LED versus HPS Lighting:
A Shoot-Out on the Nason Street Corral

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Abstract: The City of Moreno Valley has opened a new roadway featuring light-emitting diode (LED) street lighting. The authors utilized a light meter to gauge the performance of the roadway lighting system using both new LED and new High-Pressure Sodium (HPS) luminaires. The field calculations were used to verify a computer model of the lighting system using a readily available lighting analysis computer program whose methodology replicates the methods developed by the Illuminating Engineering Society of North America. The paper presents quantitative and qualitative analysis of the performance of the HPS and LED lighting systems both individually and comparatively, and also considers the performance of the computer model against the field data. A cost analysis is presented which considers the electrical service provider and agency responsible for maintenance (e.g. franchise electrical utility maintained versus agency maintained).

Introduction

Roadway lighting is essential to increase visibility for drivers and other roadway users. This increased visibility translates to reduced nighttime collisions and improved safety for vehicles, pedestrians, and cyclists. However, with the current fiscal climate, agencies must continuously seek methods of reducing impacts to their ever shrinking infrastructure maintenance budgets without compromising safety. One potential means to maintain roadway safety, yet reduce perpetual costs, is through the use of LED street lighting.

Like many other agencies, the City of Moreno Valley typically requires HPS street lighting for new development and Capital Improvement Program projects. With every installation, ongoing maintenance costs rise. This demonstration project is intended to determine if tangible long-term benefits can be realized through the use of LED lighting as a direct replacement for HPS.

Site Characteristics

Nason Street is a north-south arterial roadway with 2 lanes in each direction, a curb to curb width of eighty-six feet, and a future anticipated Average Daily Traffic volume of 20,000 to 25,000 vehicles. A one mile segment of Nason Street was recently constructed from Iris Avenue to Cactus Avenue. The project cost approximately $10 million to construct, and included curb and gutter, a raised fourteen- foot- wide landscaped center median, sidewalk, and buffered bike lanes. The roadway lighting system consists of staggered 185 Watt LED street lights on both sides of the roadway. The lights were mounted at a height of thirty-two feet above the finished paved surface on standard marbelite poles spaced 200 foot apart on the same side of the street. The unopened roadway, with vacant adjacent properties, provided the ideal condition to measure each roadway lighting type without the influence of spillover illuminance from nearby development and vehicle headlights.

Methodology

The analysis method for computed photometric analysis, field measurement, and energy consumption are discussed herein.

Photometric Analysis

Photometric analysis is defined as modeling of lighting system performance. The model, which is generally constructed using specialized computer software, uses data supplied by luminaire manufacturers ("photometric data") specifying the intensity of light projected by the luminaire in three dimensions; luminaire placement data supplied by the analyst (specifically, mounting height, lateral position to roadway, and information about the roadway to be analyzed. The salient roadway characteristics are width and number of travel lanes. These characteristics are used to generate a photometric grid.

The photometric grid is a two-dimensional array of points. The analysis program uses the photometric data to calculate the amount of light contributed by all lighting fixtures on each point of the grid. The grid spans the roadway in the lateral dimension and the area between two fixtures on the same side of the road in the longitudinal dimension. The program then calculates certain parameters from the data, including average light levels and ratios between average, maximum, and minimum light levels, all of which are used by the analyst to gauge performance.

Photometric analysis in the United States is generally conducted in accordance with the standards of the Illuminating Engineering Society of North America (IESNA). The analysis performed by the authors is in compliance with the methodology found in its publication, "Roadway Lighting" (RP-8-00). It requires that the photometric grid contain at least two points per lane laterally, and a longitudinal spacing of no more than 15 feet. For this project, the photometric grid was established as a six-by-twenty grid on each side of the road, for a total of 240 points for both travel directions. The grid was designed to supply two points per lane in the lateral direction, including shoulder/bike lane; and ten-foot spacing in the longitudinal direction. The grid was centered on each half-roadway and between the fixtures. No consideration was made for the roadway's cross-slope. Elevations across the grid vary less than one foot.

Lighting analysis software normally will provide several outputs. The most commonly used are illuminance, the amount of light falling on each point in the photometric grid; and luminance, the amount of light that reflects from the roadway surface toward an observer. Since the purpose of this analysis was to compare performance to field data, and since the field measurements were of light incident on the detector, the photometric analysis reports illuminance.

Although this section has described analysis of the lighting system for roadway purposes, the method is easily adapted or extended to analyze similar facilities such as bikeways and walkways. However, such analysis is beyond the scope of this paper.

Normally, a light loss factor is applied, the purpose of which is to predict lighting levels at the end of life of the luminaires, which generally will produce less light over time. Since in this case a brand-new lighting system was modeled, the light-loss factor was disabled (i.e., set to 1, meaning no loss).

The analysts used Dialux lighting analysis software to perform the analysis. This program, which is compliant with IESNA methodology, is available for download and installation for the Microsoft Windows platform at no cost from www.dial.de. Photometric data from General Electric was obtained for both types of fixtures. Table 1 presents the LED and HPS luminaire part numbers and corresponding photometric data, for use in confirming the results.

Table 1: Luminaire Data

Type	GE Part #	Photometric File
Light-Emitting Diode (LED)	ERS30MXBX5402	454931
High-Pressure Sodium (HPS)	MSCL20S0A22FMC3	451006

Field Measurement

The photometric grid described in the above section was applied to the analysis area using (*x*, *y*) coordinates supplied by the analysis program, and was marked on the roadway using traffic paint. The same grid was used for both field measurements.

To allow for ease of analysis of energy consumption, the lighting analysis grid needed to be situated at the end of a circuit. Since the break point between electrical circuits was found on a horizontal curve, the resulting photometric grid needed to be adapted to the curved roadway. The centerline curve radius of the road in this area is 2000 feet. To adapt the grid to the curved roadway, measurements were made along both outer curb lines, and the grid points were placed radially based on stationing established on the outer curbs. The instrument used to lay out the grid was a standard roller wheel. All points are estimated to be within one foot of the true location.

The field data were collected using a light meter manufactured by Extech Instruments, model 407026. The device utilizes a domed white surface which is designed to capture light coming from all directions above the horizontal plane. The meter is calibrated to replicate the sensitivity of the human eye to light at various wavelengths in accordance with a commonly-used model of the human eye's sensitivity to light at various wavelengths published by the International Commission on Illumination (C.I.E.), known as the Standard Photopic Observer. The meter can be set to perform adjustments to account for the particular characteristics of sodium, fluorescent, and mercury fixtures. The data collection was performed with the light meter set to "sodium" for HPS measurements and "daylight" (i.e., no adjustment) for LED measurements.

Field data were collected by the authors during full night conditions on April 3 and April 11, 2013. The moon was not present in the sky at the time the data was gathered. Since the roadway is in an undeveloped area, there was also no contribution from lighting other than the roadway lighting fixtures. The road was closed to traffic on those dates. The field personnel took care to not shadow light from any contributing luminaires; generally this was accomplished by standing between the detector and the outside curb.

Energy Consumption of LED versus HPS

As mentioned previously, the specific location of the field measurements was chosen to have five lights at the end of a circuit. This provided an opportunity to install a meter at the beginning of the circuit to measure total energy usage. The 185 Watt LED lights were monitored for a period of 23 days and their consumption averaged 2.12 kWh per night. Subsequently, maintenance staff replaced the LED lights with 200W HPS fixtures, and energy use was monitored for a period of 8 days. The monitoring period was shorter for the HPS lighting due to the construction schedule and the planned opening of the roadway. Although the monitoring period was less, this variable is not considered critical as the average energy consumption was not expected to significantly change over a longer time period. The HPS light consumption averaged 2.60 kWh per night. In comparing the two lighting types, there was approximately **22.53%** more energy consumed by the 200W HPS lights.

Photometric Results and Comparisons

Tables 2 and 3 present the two most commonly used measures of roadway lighting performance: Average Illuminance, and the Uniformity Ratio; which is defined as the ratio of the average illuminance to the minimum illuminance, where minimum illuminance is the smallest value in the photometric grid.

Table 2: Photometric Analysis Results Cross-Comparison:
Average Illuminance (Lux)

	Field Measured	Calculated
High-Pressure Sodium (HPS)	13.0	18.4
Light-Emitting Diode (LED)	15.7	17.7

For both lighting technologies, the calculated average illuminance levels are higher than the field-measured values. The discrepancy is greater for the HPS system. The IES-recommended average lighting level for a major roadway with low pedestrian traffic is between six and nine lux, depending on which pavement classification is used. Both lighting systems exceed this level of light when new. As lighting levels degrade over time, the margin between actual and recommended lighting levels would be reduced. The LED system provides a greater margin.

Table 3: Photometric Analysis Results Cross-Comparison: Uniformity Ratio
Minimum Illuminance Value (Average:Min Ratio)

	Field Measured	Calculated
High-Pressure Sodium (HPS)	1 (13:1)	5 (3.7:1)
Light-Emitting Diode (LED)	1 (15.7:1)	4 (4.1:1)

The large difference between calculated and field-measured uniformity ratios is due to the substantial difference in percent terms between the calculated and field-observed minimum values.

Since the IES-recommended uniformity ratio for major roads is 3:1 or better, neither lighting technology satisfies the recommendation whether on a calculated or field-measured basis. The City of Moreno Valley uses standard street lighting spacing and does not generally custom-design lighting systems to achieve IES recommended lighting levels. For this street, the uniformity ratio could have been improved by placing the street lighting standards closer together at a greater system cost.

When observing the ground illuminance, the authors noted the quality of the installed LED lighting. With a color temperature of 5000 Kelvin, the LED light appeared closer to a daylight condition, thus producing a perception of enhanced roadway visibility.

Installation and Operational Costs

At the time of installation, the LED luminaires had an initial cost of $775.00 each as compared to $189.00 each for the HPS luminaires. Labor to install each of the fixtures is considered the same as no special installation method is required for LED lighting.

In Moreno Valley, electrical power is provided by Southern California Edison Company (SCE) and a Moreno Valley owned utility company (MVU). Street lights, once installed, are typically owned and maintained by the serving utility company. Costs of electrical usage and ongoing maintenance are contained in one monthly flat rate charged per light. This tariff rate schedule, known as LS-1 lighting, is approximately $9.75 per fixture for SCE and MVU respectively for HPS fixtures. For LED lighting, the monthly flat rate is $14.73 for both SCE and MVU per fixture. Thus LED fixtures cost $4.98 more per fixture per month. Although LED lighting requires less energy to operate, both utility companies cite the higher initial product cost, the uncertainty of useful life, and potentially higher frequency of replacement / maintenance as the justification for charging the higher monthly flat rate. Based upon the current monthly rates for LS-1 lighting, the HPS and LED light costs per fixture on an annual basis will be approximately $117.00 and $176.76, respectively.

For agencies that own and maintain their street light system, there is more of an opportunity to take advantage of the value of reduced energy consumption. The tariff rate for this condition is known as LS-3 lighting. Typical electricity costs are 6.3 cents per kWh. Using 0.48 kWh less electricity per night equates to a cost savings of approximately $11.00 per year per fixture.

Experience has shown that HPS lamps have a typical useful life of five years before requiring replacement. Although LED street light longevity is yet to be proven over time, manufacturer’s data indicates life expectancy in excess of ten years before need of replacement, essentially reducing the replacement frequency by 50%. Considering staff time, equipment, materials, and projected energy savings for a ten year period, an approximate $250 -300 cost reduction could be realized with each fixture retrofit.

Summary / Conclusions

With this project, it was been determined that LED lighting outperforms HPS in terms of uniformity and average illuminance, and consumes less energy to operate. Although the initial product costs are higher, certainly LED lighting affords the opportunity to reduce replacement frequency and overall maintenance costs over time, and still maintain or enhance roadway safety. It is anticipated that, as research continues and manufacturing prices decline, agencies will make LED lighting a standard for all new and retrofit installations.

Further Research

Further research would be beneficial in the following areas:

- ❑ Install LED fixtures on other roadways and gather additional field measurements. This would provide a large data set to determine the validity of the predicted data from the Dialux lighting analysis software.
- ❑ Develop long term degradation rates for LED lighting to determine useful life.

Authors' Information:

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John Kerenyi has been employed by the City of Moreno Valley as a Senior Engineer since 2006. He has contributed to development review, capital projects, and ITS deployment programs during his employment there. Prior to his engagement with Moreno Valley, he worked at Kimley-Horn and Associates and KOA Corporation. He graduated with a Bachelor's Degree in Engineering in 1993 from Harvey Mudd College in Claremont, California. He is a registered Traffic Engineer and Electrical Engineer in California.

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