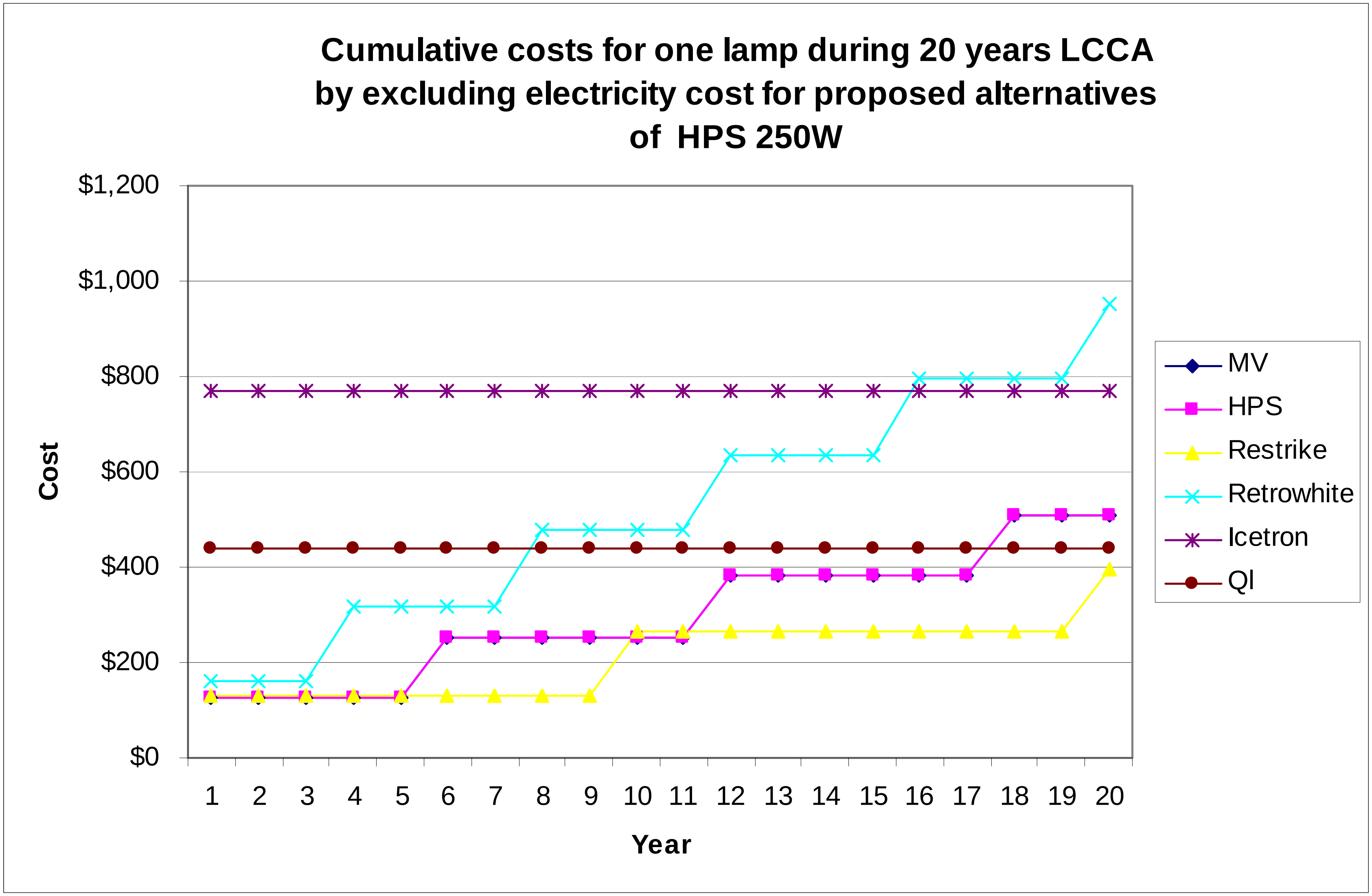


Figure 68: Cumulative costs for one lamp for proposed alternatives of HPS 250W by excluding electricity

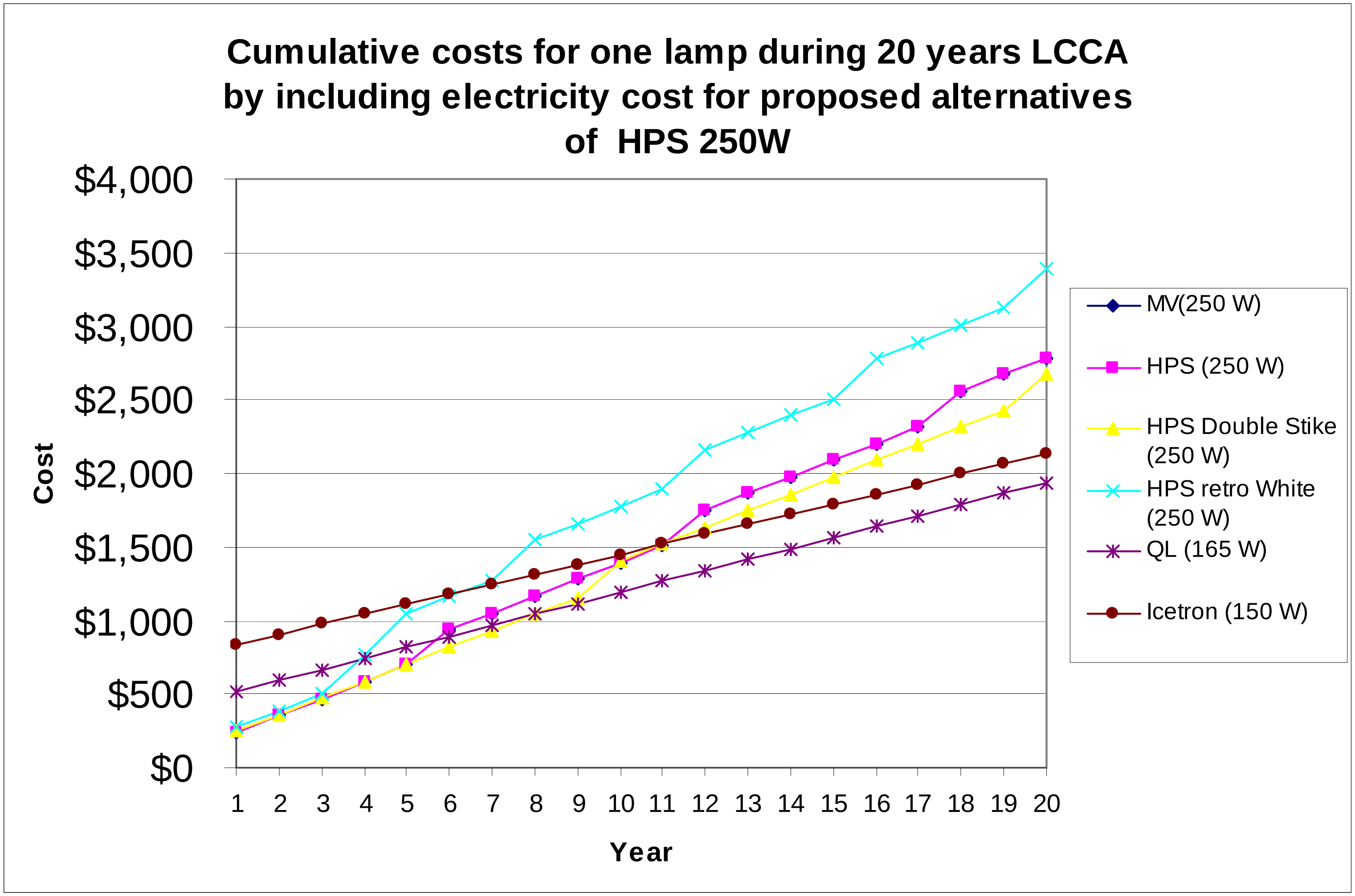


Figure 69: Cumulative costs for one lamp for proposed alternatives of HPS 250W by including electricity

NJ STATE ROAD LAMP DISTRIBUTION ANALYSIS

Based on obtained data from NJDOT, there are an estimated 45,000 lamps in state roadways, 15,750 of them (35%) are HPS 250W, 22,500 of them (50%) are HPS 150W, and 6750 of them (15%) are HPS 400W. As mentioned before, HPS 400W has a very specific application, critical site, and does not seem to have a suitable alternative in the current lighting market. Therefore, the research team has eliminated the HPS 400W from this analysis.

This portion of the study applies cumulative costs for NJ state roadways by applying two approaches: including electricity cost in one and excluding electricity cost from the other analysis. Applying the electricity cost in calculation reveals the best lamp technology in saving energy, compared with the other proposed alternatives. On the other hand, if NJDOT intends to know the best cost effective lamp, regardless of energy cost, this analysis would also satisfy this goal.

For precise comparison between present and proposed situations, the exact number and wattage of each lamp is applied in calculation. In some cases which the lamp's wattage does not exist, the closest alternative would be applied. For instance, whereas there is no HPS 150W retro white lamp, for implementing the NJ state road with more than 22,000 150W lamps, HPS 150W is substitute for this portion and then 250W, HPS retro white, is proposed in calculation for more than 15,000 lamps, as it appears in Figure 70 and Figure 71. To better understand, the following calculation is applied for year 1 by including electricity cost for HPS & HPS retro white proposed alternative:

Year 1: (150W HPS lamp cost + labor relamping cost + annual electricity cost)* total lamps alternative for HPS 150W) + (250W retrowhite lamp cost + labor relamping cost + annual electricity cost)* total lamps alternative for HPS 250W) =
(7+120+68)*22500 +((39+120+114)*15750= $8,687,250

This procedure is recurring every 6 years for HPS 150W, and every 4 years for HPS retro white 250W, because of the lamps' mean life

Another case, which is following the same category, is LED and QL. At this time LED 42W can not be a substitute for HPS 150W (due to light distribution and other factors); however, the LED technology rapidly progressing toward better LED illumination. In the near future the research team believes the combination of LED and QL may be a good alternative for present HPS 150W and 250W, as it appears in Figure 70.

It is necessary to emphasize, once more, that this analysis is based on the manufacturer's rated lamp mean life and quoted price for each lamp. Costs are accurate and based on bulk price and correct wattage, and few of them are estimated based on the price of one unit or different wattage. For example, Icetron's price is based on one unit lamp, which definitely is different from bulk price. This is an important factor, which readers have to consider.

In Conclusion, the following graphs, which are extorted from data in Appendix 15 and Appendix 16, are concluded. The results reveal that a combination of QL & LED has the least costs by including electricity cost in estimation and QL and HPS Restrike, jointly, have the least costs by excluding electricity cost during 20 years LCCA.

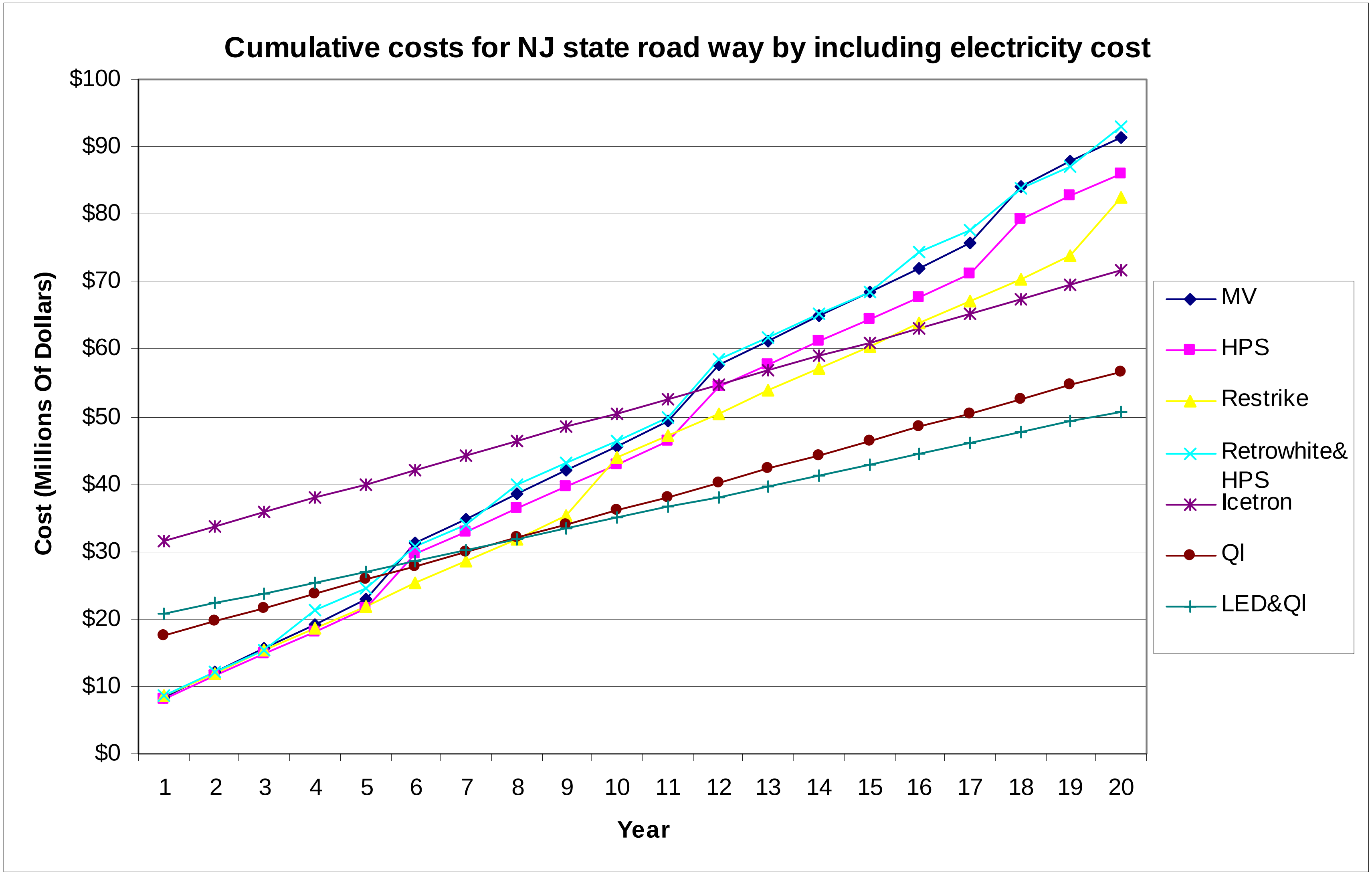


Figure 70: Cumulative costs for NJ case study for proposed alternatives by including electricity

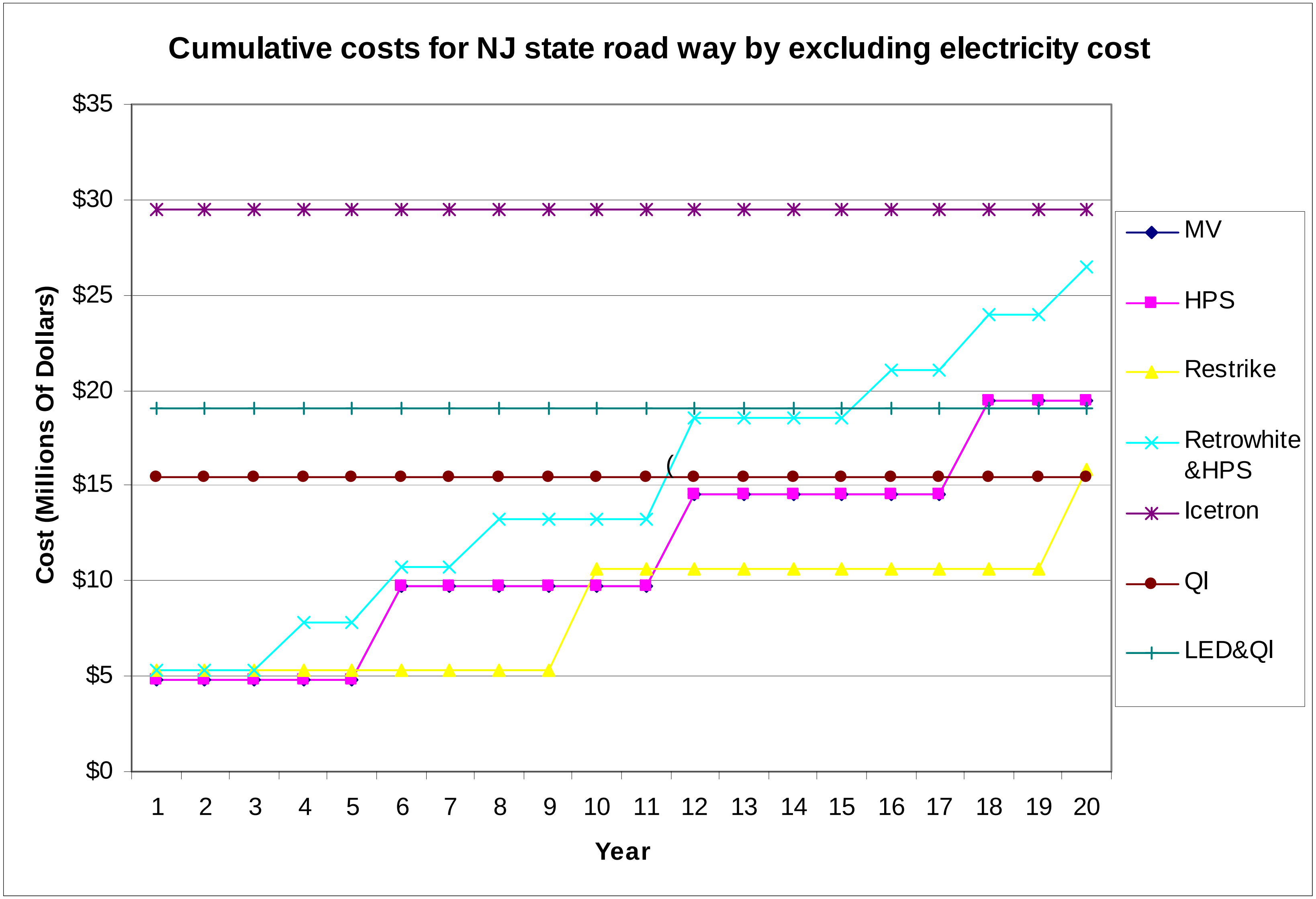


Figure 71: Cumulative costs for NJ case study for proposed alternatives by excluding electricity

RECOMMENDATIONS

The research team reviewed the available literature and experimental data. The authors believe the study should be revisited after several years of applied research (field trials) results. At present, NJDOT claims that a large percentage of roadway lighting is not working properly and that the small relamping personnel are struggling to keep up with proper maintenance. The same personnel are responsible for traffic signals and other high priority lighting, thus straining to maintain the over 45,000 overhead lamps on the highways. In addition, the operation of the 45,000 lamps has significant energy consumption costs. These, and many other factors, clearly demonstrate the extent of the problem; it is not merely a dollar issue or a labor/maintenance issue or a safety and public assistance issue, but a complicated combination of these issues. A high initial cost solution could solve many of the NJDOT's long-term labor and safety issues, however, the solution must meet accepted specifications. Therefore, the research team lists the following recommendations for future consideration:

1. Currently, LEDs do not offer adequate lighting (mainly due to poor distribution patterns) to be considered an appropriate replacement for HPS. However, research shows new emerging LED technologies, and even prior to publishing these results, the authors believe that new technologies will have become commercially available. LEDs should be closely followed, as the technology is worthwhile, as shown in the LCCA calculations.

2. Calculation of pole spacing and uniformity ratio are based on various design factors, which should be estimated from lamps and fixtures provided by the manufactures. Unfortunately, this data was not obtainable at the time this report was written. Once these factors are available and accepted, the NJDOT will need to take a closer look at pole spacing and uniformity ratio. Obviously, the existing locations of poles will not be altered, however, new construction in areas without lighting can be considered with the new criteria. Even existing poles can be considered for retrofits if the uniformity ratio is revised. In the end, designers must ask themselves if installing lighting (based on LEM) in areas currently without lighting is worse than leaving the location as is.

3. The research team believes more work could be done in field verification. Applying each proposed alternative and evaluating them by a team of members of different ages and gender could give future studies better results. The authors were particularly interested in work conducted where an observer had to decide if a pedestrian was a hazard (facing toward the street as if ready to cross) or not (facing away from the street as if departing). This type of human subject research would provide considerable insight into developing New Jersey specific Lumen Effective Multipliers (LEM) for each new technology to be considered.

4. Conserving energy and environmental conservation are two important factors which require more attention. Solar systems, along with LEDs inherently low wattages, will more than likely pioneer this field. The resulting system will save energy costs (as it is powered from LEDs), labor costs (LEDs have a considerably long life), safety costs (LEDs have a low failure rate and in clusters this becomes negligible), and are even friendly to light pollution issues (the LEDs are directional so light only goes where it is needed and only minimal to the sky).

5. Tunnel and bridge lighting was considered to be out of scope of this project, however, the authors have some recommendations on this as well. Currently, many tunnels do not have an appropriate lighting plan; and due to environment, (wind/rain/snow) bridge lighting is always a challenge. The authors feel strongly that either the induction lights, such as the QL or LED sources, are the solution. All literature is in agreement that these are vibration resistant, heat/cold resistant and have long lives. This is exactly what is required. Furthermore, during the field and experimental evaluations, the research team shook and rattled the lamps; even though this is not as scientific as would be preferred, it still implied a real durability. Therefore, the authors suggest installing QL and LEDs in a tunnel bridge scenario and simply evaluate their real world performance.

CONCLUSIONS

This study investigated current technologies which could be used to replace existing HPS lamps which are currently used in overhead roadway lighting. In the first phase, the Literature Search, white light sources demonstrated better features than sodium light sources because they produce all wavelengths of light and have a “higher” Color Rendering Index (CRI). As a result, QL, Icetron, and LED were documented to have better CRI, Correlated Color Temperature (CCT), and mean life than HPS.

The next phase of the research, the field verification, confirmed that white light source had better visibility and color rendering, experimentally. It was observed by the research team that pavement details were more noticeable. The primary goal of overhead lighting is to provide adequate lighting levels to illuminate obstructions and other roadway objects to assist drivers in making decisions. The lamps were left in place at the NJDOT complex just outside Ewing in Trenton, New Jersey. The lamps present at the NJDOT facility include HPS, QL, Icetron, LED, and Retro-white.

In the final phase of research, a Life Cycle Cost Analysis (LCCA) was conducted. Lamps included in the evaluation consisted of Mercury Vapor, High Pressure Sodium, High Pressure Sodium Restrike HPS, HPS Retro White, QL, Icetron, and LED for duration of 20 years (QL, Icetron, and LED manufactured mean life). Conclusively, QL, and LED present a low cumulative costs during 20 years (with and without including electricity cost). However, LED does not offer a good light distribution at the present time, but can be considered as a good competitor in the near future.

In conclusion, lamps can no longer be compared by lumens per watt, and new specifications must be developed to accommodate new types of technologies, including LEDs. QL and Icetron are recommended for use once the revised specifications are released. LEDs are recommended once the manufactures improve the light distribution and the revised specifications are released. Restrike HPS lamps are recommended for immediate implementation and they are acceptable under the current lighting specifications. The Restrike HPS will not save any energy costs, but will have a substantial labor savings to the department, potentially cutting the necessary relamping effort in half; all other costs for energy and materials will remain roughly the same. The HPS Retro White is also recommended for immediate implementation in select locations. The HPS Retro White meets the current specifications and it produces a better quality light. The lamps have a reduced life (about 60 percent of HPS) and use marginally more energy than the traditional HPS; however, in critical areas such as near police stations, high accident areas, emergency management areas, evacuation routes, among others, these lamps can provide better light and thus enhance the safety of such locations. Currently, they are not recommended for Cobrahead fixtures, but can be used in Freeway fixtures; the manufacture has indicated that the Cobrahead compatible lamps will be commercially available soon.

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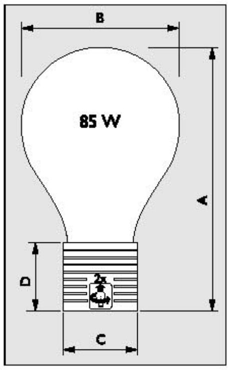
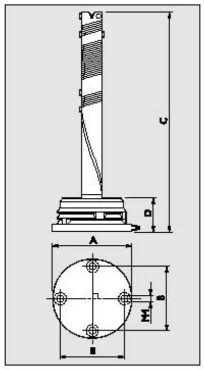
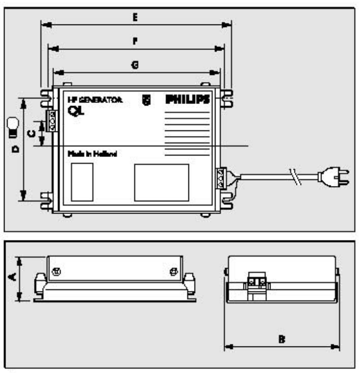
85 Watt QL Induction Lighting Lamp System



Discharge Vessel (Bulb)



Power Coupler



Generator

■ Ordering Information

Ordering Code	Product Number	Description	Pkg. Qty.
QL85W/S13	246652	Generator, 120V	6
QL85W/S03	225714	Generator, 230V	6
QL85W/PC	249441	Power Coupler	6
QL85W/830	249458	Discharge Vessel (3000K)	6
QL85W/840	249466	Discharge Vessel (4000K)	6

Note: QL system requires all three components to operate.

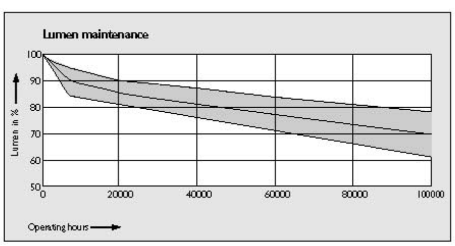
■ Mechanical Characteristics

Discharge Vessel (Bulb), Max.:	Power Coupler, Max.:
A) 7.11" (180.5mm)	A) 2.22" (56.5mm)
B) 4.37" (111mm)	B) 1.58" (40.1mm)
C) 2.25" (57mm)	C) 6.40" (162.5mm)
D) 1.94" (49mm)	D) 0.984" (25mm)
	M4 = 4mm screw diameter

Generator, Nom.:	Coaxial Cable, Length
A) 1.63" (41.5mm)	17.0" (431.8mm)
B) 4.06" (103mm)	
C) 0.88" (22.4mm)	
D) 3.15" (80mm)	
E) 5.9" (150mm)	
F) 5.51" (140mm)	
G) 5.12" (130mm)	

■ Physical Characteristics

Discharge Vessel (Bulb) Finish	Phosphor Coated
Max. Discharge Vessel (Bulb) Wall Temp.	135°C (275°F)
Max. Generator Temp.	65°C (149°F)
Max. Power Coupler Temp	90°C (194°F)



■ Operating Characteristics

Rated Initial Lumens	6000
Mean Lumens, Approx.	4800
Rated Average Life, Hours	100,000
Correlated Color Temp. (CCT)	3000K, 4000K
CIE Chromaticity, Approx.:	
3000K	x-.442, y-.404
4000K	x-.392, y-.385
Color Rendering Index (CRI)	80+
Efficacy (LPW)	72

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Markham, Ontario L6C 2S3
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QL 85 Watt Induction Lighting Lamp System

Additional Data (Subject to change without notice)

■ Operating Position

Universal

■ Electrical Characteristics

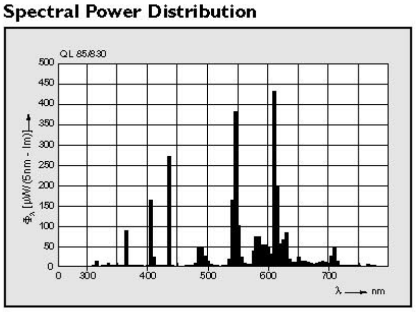
	120V System	230V System
System Power Wattage, Nom.	87	85
System Power Wattage, Min.	78.5	76.5
System Power Wattage, Max.	95.5	93.5
AC Supply Voltage, Nom.	120	230
AC Supply Voltage, Min.	108	184
AC Supply Voltage, Max.	132	255
DC Supply Voltage, Nom.	120	230
DC Supply Voltage, Min.	108	190
DC Supply Voltage, Max.	132	264
Supply Frequency Hz, Nom.	50/60 DC	50/60 DC
Supply Frequency Hz, Min.	47 DC	47 DC
Supply Frequency Hz, Max.	63 DC	63 DC
Supply Current mA, Nom.	710	400
Inrush Current Amps, Max.	25	45
Duration Inrush Current (50% pulse width) Isec, Max.	550	350
Power factor, Nom.	0.96	0.96
HF Output Frequency MHz, Nom.	2.65	2.65
HF Output Frequency MHz, Min.	2.3	2.3
HF Output Frequency MHz, Max.	3.0	3.0
HF Output Voltage kV, Max.	1.5	1.5
Leakage Current mArms, Max.	0.5	0.5
Total Harmonic Distortion	<10%	<10%
Min. Operating Temp.	-40°C (-40°F)	-40°C (-40°F)

■ Standards and Approvals

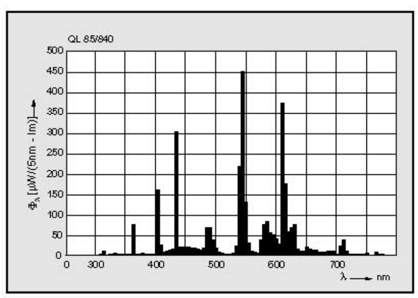
Philips QL systems comply with all relevant international rules and regulations, including:

Safety	EN 60928
Performance	EN 60929
Harmonics	EN 61000-3-2
Radio Freq. Interference <30MHz	EN 55015
Radio Freq. Interference >30MHz	EN 55022
RFI is measured in FCC Class A, a reference luminaire)	FCC Part 18, Subpart C ANSI C63.4-1992
Immunity to: Supply transients, voltage dips and electrostatic discharge	EN 61547
Vibration and Shock Tests	IEC 68-2-29 FC IEC 68-2-29 EB
Approvals:	UL #935, #840
CSA C22.2#74-92, C22.2#950-M89 (Bi-national UL 950)	
Quality Standard	ISO 9001
Environmental Management System	ISO 14001

Spectral Power Distribution



3000K



4000K

Philips Lighting Company

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Appendix 2: HPS Retro White

MasterColor. **Ceramic Metal Halide**

HPS-Retro White™

Replace yellow light with crisp, bright white light with just a simple twist!

Standard HPS Lamp | MasterColor HPS-Retro White

Ideal for industrial applications, warehouses, post top applications and parking lots

- **Optimized for Operation on HPS Ballasts**
- **No Shut Off Required**
  Ideal for 24-hour a day, 7-day a week operations (relamp fixtures at or before the end of rated life)
- **Patent-Pending Coil Design Offers Protection for Open Fixture Rating**
- **Uses ALTO® Lamp Technology to Pass EPA's TCLP* Test for Non-Hazardous Waste**
  Offers reduced cost for hazardous waste disposal
- **85%+ Lumen Maintenance**

* The TCLP is the US EPA's Toxicity Characteristic Leaching Procedure.

Visit our website at www.mastercolor.com

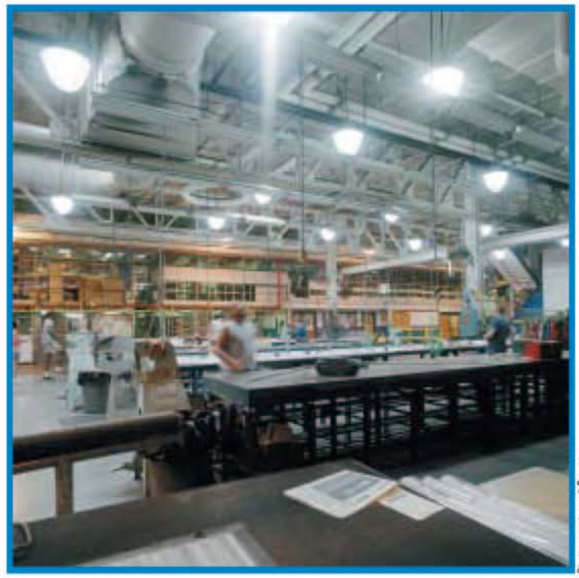
PHILIPS

Boeing Made the Switch!

...from yellow to MasterColor® HPS-Retro White™

"The HPS-Retro White lamps allowed us to change HPS fixtures to white light without replacing the fixtures. The 17% reduction in footcandles has been compensated by the brighter light. The brighter lamps have eliminated shadows. HPS-Retro White has provided another tool for better lighting by just changing the lamp."

John W. Daigh, Boeing Plant Engineering



Photos courtesy of Boeing

Boeing Plant, Wichita, Kansas. Standard HPS bulbs (left) were replaced by MasterColor HPS-Retro White bulbs (above) in July, 2001.

A Mail-Handling Facility Made the Switch!

...from yellow to MasterColor® HPS-Retro White™

In a mail-handling facility in Minnesota, standard HPS bulbs (above) were replaced by MasterColor HPS-Retro White bulbs (right).

Don Wong Photo, Inc

The Ceramic Discharge Arc Tube is more robust than the traditional quartz arc tube

- Superior lumen maintenance
- Crisp, bright, white light

Patent-Pending "Coil Design"

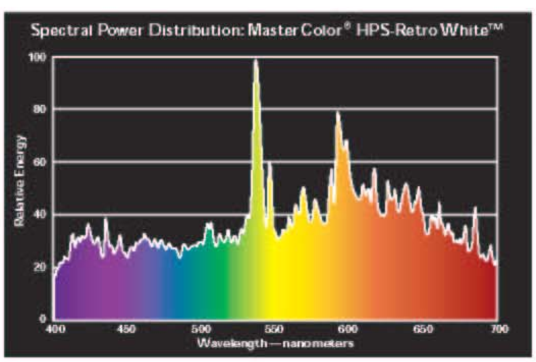
- Rated for open fixture use
- Ability to operate 24/7 without shut off†

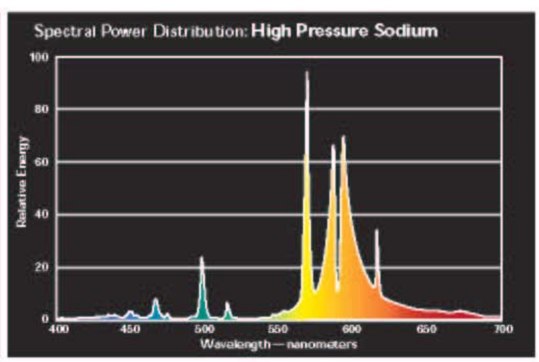
Uses ALTO Lamp Technology

- Passes the EPA's Toxicity Characteristic Leaching Procedure (TCLP)†† for non-hazardous waste.
- This lamp is better for the environment because of its reduced mercury content. See Philips' ALTO® Brochure for more information, which is available online at: **http://www.lighting.philips.com/nam/products/catalog.php**

Compare the Type of Costs for the White Light Alternative!

New Metal Halide Fixture	Lamp/Ballast Retrofit	MasterColor® HPS-Retro White™
- Labor - Lamp - Ballast - Disposal - Fixture	- Labor - Lamp - Ballast - Disposal	- Labor - Lamp





† Relamp fixtures at or before end of rated life.
†† Consult local laws & regulations which may vary.

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MasterColor® HPS-Retro White™

Electrical, Technical and Ordering Data (Subject to change without notice)

Product Number	Ordering Code	Nom. Watts	Bulb	Base	Std. Pkg. Qty.	ANSI Ballast Code	Color Temp. (Kelvin)	CRI	Rated Average Life (Hrs.)[351]	Approx. Initial Lumens[352]	Mean Lumens[353]
13093-0	CDM 250 S50/V/O/4K	250	ED-18	Mog.	12	S50/O	4000K	85	15,000	22,500	19,125
13094-8	CDM 400 S51/V/O/4K	400	ED-18	Mog.	12	S51/O	4000K	85	15,000	34,000	28,900

351) Rated average life is the life obtained, on the average, from large representative groups of lamps in laboratory tests under controlled conditions at 10 or more operating hours per start. It is based on survival of at least 50% of the lamps and allows for individual lamps or groups of lamps to vary considerably from the average. For lamps with a rated average life of 24,000 hours, life is based on survival of 67% of the lamps.
352) Values for vertical operation of lamp.
353) Approximate lumen output at 40% of lamp rated average life.

V = Vertical operation ± 15°
ANSI Code: O = Open Fixture Rated

Recommended Warnings, Cautions, and Operating Instructions

WARNING: "These lamps can cause serious skin burn and eye inflammation from short wave ultraviolet radiation if outer envelope of the lamp is broken or punctured. Do not use where people will remain for more than a few minutes unless adequate shielding or other safety precautions are used. Certain lamps that will automatically extinguish when the outer envelope is broken or punctured are commercially available." This lamp complies with FDA radiation performance standard 21 CFR subchapter I. (USA: 21 CFR 1040.30 Canada: SOR/ DORS/80-381).

If the outer bulb is broken or punctured, turn off at once and replace the lamp to avoid possible injury from hazardous short wave ultraviolet radiation. Do not scratch the outer bulb or subject it to pressure as this could cause the outer bulb to crack or shatter. A partial vacuum in the outer bulb may cause glass to fly if the envelope is struck.

WARNING: The arc-tube of metal halide lamps are designed to operate under high pressure and at temperatures up to 1000° C and can unexpectedly rupture due to internal or external factors such as a ballast failure or misapplication. If the arc-tube ruptures for any reason, the outer bulb may break and pieces of extremely hot glass might be discharged into the surrounding environment. If such a rupture were to happen, **THERE IS A RISK OF PERSONAL INJURY, PROPERTY DAMAGE, BURNS AND FIRE.**

These lamps are designed to retain all the glass particles should an arc tube rupture occur. The following operating instructions are recommended to minimize these occurrences.

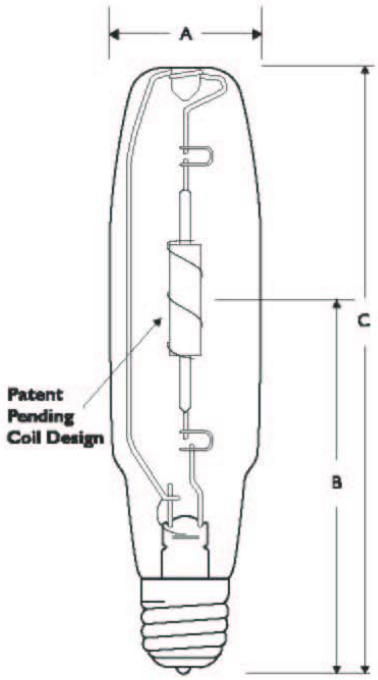
RELAMP FIXTURES AT OR BEFORE THE END OF RATED LIFE. Allowing lamps to operate until they fail is not advised and may increase the possibility of inner arc tube rupture.

This lamp contains an arc tube with a filling gas containing Kr-85 and is distributed by Philips Lighting Company, a division of Philips Electronics North America Corporation, Somerset, New Jersey, 08875.

CAUTION: TO REDUCE THE RISK OF PERSONAL INJURY, PROPERTY DAMAGE, BURNS AND FIRE RESULTING FROM AN ARC-TUBE RUPTURE THE FOLLOWING LAMP OPERATING INSTRUCTIONS MUST BE FOLLOWED.

Lamp Operating Instructions:

1) RELAMP FIXTURES AT OR BEFORE THE END OF RATED LIFE. Allowing lamps to operate until they fail is not advised and may increase the possibility of inner arc tube rupture.
2) Before lamp installation/replacement, shut power off and allow lamp and fixture to cool to avoid electrical shock and potential burn hazards.
3) Use only auxiliary equipment meeting Philips and/or ANSI standards. Use within voltage limits recommended by ballast manufacturer.
   A. Operate lamp only within specified limits of operation.
   B. For total supply load refer to ballast manufacturers electrical data.
4) Periodically inspect the outer envelope. Replace any lamps that show scratches, cracks or damage.
5) If a lamp bulb support is used, be sure to insulate the support electrically to avoid possible decomposition of the bulb glass.
6) Protect lamp base, socket and wiring against moisture, corrosive atmospheres and excessive heat.
7) Time should be allowed for lamps to stabilize in color when turned on for the first time. This may require several hours of operation, with more than one start. Lamp color is also subject to change under conditions of excess vibration or shock, and color appearance may vary between individual lamps.
8) Lamps may require 10 to 20 minutes to re-light if there is a power interruption.
9) Take care in handling and disposing of lamps. If an arc tube is broken, avoid skin contact with any of the contents or fragments.



Dimensions (mm/in)	
A =	57/2.25
B (LCL) =	146/5.75
C (MOL) =	248/9.75

LCL = Light Center Length
MOL = Maximum Overall Length

Appendix 3: HPS Restrike

Instant Restrike High Pressure Sodium Lamps

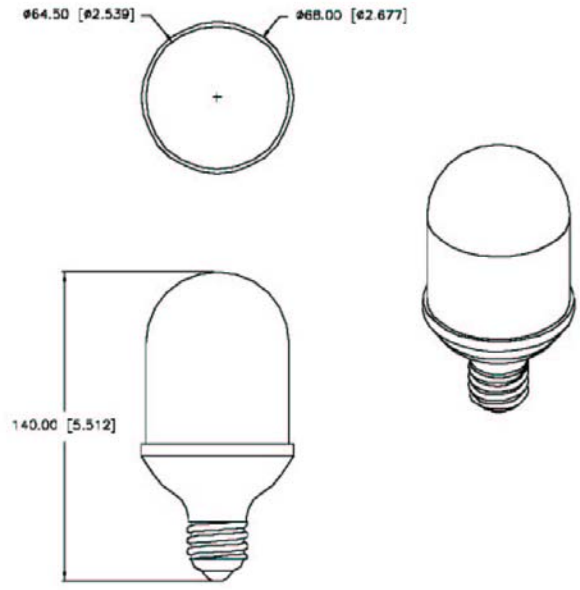
- Extra arc tube offers light instantly after momentary power interruption and will provide 80% light output within 1–2 minutes
- For applications where instant restrike is not required, rated average life is 40,000 hours
- Operates on standard HPS ballasts and auxiliary equipment
- For Warnings, Cautions and Operating Instructions, see page 102

Lamp Watts	Bulb	Base	Product Number 046677-	Symbols, Footnotes	Ordering Code	ANSI Code/ Ballast Ref.	Pkg.• Qty.	Description (Operating Position—Universal, unless otherwise indicated)	LCL (In.)	MOL (In.)	Rated Avg. Life, Hrs. (351)	Approximate Lumens, (352) Initial	Mean(353)	CRI	CCT (K)
50	ED-23½	Mog.	35467-0	■★	**C50S68/2**	S68	12	G, S (360, 373, 376)	5	7¾	24,000+	3800	3450	21	2100
70	ED-23½	Mog.	26541-3	■★	**C70S62/2**	S62	12	G, S (360, 373, 376)	5	7¾	24,000+	5600	5050	21	2100
100	ED-23½	Mog.	26560-3	■★	**C100S54/2**	S54	12	G, S (360, 373, 376)	5	7¾	24,000+	9100	8190	21	2100
150	ED-23½	Mog.	26561-1	■★	**C150S55/2**	S55	12	G, S (360, 373, 376)	5	7¾	24,000+	15,600	14,000	21	2100
250	ED-18	Mog.	37717-6	■★	**C250S50/2**	S50	12	G, S (360, 373, 376)	5¾	9¾	24,000+	27,500	24,750	21	2100
400	ED-18	Mog.	37688-9	■★	**C400S51/2**	S51	12	G, S (360, 373, 376)	5¾	9¾	24,000+	49,000	44,000	21	2100
1000	E-25	Mog.	20412-3	■★	**C1000S52/2**	S52	6	G, S (360, 373, 376)	8¾	15 1/16	24,000+	140,000	126,000	21	2100

Appendix 4: Sunbrite LED Screw Lamps

UNCONTROLLED DOCUMENT

PART NUMBER: SSP-48TE279120 | REV.



ELECTRO-OPTICAL CHARACTERISTICS T_A=25°C V_f= 120VAC

PARAMETER	MIN	TYP	MAX	UNITS	TEST COND
PEAK WAVELENGTH		-		nm	
FORWARD VOLTAGE		120		VAC	
AXIAL INTENSITY		20000		mcd	V_f =120VAC
VIEWING ANGLE		360		2x theta	
EMITTED COLOR:	WHITE				
EPOXY LENS FINISH:	CLEAR				

LIMITS OF SAFE OPERATION AT 25°C PER CHIP

PARAMETER	MAX	UNITS
PEAK FORWARD CURRENT*	150	mA
STEADY CURRENT	30	mA
POWER DISSIPATION	105	mW
DERATE FROM 25°C	-1.2	mW/°C
OPERATING, STORAGE TEMP.	-40 TO +85	°C

* t<10µS

NOTES:

1. 32 LEDS PER BULB.

UNCONTROLLED DOCUMENT

*UNLESS OTHERWISE SPECIFIED TOLERANCES PER DECIMAL PRECISION ARE: X=±1 (±0.039), X.X=±0.5 (±0.020), X.XX=±0.25 (±0.010), X.XXX=±0.127 (±0.005). LEAD SIZE=±0.05 (±0.002), LEAD LENGTH=±0.75 (±0.030). MIN= +DECIMAL PRECISION/-0.00 MAX= +0.00/-DECIMAL PRECISION

REV.	PART NUMBER
	SSP-48TE279120

360° E27 SCREW IN BASED LED LIGHT, ULTRA WHITE LEDS, WATER CLEAR LENS.

CONFIDENTIAL INFORMATION

THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF SUNBRITE LEDS. EXCEPT AS SPECIFICALLY AUTHORIZED IN WRITING BY SUNBRITE LEDS, THE HOLDER OF THIS DOCUMENT SHALL KEEP ALL INFORMATION CONTAINED HEREIN CONFIDENTIAL AND SHALL PROTECT SAME IN WHOLE OR IN PART FROM DISCLOSURE AND DISSEMINATION TO ALL THIRD PARTIES.

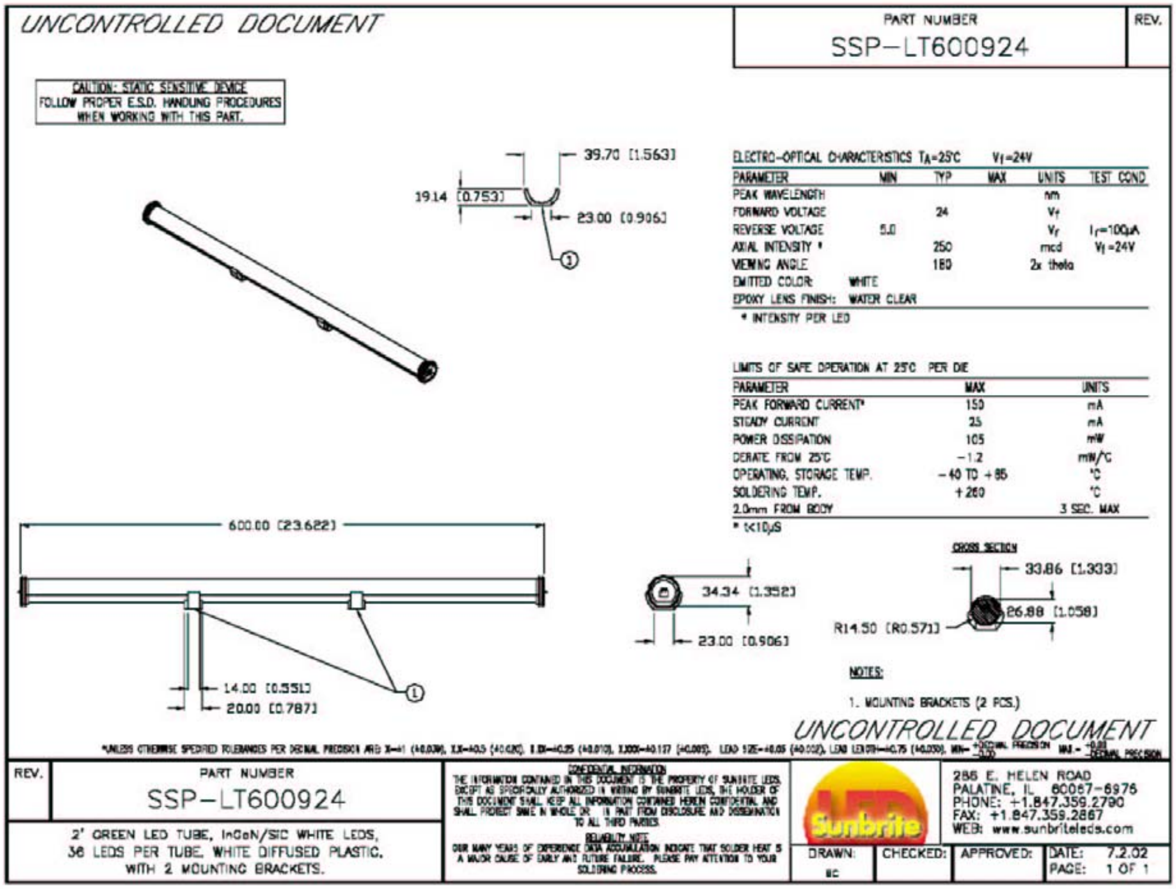
RELIABILITY ADDE

OUR MANY YEARS OF EXPERIENCE DATA ACCUMULATION INDICATE THAT SOLDER HEAT IS A MAJOR CAUSE OF EARLY AND FUTURE FAILURE. PLEASE PAY ATTENTION TO YOUR SOLDERING PROCESS.

286 E. HELEN ROAD
PALATINE, IL 60067-6975
PHONE: +1.847.359.2790
FAX: +1.847.359.2867
WEB: www.sunbriteleds.com

DRAWN:	CHECKED:	APPROVED:	DATE: 7.31.02
BC			PAGE: 1 OF 1

Appendix 5: Sunbrite LED Light Tube



UNCONTROLLED DOCUMENT

PART NUMBER: SSP−LT600924 | REV.

CAUTION: STATIC SENSITIVE DEVICE
FOLLOW PROPER E.S.D. HANDLING PROCEDURES
WHEN WORKING WITH THIS PART.

ELECTRO-OPTICAL CHARACTERISTICS T_A=25°C V_f=24V

PARAMETER	MIN	TYP	MAX	UNITS	TEST COND
PEAK WAVELENGTH				nm	
FORWARD VOLTAGE		24		V_f	
REVERSE VOLTAGE	5.0			V_r	I_r=100μA
AXIAL INTENSITY *		250		mcd	V_f=24V
VIEWING ANGLE		180		2x theta	
EMITTED COLOR: WHITE					
EPOXY LENS FINISH: WATER CLEAR					

* INTENSITY PER LED

LIMITS OF SAFE OPERATION AT 25°C PER DIE

PARAMETER	MAX	UNITS
PEAK FORWARD CURRENT*	150	mA
STEADY CURRENT	25	mA
POWER DISSIPATION	105	mW
DERATE FROM 25°C	−1.2	mW/°C
OPERATING, STORAGE TEMP.	−40 TO +85	°C
SOLDERING TEMP.	+260	°C
2.0mm FROM BODY		3 SEC. MAX

* t<10μS

NOTES:

1. MOUNTING BRACKETS (2 PCS.)

UNCONTROLLED DOCUMENT

REV.	PART NUMBER			
	SSP−LT600924			

2' GREEN LED TUBE, InGaN/SiC WHITE LEDS, 36 LEDS PER TUBE. WHITE DIFFUSED PLASTIC, WITH 2 MOUNTING BRACKETS.

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RELIABILITY NOTE
OUR MANY YEARS OF EXPERIENCE DATA ACCUMULATION INDICATE THAT SOLDER HEAT IS A MAJOR CAUSE OF EARLY AND FUTURE FAILURE. PLEASE PAY ATTENTION TO YOUR SOLDERING PROCESS.

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DRAWN:	CHECKED:	APPROVED:	DATE: 7.2.02
BC			PAGE: 1 OF 1

Appendix 6: SOL Solar Light Specification

SOLAR OUTDOOR LIGHTING, INC.

STANDARD FEATURES

- UL Listed
- 2-Year System Warranty
- 20-Year Solar Panel Warranty
- Protective Solar Panel Mount
- Maintenance-Free Gel Batteries
- Five-Day Battery Reserve
- Omni-Directional
- Technical Service 800 Number

LIGHTING APPLICATIONS

- Streets, Parks
- Parking Areas
- Security-Safety Zones
- Gates, Entrances
- Boat Ramps
- Jogging, Bike Paths
- Remote Locations

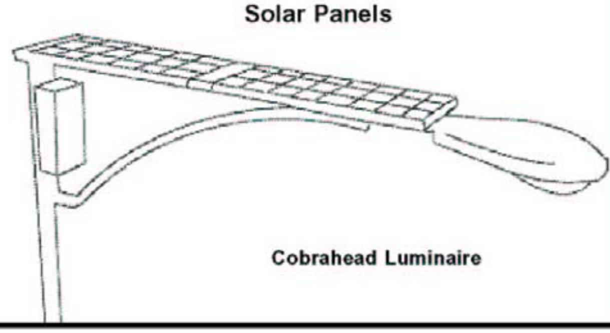
BENEFITS

- Immune to Power Outages
- Easy Installation
  - *Modular, pre-drilled
  - *Quick connect plugs
  - *Direct burial
- No Trenching-No Wiring
- No Transformers
- No Meters

SOLAR OUTDOOR LIGHTING, INC.

Solar Outdoor Lighting, Inc.
3210 S.W. 42nd Ave
Palm City, Florida 34990
Tel: (800) 959-1329
Tel: (561) 286-9461
Fax: (561) 286-9616
Email: info@solarlighting.com
Homepage: www.solarlighting.com

SL SERIES



The SL Series features a patented solar panel mounting system in which the panels lay flat on the mounting bracket. The flat panels allow the light to be installed in any direction, regardless of the sun path. This makes the SL ideal for multi-directional installations such as winding streets or parking lots, and all installations within 15 degrees of the Equator.

Important in areas exposed to high winds, the flat panel design presents a low wind profile. In high wind exposure, SL performance is legendary. During Hurricane Andrew in South Florida, SL models withstood well over 160 mph winds and provided the only light available over a five square mile area.

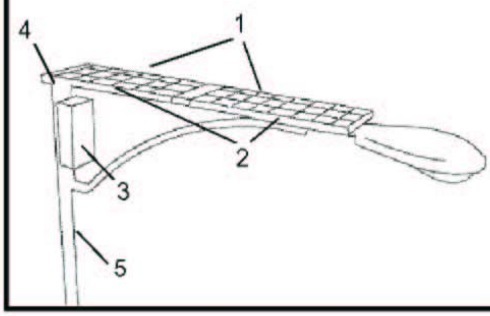
The SL Series is a highly reliable, stand-alone lighting system. The luminaire, solar panels (with vandal protection backing), rugged battery enclosure, panel mounting platform and mounting bracket provide a totally integrated, self-contained lighting source.

SL SERIES

SL Series
Lighting System Specifications

All inclusive lighting system with standard cobrahead luminaire. Shoebox luminaire may also be used. See Standard Luminaires for distribution patterns.

MOUNTING BRACKET ASSEMBLY



1. Solar panels lie flat for omni-directional placement of the light assembly.
2. Underside of solar panels is protected with aluminum panel pans.
3. Vented aluminum battery box holds batteries and controller. It is mounted on the main support bracket and is shaded by the panels.
4. Sturdy schedule 40 aluminum and stainless steel hardware throughout.
5. Mounts on any pole 4 inch O.D. or greater.

POWER COMPONENTS

	Single Panel	Double Panel
Panel Wattage-Output Amps Solarex SX Series	55w-3.33A 65w-3.77A 75w-4.54A 85w-4.97A	110w-6.66A 130w-7.54A 150w-9.08A 170w-9.94A
Approximate Module Dimensions (Inches)	55w-20x44 65w-20x44 75w-20x57 85w-20x57	110w-20x88 130w-20x88 150w-20x114 170w-20x114
Batteries-Maintenance Free Gel Cell Number-Total Amp Hour Capacity	1=80 AH or 1=98 AH	2=160 AH or 2=196 AH
Weight and Effective Projected Area (EPA) Weight (lb)-EPA (sq ft-sf) at 0 Degrees (includes luminaire and arm)	55w-135lb-4.77sf 65w-140lb-4.77sf 75w-150lb-6.24sf 85w-150lb-6.24sf	110w-190lb-8.4sf 130w-200lb-8.4sf 150w-210lb-8.9sf 170w-210lb-8.9sf

CONTROLLERS

	SCU-1	Morningstar
Input Maximum Current	16 Amps	20 Amps
Load Current Maximum	20 Amps	20 Amps
Low Voltage Disconnect (LVD)	11.5 VDC	11.7 VDC
Low Voltage Reconnect (LVR)	12.75 VDC	12.8 VDC
High Voltage Disconnect (HVD)	15 VDC	N/A
Charge Stop Voltage	14.4 VDC	14.1 VDC
Dusk Set Point	VOC<4 VDC	VOC<4 VDC
Dawn Set Point	VOC>8 VDC	VOC>8 VDC

Product Information Bulletin

ICETRON® BLACKLIGHT ECOLOGIC®

Inductively Coupled Electrodeless Systems

SYLVANIA ICETRON® Blacklight ECOLOGIC® lamps and QUICKTRONIC® electronic ballasts provide a new, energy efficient, long life solution for special effects and industrial lighting applications.

The inductively coupled electrodeless lamp uses magnetic-induction technology instead of an electrode at each end of the fluorescent tube to generate blacklight, long wave ultraviolet energy. The absence of electrodes allows much longer lamp life.

The ICETRON Blacklight system replaces short life (typically 800 hours) HID systems. With 75% of initial blacklight energy maintained at 5000 hours, this system can significantly reduce the frequency of lamp replacement and the related labor costs.

The electrodeless construction of the ICETRON lamp is also more suited to short cycle operation than typical HID lamps yet also allows extended cycle operation.

- Blacklight phosphor: peak emission @ 368 nm
- Special Effects and industrial lighting applications
- Long life system
- Ballast average rated life: 100,000 hours
- Lamp life dependent on application
- 75% UV maintenance at 5000 hours
- 100W & 150W lamps
- Instant on – instant restrike
- Same ballasts as white light ICETRON lamps
- Universal voltage ballasts
- Starting temperatures as low as –40°F
- Amalgam technology for wide operating temperature range
- Ballast remote mounting possible

SYLVANIA ICETRON ECOLOGIC fluorescent lamps are designed to pass the Federal Toxicity Characteristic Leaching Procedure (TCLP)[1] criteria for classification as non-hazardous waste in most states.[2]

[1] TCLP test results are based on NEMA LL Series standards and are available on request.

[2] Lamp disposal regulations may vary; check your local & state regulations.

Product Availability

Lamp	Ballast	System Wattage 120 / 277V
ICE100/BL/2P	QT 1x100ICE/UNV-T	106 / 103
ICE100/BL/2P	QT 1x150ICE/UNV-T	154 / 149
ICE150/BL/2P	QT 1x150ICE/UNV-T	161 / 156

Application Information

Applications

Special effects lighting
Industrial curing
Industrial inspection

Application Notes

1. Universal operating position – For non-horizontal lamp operation, the amalgam tip should be pointed down.
2. Universal input voltage: 120/277 volts, 50/60 Hz.
3. Low EMI – complies with FCC Non-Consumer limits.

Thermal Characteristics

1. Fixture must act as heat sink for lamp induction cores and ballast – good thermal coupling required.
2. Maximum bulb wall temperature of 302°F (150°C).
3. Maximum fixture temperature at lamp base mounting of 212°F (100°C).
4. Amalgam tip temperature for 90% radiant energy output 130-260°F (55-125°C).
5. Max 158°F (70°C) ballast temperature for 150W and 149°F (65°C) for 100W at test point Tc on ballast label.
6. Ballast may be mounted up to 66 feet from lamp. Please request mounting instructions.
7. For cold temperature application, use suitably enclosed fixture to maximize radiant energy output.
8. Amalgam tip covers (NAED 22093) available for faster warm-up under very cold operating conditions.
9. ICETRON TYPE-1 outdoor ballast must be within overall electrical enclosure and fully protected from any exposure to moisture.
10. 24" wiring extension/harness available (NAED 49755).

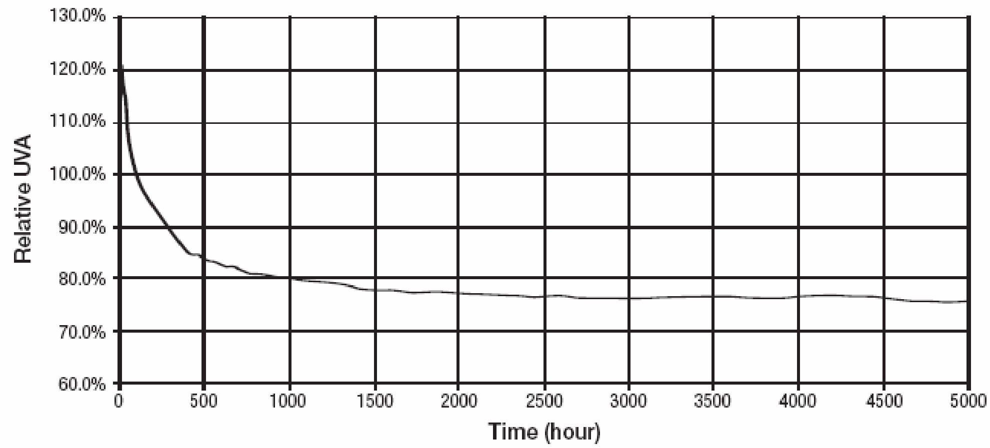
SEE THE WORLD IN A NEW LIGHT SYLVANIA

FL065R1

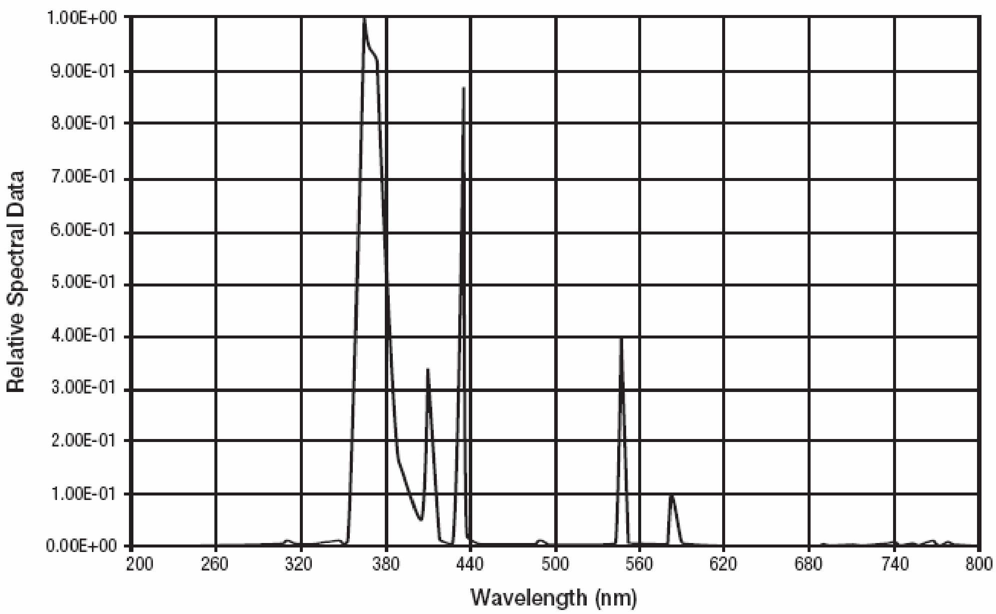
Technical Information

ICETRON Blacklight UVA Maintenance

(100W lamp on 100W ballast)



Spectral Power Distribution – Blacklight



UVA Output Characteristics – Blacklight

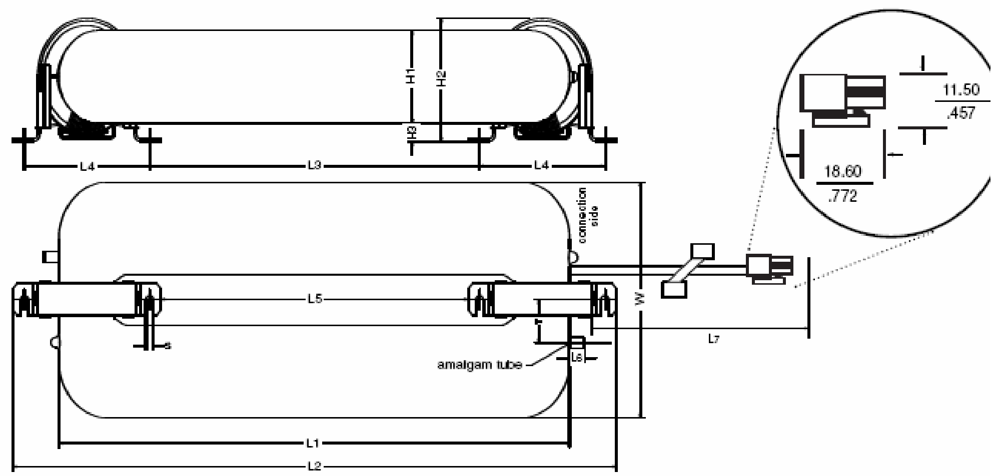
Emission peak at wavelength	Nm	368 ± 2 nm
Minimum UVA irradiance (320-400 nm)[1] at 100 hr	µW/cm²	3700

[1] Measured on a line normal to the plane of the bulb centerline aligned with the geometric center of the bulb and at a distance of 25 cm from the surface of the bulb.

Lamp Dimensions

	Dim.*	ICETRON 100 In.	ICETRON 100 (mm)	ICETRON 150 In.	ICETRON 150 (mm)
Height of glass	H1	2.13 ± 0.04	54 ± 1	2.13 ± 0.04	54 ± 1
Overall height	H2	2.87 ± 0.08	73 ± 2	2.87 ± 0.08	73 ± 2
Tube to mount height	H3	.039 (Min)	10 (Min)	.039 (Min)	10 (Min)
Length of main body	L1	9.84 ± 0.05	250 ± 1.2	13.78 ± 0.05	350 ± 1.2
Overall Length	L2	12.4 (Max)	315 (Max)	16.34 (Max)	415 (Max)
Mount hole spacing (between cores)	L3	5.02 ± 0.06	127.4 ± 1.5	9.00 ± 0.06	228.5 ± 1.5
Mount hole spacing (each core)	L4	3.36 ± 0.04	85.3 ± 0.9	3.36 ± 0.04	85.3 ± 0.9
Bracket spacing	L5	4.13 (Min)	105 (Min)	8.07 (Min)	205 (Min)
Amalgam tip length	L6	0.59 (Max)	15 (Max)	0.59 (Max)	15 (Max)
Lead wire length	L7	24.00 (Min)	609.6 (Min)	24.00 (Min)	609.6 (Min)
Slot width	S	0.20 ± 0.01	5.1 ± 0.2	0.20 ± 0.01	5.1 ± 0.2
Tip to centerline	T	0.98 ± 0.08	25 ± 2	0.98 ± 0.08	25 ± 2
Width	W	5.41 ± 0.06	137.5 ± 1.5	5.41 ± 0.06	137.5 ± 1.5
Lamp weight – lb (kg)		2.1 lbs	0.95 kg	2.5lbs	1.14 kg

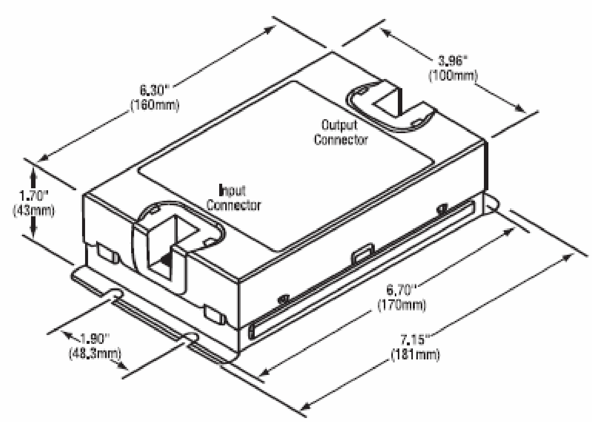
* Dimensions subject to change



Ballast Dimensions

Dimensions:
Overall: 7.15" L x 3.96" W x 1.70" H
Mounting: 6.70" L x 1.90" W

Packaging:
Quantity: 5
Weight: 1.9 lbs ea. (approx.)



Sample Specification
System shall be (100W or 150W) ICETRON® ECOLOGIC® inductively coupled electrodeless Blacklight lamp and ballast system. The ballast average rated life shall be 100,000 hours. System's useful life will be application dependent. Lamps shall be designed to pass the Federal TCLP test.

Warranty Information
QUICKTRONIC® ICE ballasts shall be warranted for up to 60 months. Check with OSRAM SYLVANIA for further details.

OSRAM SYLVANIA
National Customer Service and Sales Center
18725 N. Union Street
Westfield, IN 46074

Industrial & Commercial
Phone: 1-800-255-5042
Fax: 1-800-255-5043

National Accounts
Phone: 1-800-562-4671
Fax: 1-800-562-4674

OEM/Specialty Markets
Phone: 1-800-762-7191
Fax: 1-800-762-7192

Photo-Optic
Phone: 1-888-677-2627
Fax: 1-800-762-7192

OSRAM SYLVANIA
Ballast Division
800 N. Church Street
Lake Zurich, IL 60047
Phone: 1-800-654-0089
Fax: 1-847-726-6424

In Canada
OSRAM SYLVANIA LTD.
Headquarters
2001 Drew Road
Mississauga, ON L5S 1S4

Industrial & Commercial
Phone: 1-800-263-2852
Fax: 1-800-667-6772

Special Markets
Phone: 1-800-265-2852
Fax: 1-800-667-6772

Ordering and Specification Information

SYSTEMS

Lamp Description	Ballast Description	System Wattage
ICE100/BL/2P/ECO	QT1x100ICE/UNV-T	106/103
ICE100/BL/2P/ECO	QT1x150ICE/UNV-T	154/149
ICE150/BL/2P/ECO	QT1x150ICE/UNV-T	161/156

LAMPS

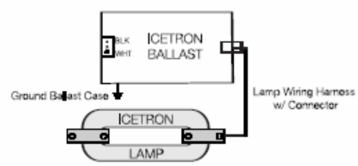
Item Number	Ordering Description
26106	ICE100/BL/2P/ECO
26154	ICE150/BL/2P/ECO

BALLASTS

Item Number	Ordering Description	Voltage Range	Compatible Lamps
49753	QT1X100 ICE/UNV-T	120-277	ICE100/2P/ECO
49772	QT1X150 ICE/UNV-T	120-277	ICE100/2P/ECO, ICE150/2P/ECO

Ballast Specification

Lamp Frequency: 200-300 KHz
Input Frequency: 50/60Hz
Voltage Range: 120 to 277 ± 10%
UL Listed Class P, Type1 Outdoor CSA Certification
Lamp CCF: Less than 1.7
Low THD: Less than 20%
158°F (70°C) Maximum Temperature for QT1X150 ICE/UNV-T at test point Tc on ballast label
149°F (65°C) Maximum Temperature for QT1X100 ICE/UNV-T at test point Tc on ballast label
Class A Sound Rating
Starting Temperature -40°F (-40°C) minimum
Power Factor: Greater than 95%
FCC 47CFR Part 18 Non-Consumer
ANSI 62.41 Cat. A Transient Protection
Ballast Dimension: 7.15" L x 3.96" W x 1.70" overall



Ordering Guide

ICE100/BL/2P

ICE	100	/	BL	/	2P	/	ECO
Inductively Coupled Electrodeless	Lamp Wattage 100W, 150W		Blacklight		2 Prong Connector		ECOLOGIC TCLP Compliant

QT1X100ICE/UNV-T

QT	1X	100	ICE	/	UNV	-T
QUICKTRONIC	# Lamps	Primary Lamp Wattage	ICETRON Inductively Coupled Electrodeless		Line Voltage 120 to 277V	Top Mount

CAUTION: This lamp emits ultraviolet (UV) power during operation and is in Risk Group 2 per ANSI/IESNA RP-27.3-96. Exposure at less than 0.75 meter (30 inches) should be limited; for example, exposure at 0.5 m (20 in.) should not exceed 4 hours in an 8 hour interval (see ANSI/IESNA RP-27.1-96). Certain medications and chemicals can increase an individual's sensitivity to UV. Consult your physician for specific information. Protective eyewear should be worn in occupational situations involving long-term exposure in close proximity to the lamp. This lamp is not intended and should not be used for diagnostic, therapeutic, or cosmetic purposes.

Visit our website: www.sylvania.com

Appendix 8: Requisitions for Price

SAMSON ELECTRICAL SUPPLY

1764 New Durham Road • PO Box 527
South Plainfield, NJ 07080
732-393-7070 • Fax: 732-393-7080
www.samsonelectrical.com

RUTGER

QUOTATION NUMBER
1047460-0000-01
732-932-3372

QUOTATION NUMBER
1047460-0000-01

BILL TO: RUTGERS STATE UNIVERSITY
DISBRS. CONTROL/INV. PROC.
P.O. BOX 1089
PISCATAWAY NJ 08855-1089

SHIP TO: RUTGERS STATE UNIVERSITY
65 DAVIDSON ROAD
PISCATAWAY NJ 08854

CUSTOMER P.O. NO. ATTN: PAT

CUSTOMER P.O. NO. ATTN: PAT

QUOTATION***QUOTATION******QUOTATION******QUOTATION******QUOTATION***

QUOTATION NUMBER	SLSMN	ORDER DATE	TAKER	CUSTOMER P.O. NUMBER	DATE
1047460-0000-01	119	04/07/05	154	ATTN: PAT	

INSTRUCTIONS	FRT.	PAGE NO.
	B	1

QUANTITY ORDERED	QUANTITY B.O./NET.	QUANTITY SHIPPED	DISP.	ITEM CODE AND DESCRIPTION	U/M	UNIT PRICE	AMOUNT
				JOIN US ON WEDNESDAY FOR LUNCH APRIL THRU OCTOBER 11AM TO 1PM			
500				PHIL H33GL-400/DX E37MOG MV LAMP	EA	6.6000	3300.00
500				PHIL C150S55/2 CLR BT25MOG HPS LAMP	EA	23.3500	11675.00
500				*PHIL CDM250S50/V/O/4K 250W MH LAMP	E	38.7500	19375.00
500				PHIL C250S50/2 CLR E18MOG HPS LAMP	EA	11.5000	5750.00
500				PHIL H37KC-250/DX BT28MOG MV LAMP	EA	6.6000	3300.00

CODE EXPLANATION [illegible]

FREIGHT IN	FREIGHT OUT

SUB TOTAL	43,400.00
MISC. CHARGE	
TEL.E. CHARGE	
FREIGHT TOTAL	
FED./OTHER TAX	0.00
STATE TAX	0.00
PAYMENT REC'D.	0.00

TOTAL AMOUNT DUE
43,400.00

ORIGINAL

Requisitions for Price

From: Dan Black [mailto:Dan.Black@dot.state.nj.us]
Sent: Thursday, March 24, 2005 3:31 PM
To: szary@rci.rutgers.edu
Subject: RE: NJDOT Replacement Cost

Pat,

Very rough estimates would be 50% 150W, 35% 250W & 15% 400W. The pricing for 150w is $6.18, 250w is $6.28 and 400w is $6.48.

Dan Black
Bureau of Electrical Engineering & Support
(609) 530-5383

Requisitions for Price

Subject:	Luxbright LED streetlights
From:	"Steve Wright" <swright@n2.net>
Date:	Mon, April 11, 2005 12:53 pm
To:	nadereh@eden.rutgers.edu
Priority:	Normal
Options:	View Full Header | View Printable Version | View Message details | View as HTML

Nadereh,

Luxbright offers 36 watt LED streetlights in our own Luxaire Fixture shown on the website. Price for 100 pc orders is $456 for complete, sealed fixture. We also offer retrofit insert light engines for most common fixtures, but the retrofit does not offer all the advantages of our low wind profile,full cutoff,fully sealed Luxaire fixture. The price for Cobra retrofit models (remove glass and insert Luxbright module) is $420 in 100 piece quantities.
The return on investment in these lights comes from not only the electricity savings, but from service and bulb changing. Over the life of the LED light source, the national average is 3.5 service calls up a lift truck to maintain a conventional HID or HPS fixture.
Our best application is replacing 50-75 HPS, mercury, and LPS type II, fixtures. While our " total lumen" output is lower, the "useful" lumens and color of our light is preferred by residents and law enforcement agencies. The above pricing reflects the high visibility that a product placement with Rutgers might afford our company. I look forward to further discussions with you.

Steve Wright
President
Luxbright, LLC

858 452 0294

Appendix 9: SPV factors for calculating the present value of future single costs (non fuel)

	Single Present Value (SPV) Factors		
Number of years from base date	DOE Discount rate 3.0%	OMB Discount Rates Short term 2.4%	Long Term 3.5%
0.25	0.993	0.994	0.991
0.50	0.985	0.988	0.983
0.75	0.978	0.982	0.975
1	0.971	0.977	0.966
2	0.943	0.954	0.934
3	0.915	0.931	0.902
4	0.888	0.909	0.871
5	0.863	0.888	0.842
6	0.837	0.867	0.814
7	0.813	0.847	0.786
8	0.789	0.827	0.759
9	0.766	0.808	0.734
10	0.744	0.789	0.709
11	0.722		0.685
12	0.701		0.662
13	0.681		0.639
14	0.661		0.618
15	0.642		0.597
16	0.623		0.577
17	0.605		0.557
18	0.587		0.538
19	0.570		0.520
20	0.554		0.503
21	0.538		0.486
22	0.522		0.469
23	0.507		0.453
24	0.492		0.438
25	0.478		0.423
26	0.464		0.409
27	0.450		0.395
28	0.437		0.382
29	0.424		0.369
30	0.412		0.356

Appendix 10: UPV factors for calculating the present value of annually recurring costs changing at a constant

DOE discount rate = 3.0%

Modified Uniform Present Value (UPV*) Factors (non-fuel)

Number of years from base date	Annual rate of price change										
	-4%	-3%	-2%	-1.75%	-1%	0%	1%	2%	3%	4%	5%
1	0.93	0.94	0.95	0.95	0.96	0.97	0.98	0.99	1.00	1.01	1.02
2	1.80	1.83	1.86	1.86	1.89	1.91	1.94	1.97	2.00	2.03	2.06
3	2.61	2.66	2.72	2.73	2.77	2.83	2.88	2.94	3.00	3.06	3.12
4	3.37	3.45	3.54	3.56	3.63	3.72	3.81	3.90	4.00	4.10	4.20
5	4.07	4.19	4.32	4.35	4.45	4.58	4.72	4.86	5.00	5.15	5.30
6	4.72	4.89	5.06	5.10	5.24	5.42	5.61	5.80	6.00	6.21	6.42
7	5.33	5.55	5.77	5.82	5.99	6.23	6.48	6.73	7.00	7.28	7.57
8	5.90	6.16	6.44	6.51	6.72	7.02	7.33	7.66	8.00	8.36	8.73
9	6.44	6.75	7.08	7.16	7.42	7.79	8.17	8.57	9.00	9.45	9.92
10	6.93	7.30	7.68	7.78	8.09	8.53	8.99	9.48	10.00	10.55	11.13
11	7.39	7.81	8.26	8.38	8.74	9.25	9.80	10.38	11.00	11.66	12.37
12	7.82	8.30	8.81	8.94	9.36	9.95	10.59	11.27	12.00	12.78	13.63
13	8.22	8.76	9.34	9.49	9.96	10.63	11.36	12.15	13.00	13.92	14.91
14	8.59	9.19	9.83	10.00	10.54	11.30	12.12	13.02	14.00	15.06	16.22
15	8.94	9.60	10.31	10.50	11.09	11.94	12.87	13.89	15.00	16.22	17.56
16	9.27	9.98	10.76	10.97	11.62	12.56	13.60	14.74	16.00	17.39	18.92
17	9.57	10.34	11.19	11.41	12.13	13.17	14.32	15.59	17.00	18.57	20.30
18	9.85	10.68	11.60	11.84	12.62	13.75	15.02	16.43	18.00	19.76	21.72
19	10.11	11.00	11.99	12.25	13.09	14.32	15.71	17.26	19.00	20.96	23.16
20	10.36	11.30	12.36	12.64	13.54	14.88	16.38	18.08	20.00	22.17	24.63
21	10.59	11.58	12.71	13.01	13.98	15.42	17.05	18.90	21.00	23.39	26.12
22	10.80	11.85	13.04	13.36	14.40	15.94	17.69	19.70	22.00	24.63	27.65
23	11.00	12.10	13.36	13.10	14.80	16.44	18.33	20.50	23.00	25.88	29.21
24	11.18	12.34	13.66	14.02	15.18	16.94	18.96	21.29	24.00	27.14	30.79
25	11.35	12.56	13.95	14.33	15.56	17.41	19.57	22.08	25.00	28.41	32.41
26	11.51	12.77	14.23	14.62	15.91	17.88	20.17	22.85	26.00	29.70	34.06
27	11.66	12.97	14.49	14.90	16.26	18.33	20.76	23.62	27.00	31.00	35.74
28	11.80	13.16	14.73	15.17	16.59	18.76	21.34	24.38	28.00	32.31	37.45
29	11.93	13.33	14.97	15.42	16.90	19.19	21.90	25.14	29.00	33.63	39.20
30	12.05	13.50	15.20	15.67	17.21	19.60	22.46	25.88	30.00	34.97	40.98

Appendix 11: Cumulative cost for current and proposed alternatives of HPS150W during 20 years Life Cycle Cost Analysis by including electricity in calculation for one lamp

	Year 1	Year2	Year3	Year4	Year5
HPS (150 W)	$195	$263	$331	$399	$467
MV (175 W)	$207	$287	$367	$447	$527
HPS Restrike (150 W)	$211	$279	$347	$415	$483
LED (40 W)	$558	$576	$594	$612	$630
Icetron (100 W)	$816	$862	$908	$954	$1,000
QL (85 W)	$419	$458	$497	$536	$575

	Year6	Year7	Year8	Year9	Year10
HPS (150 W)	**$662**	$730	$798	$866	$934
MV (175 W)	**$734**	$814	$894	$974	$1,054
HPS Restrike (150 W)	$551	$619	$687	$755	**$966**
LED (40 W)	$648	$666	$684	$702	$720
Icetron (100 W)	$1,046	$1,092	$1,138	$1,184	$1,230
QL (85 W)	$614	$653	$692	$731	$770

	Year11	Year12	Year13	Year14	Year15
HPS (150 W)	$1,002	**$1,197**	$1,265	$1,333	$1,401
MV (175 W)	$1,134	**$1,341**	$1,421	$1,501	$1,581
HPS Restrike (150 W)	$1,034	$1,102	$1,170	$1,238	$1,306
LED (40 W)	$738	$756	$774	$792	$810
Icetron (100 W)	$1,276	$1,322	$1,368	$1,414	$1,460
QL (85 W)	$809	$848	$887	$926	$965

	Year16	Year17	Year18	Year19	Year20
HPS (150 W)	$1,469	$1,537	**$1,732**	$1,800	$1,868
MV (175 W)	$1,661	$1,741	**$1,948**	$2,028	$2,108
HPS Restrike (150 W)	$1,374	$1,442	$1,510	$1,578	**$1,789**
LED (40 W)	$828	$846	$864	$882	$900
Icetron (100 W)	$1,506	$1,552	$1,598	$1,644	$1,690
QL (85 W)	$1,004	$1,043	$1,082	$1,121	$1,160

*** Bold font indicates a year in which a relamping occurs.**

Appendix 12: Cumulative cost for current and proposed alternatives of HPS150W during 20 years Life Cycle Cost Analysis by excluding electricity in calculation for one lamp

	Year 1	Year2	Year3	Year4	Year5
HPS (150 W)	$127	$127	$127	$127	$127
MV (175 W)	$127	$127	$127	$127	$127
HPS Restrike (150 W)	$143	$143	$143	$143	$143
LED (40 W)	$540	$540	$540	$540	$540
Icetron (100 W)	$770	$770	$770	$770	$770
QL (85 W)	$380	$380	$380	$380	$380

	Year6	Year7	Year8	Year9	Year10
HPS (150 W)	**$254**	$254	$254	$254	$254
MV (175 W)	**$254**	$254	$254	$254	$254
HPS Restrike (150 W)	$143	$143	$143	$143	**$286**
LED (40 W)	$540	$540	$540	$540	$540
Icetron (100 W)	$770	$770	$770	$770	$770
QL (85 W)	$380	$380	$380	$380	$380

	Year11	Year12	Year13	Year14	Year15
HPS (150 W)	$254	**$381**	$381	$381	$381
MV (175 W)	$254	**$381**	$381	$381	$381
HPS Restrike (150 W)	$286	$286	$286	$286	$286
LED (40 W)	$540	$540	$540	$540	$540
Icetron (100 W)	$770	$770	$770	$770	$770
QL (85 W)	$380	$380	$380	$380	$380

	Year16	Year17	Year18	Year19	Year20
HPS (150 W)	$381	$381	**$508**	$508	$508
MV (175 W)	$381	$381	**$508**	$508	$508
HPS Restrike (150 W)	$286	$286	$286	$286	**$429**
LED (40 W)	$540	$540	$540	$540	$540
Icetron (100 W)	$770	$770	$770	$770	$770
QL (85 W)	$380	$380	$380	$380	$380

*** Bold font indicates a year in which a relamping occurs.**

Appendix 13: Cumulative cost for current and proposed alternatives of HPS 250W during 20 years Life Cycle Cost Analysis including electricity in calculation for one lamp

	Year 1	Year2	Year3	Year4	Year5
HPS (250 W)	$241	$355	$469	$583	$697
MV(250 W)	$241	$355	$469	$583	$697
HPS Restrike (250 W)	$246	$360	$474	$588	$702
HPS Retro White (250 W)	$273	$387	$501	**$774**	$1,047
Icetron (150 W)	$838	$906	$974	$1,042	$1,110
QL (165 W)	$515	$590	$665	$740	$815

	Year6	Year7	Year8	Year9	Year10
HPS (250 W)	**$938**	$1,052	$1,166	$1,280	$1,394
MV(250 W)	**$938**	$1,052	$1,166	$1,280	$1,394
HPS Restrike (250 W)	$816	$930	$1,044	$1,158	**$1,404**
HPS Retro White (250 W)	$1,161	$1,275	**$1,548**	$1,662	$1,776
Icetron (150 W)	$1,178	$1,246	$1,314	$1,382	$1,450
QL (165 W)	$890	$965	$1,040	$1,115	$1,190

	Year11	Year12	Year13	Year14	Year15
HPS (250 W)	$1,508	**$1,749**	$1,863	$1,977	$2,091
MV(250 W)	$1,508	**$1,749**	$1,863	$1,977	$2,091
HPS Restrike (250 W)	$1,518	$1,632	$1,746	$1,860	$1,974
HPS Retro White (250 W)	$1,890	**$2,163**	$2,277	$2,391	$2,505
Icetron (150 W)	$1,518	$1,586	$1,654	$1,722	$1,790
QL (165 W)	$1,265	$1,340	$1,415	$1,490	$1,565

	Year16	Year17	Year18	Year19	Year20
HPS (250 W)	$2,205	$2,319	**$2,560**	$2,674	$2,788
MV(250 W)	$2,205	$2,319	**$2,560**	$2,674	$2,788
HPS Restrike (250 W)	$2,088	$2,202	$2,316	$2,430	**$2,676**
HPS Retro White (250 W)	**$2,778**	$2,892	$3,006	$3,120	**$3,393**
Icetron (150 W)	$1,858	$1,926	$1,994	$2,062	$2,130
QL (165 W)	$1,640	$1,715	$1,790	$1,865	$1,940

*** Bold font indicates a year in which a relamping occurs.**

Appendix 14: Cumulative cost for current and proposed alternatives of HPS 250W during 20 years Life Cycle Cost Analysis excluding electricity in calculation for one lamp

	Year 1	Year2	Year3	Year4	Year5
HPS (250 W)	$127	$127	$127	$127	$127
MV(250 W)	$127	$127	$127	$127	$127
HPS Restrike (250 W)	$132	$132	$132	$132	$132
HPS Retro White (250 W)	$159	$159	$159	**$318**	$318
Icetron (150 W)	$770	$770	$770	$770	$770
QL (165 W)	$440	$440	$440	$440	$440

	Year6	Year7	Year8	Year9	Year10
HPS (250 W)	**$254**	$254	$254	$254	$254
MV(250 W)	**$254**	$254	$254	$254	$254
HPS Restrike (250 W)	$132	$132	$132	$132	**$264**
HPS Retro White (250 W)	$318	$318	**$477**	$477	$477
Icetron (150 W)	$770	$770	$770	$770	$770
QL (165 W)	$440	$440	$440	$440	$440

	Year11	Year12	Year13	Year14	Year15
HPS (250 W)	$254	**$381**	$381	$381	$381
MV(250 W)	$254	**$381**	$381	$381	$381
HPS Restrike (250 W)	$264	$264	$264	$264	$264
HPS Retro White (250 W)	$477	**$636**	$636	$636	$636
Icetron (150 W)	$770	$770	$770	$770	$770
QL (165 W)	$440	$440	$440	$440	$440

	Year16	Year17	Year18	Year19	Year20
HPS (250 W)	$381	$381	**$508**	$508	$508
MV(250 W)	$381	$381	**$508**	$508	$508
HPS Restrike (250 W)	$264	$264	$264	$264	**$396**
HPS Retro White (250 W)	**$795**	$795	$795	$795	**$954**
Icetron (150 W)	$770	$770	$770	$770	$770
QL (165 W)	$440	$440	$440	$440	$440

*** Bold font indicates a year in which a relamping occurs.**

Appendix 15: NJ Case; Cumulative cost during 20 years Life Cycle Cost Analysis by including electricity in calculation

Sample of calculation for (MV 175W & 250W) :
Year 1: (lamp cost + labor relamping cost + annual electricity cost)* total lamps alternative for HPS 150W) + (lamp cost + labor relamping cost + annual electricity cost)* total lamps alternative for HPS 250W) = ((7+120+80)*22500)+((7+120+114)*15750
This procedure is recurring every 6 years for MV because of mean life (replacing lamp is bolded in table).
Year 2: Electricity cost for lamp alternative for HPS 150W + Electricity cost for lamp alternative for HPS 250W + total cost from pervious year = (80*22500) + (114*15750) + total cost year1

	Year 1	Year2	Year3	Year4	Year5
MV(175 W & 250 W)	$8,453,250	$12,048,750	$15,644,250	$19,239,750	$22,835,250
HPS (150 W &250 W)	$8,183,250	$11,508,750	$14,834,250	$18,159,750	$21,485,250
HPS Restrike (150 W & 250 W)	$8,622,000	$11,947,500	$15,273,000	$18,598,500	$21,924,000
HPS Retro White (250 W) & HPS 150 W	$8,687,250	$12,012,750	$15,338,250	**$21,168,000**	$24,493,500
Icetron (100W & 150 W)	$31,558,500	$33,664,500	$35,770,500	$37,876,500	$39,982,500
QL (85 W & 165 W)	$17,538,750	$19,597,500	$21,656,250	$23,715,000	$25,773,750
LED (40 W) & QL(165W)	$20,666,250	$22,252,500	$23,838,750	$25,425,000	$27,011,250

	Year6	Year7	Year8	Year9	Year10
MV(175 W & 250 W)	**$31,288,500**	$34,884,000	$38,479,500	$42,075,000	$45,670,500
HPS (150 W &250 W)	**$29,668,500**	$32,994,000	$36,319,500	$39,645,000	$42,970,500
HPS Restrike (150 W & 250 W)	$25,249,500	$28,575,000	$31,900,500	$35,226,000	**$43,848,000**
HPS Retro White (250 W) & HPS 150 W	**$30,676,500**	$34,002,000	**$39,831,750**	$43,157,250	$46,482,750
Icetron (100W & 150 W)	$42,088,500	$44,194,500	$46,300,500	$48,406,500	$50,512,500
QL (85 W & 165 W)	$27,832,500	$29,891,250	$31,950,000	$34,008,750	$36,067,500
LED (40 W) & QL(165W)	$28,597,500	$30,183,750	$31,770,000	$33,356,250	$34,942,500

*** Bold font indicates a year in which a relamping occurs.**

	Year11	Year12	Year13	Year14	Year15
MV(175 W & 250 W)	$49,266,000	**$57,719,250**	$61,314,750	$64,910,250	$68,505,750
HPS (150 W &250 W)	$46,296,000	$54,479,250	$57,804,750	$61,130,250	$64,455,750
HPS Restrike (150 W & 250 W)	$47,173,500	$50,499,000	$53,824,500	$57,150,000	$60,475,500
HPS Retro White (250 W) & HPS 150 W	$49,808,250	$58,495,500	$61,821,000	$65,146,500	$68,472,000
Icetron (100W & 150 W)	$52,618,500	$54,724,500	$56,830,500	$58,936,500	$61,042,500
QL (85 W & 165 W)	$38,126,250	$40,185,000	$42,243,750	$44,302,500	$46,361,250
LED (40 W) & QL(165W)	$36,528,750	$38,115,000	$39,701,250	$41,287,500	$42,873,750

	Year16	Year17	Year18	Year19	Year20
MV(175 W & 250 W)	$72,101,250	$75,696,750	**$84,150,000**	$87,745,500	$91,341,000
HPS (150 W &250 W)	$67,781,250	$71,106,750	**$79,290,000**	$82,615,500	$85,941,000
HPS Restrike (150 W & 250 W)	$63,801,000	$67,126,500	$70,452,000	$73,777,500	**$82,399,500**
HPS Retro White (250 W) & HPS 150 W	**$74,301,750**	$77,627,250	**$83,810,250**	$87,135,750	**$92,965,500**
Icetron (100W & 150 W)	$63,148,500	$65,254,500	$67,360,500	$69,466,500	$71,572,500
QL (85 W & 165 W)	$48,420,000	$50,478,750	$52,537,500	$54,596,250	$56,655,000
LED (40 W) & QL(165W)	$44,460,000	$46,046,250	$47,632,500	$49,218,750	$50,805,000

*** Bold font indicates a year in which a relamping occurs.**

Appendix 16: NJ Case; Cumulative cost during 20 years Life Cycle Cost Analysis by excluding electricity in calculation

Sample of calculation for (MV 175W & 250W) :
Year 1: ((lamp cost + labor relamping cost)* total lamps alternative for HPS 150W) + ((lamp cost + labor relamping cost)* total lamps alternative for HPS 250W) = (7+120)*22500)+((7+120)*15750
This procedure is recurring every 6 years for MV because of mean life (replacing lamp is bolded in table).
Year 2: No costs are incurred, as this calculation excludes electricity and no lamps are replaced in this year.

	Year 1	Year2	Year3	Year4	Year5
MV(175 W & 250 W)	$4,857,750	$4,857,750	$4,857,750	$4,857,750	$4,857,750
HPS (150 W &250 W)	$4,857,750	$4,857,750	$4,857,750	$4,857,750	$4,857,750
HPS Restrike (150 W & 250 W)	$5,296,500	$5,296,500	$5,296,500	$5,296,500	$5,296,500
HPS Retro White (250 W) & HPS 150 W	$5,361,750	$5,361,750	$5,361,750	**$7,866,000**	$7,866,000
Icetron (100W & 150 W)	$29,452,500	$29,452,500	$29,452,500	$29,452,500	$29,452,500
QL (85 W & 165 W)	$15,480,000	$15,480,000	$15,480,000	$15,480,000	$15,480,000
LED (40 W) & QL(165W)	$19,080,000	$19,080,000	$19,080,000	$19,080,000	$19,080,000

	Year6	Year7	Year8	Year9	Year10
MV(175 W & 250 W)	**$9,715,500**	$9,715,500	$9,715,500	$9,715,500	$9,715,500
HPS (150 W &250 W)	**$9,715,500**	$9,715,500	$9,715,500	$9,715,500	$9,715,500
HPS Restrike (150 W & 250 W)	$5,296,500	$5,296,500	$5,296,500	$5,296,500	$**10,593,000**
HPS Retro White (250 W) & HPS 150 W	$**10,723,500**	$10,723,500	$**13,227,750**	$13,227,750	$13,227,750
Icetron (100W & 150 W)	$29,452,500	$29,452,500	$29,452,500	$29,452,500	$29,452,500
QL (85 W & 165 W)	$15,480,000	$15,480,000	$15,480,000	$15,480,000	$15,480,000
LED (40 W) & QL(165W)	$19,080,000	$19,080,000	$19,080,000	$19,080,000	$19,080,000

*** Bold font indicates a year in which a relamping occurs.**

	Year11	Year12	Year13	Year14	Year15
MV(175 W & 250 W)	$9,715,500	**$14,573,250**	$14,573,250	$14,573,250	$14,573,250
HPS (150 W &250 W)	$9,715,500	**$14,573,250**	$14,573,250	$14,573,250	$14,573,250
HPS Restrike (150 W & 250 W)	$10,593,000	$10,593,000	$10,593,000	$10,593,000	$10,593,000
HPS Retro White (250 W) & HPS 150 W	$13,227,750	$**18,589,500**	$18,589,500	$18,589,500	$18,589,500
Icetron (100W & 150 W)	$29,452,500	$29,452,500	$29,452,500	$29,452,500	$29,452,500
QL (85 W & 165 W)	$15,480,000	$15,480,000	$15,480,000	$15,480,000	$15,480,000
LED (40 W) & QL(165W)	$19,080,000	$19,080,000	$19,080,000	$19,080,000	$19,080,000

	Year16	Year17	Year18	Year19	Year20
MV(175 W & 250 W)	$14,573,250	$14,573,250	**$19,431,000**	$19,431,000	$19,431,000
HPS (150 W &250 W)	$14,573,250	$14,573,250	**$19,431,000**	$19,431,000	$19,431,000
HPS Restrike (150 W & 250 W)	$10,593,000	$10,593,000	$10,593,000	$10,593,000	**$15,889,500**
HPS Retro White (250 W) & HPS 150 W	**$21,093,750**	$21,093,750	**$23,951,250**	$23,951,250	**$26,455,500**
Icetron (100W & 150 W)	$29,452,500	$29,452,500	$29,452,500	$29,452,500	$29,452,500
QL (85 W & 165 W)	$15,480,000	$15,480,000	$15,480,000	$15,480,000	$15,480,000
LED (40 W) & QL(165W)	$19,080,000	$19,080,000	$19,080,000	$19,080,000	$19,080,000

*** Bold font indicates a year in which a relamping occurs.**