Street Light Assessment

ET09SDGE0008

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SDGE
A Sempra Energy utility®

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Preface

PROJECT TEAM

This project is sponsored by San Diego Gas & Electric's (SDG&E®) Emerging Technologies Program (ETP) with Jerine Ahmed as the project manager. Dan Weinheimer of the City of San Diego was the city contact and project manager. Emerging Technologies Associates, Inc. (ETA) provided the overall coordination of all parties involved and finalized the report. Celtic Energy, Inc. provided the technical consulting and data analysis.

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ACKNOWLEDGEMENTS

The report was completed with the equipment supplied by several lighting manufacturers. SDG&E® would like to acknowledge and thank the various vendors and the City of San Marcos. Without their participation, this assessment project would not have been possible.

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Abbreviations and Acronyms

ANSI American National Standards Institute

CCT Correlated Color Temperature

CIE Commission on Illumination

CRI Color Rendering Index

DOE Department of Energy

ETCC Emerging Technologies Coordinating Council

ETA Emerging Technologies Associates, Inc.

ETP Emerging Technologies Program

FC Foot Candle

FT Feet

HPS High Pressure Sodium

HR Hour

IES Illuminating Engineering Society of North America

IOU Investor-owned Utility

K Kelvin

kWh Kilowatt hours

LED Light Emitting Diode

LBNL Lawrence Berkley National Laboratory

LPD Lighting Power Density

LPS Low Pressure Sodium

MH Metal Halide

PG&E® Pacific Gas & Electric

PNNL Pacific Northwest National Laboratory

SDG&E® San Diego Gas & Electric

SSL Solid State Lighting

W Watts

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Executive Summary

In July, 2008, the City of San Marcos and San Diego Gas & Electric's (SDG&E®) Emerging Technologies Program (ETP) agreed to conduct an assessment project to evaluate broad spectrum lighting technologies, specifically induction and Lighting Emitting Diode (LED). The goal of the project was to determine the energy savings potential provided by white light, broad spectrum lighting, as compared to the existing low pressure sodium (LPS) street lights in a residential setting.

In addition to the assessment project goals, the City's goals were to:

- save electricity and related costs as part of its ongoing city-wide energy saving plan
- improve public safety and the existing street lighting system
- meet the State's mandates such as AB32 – Global Warming Solutions Act of 2006

The project was selected due to the City of San Marcos' willingness to allow for demonstration of broad spectrum lighting in a residential area.

Quantitative and qualitative light and electric power measurements were taken. As reflected in the tables below the system wattage, which accounts for the ballast and lamp, is different than just the lamp wattage. A 39% and 32% reduction in annual energy usage and demand were recorded with LED and induction luminaires, respectively. The simple payback is 22.0 years for LED and 22.1 years for induction lighting. However, the payback when maintenance savings are considered is 15.5 years for LED and 12.8 years for induction lighting.

Table 1: Energy and Demand Savings

Luminaire	System Wattage (W)	Power Savings (W)	Demand Savings (%)	Energy Savings (kWh)
LPS *	83	-	-	-
LED	51	32	39	134
Induction	56	27	32	113

** Base Case*

Table 2: Simple Payback - Retrofit

Luminaire	Luminaire Cost ($)	Installation Cost ($)	Total Cost ($)	Annual Energy Cost ($)	Annual Energy Savings ($)	Simple Payback (years)
LPS 55 W *				43		
LED 48 W	366	38	404	24	18	22.0
Induction 55 W	289	38	327	28	15	22.1

** Base Case*

This assessment project will assist not only the City of San Marcos, but numerous cities across the country to determine the street lighting retrofit options, calculate the pros and cons of each technology and determine the impact of the streetlights on its residents and other stakeholders such as the local law enforcement agencies and astronomer community. Local conditions and requirements as well as economic considerations may directly impact the outcome of similar assessment projects. **Therefore, readers are advised that each installation is unique.** The results of this project corroborate similar studies, specifically those conducted by Pacific Gas & Electric (PG&E®) in the cities of Oakland, San Francisco and San Jose, California.

Based upon the findings of this project, it is recommended that future projects conducted consider methodology to determine the impact of broad spectrum street lighting on driver visual acuity and responsiveness at various speeds to broad spectrum lighting technologies. Additionally, a more in depth constituent survey may provide valuable insight as to the perception and receptiveness of such street lighting technology.

Introduction

In response to an overwhelming interest in innovations in street lighting technology among cities in its territory, San Diego Gas & Electric's (SDG&E®) objective with this assessment was to perform a comparison of the new technologies against traditional low pressure sodium (LPS) technology by assessing various manufacturers' products in both LED and induction lighting technologies, and validating manufacturer claims regarding energy savings, light levels and light characteristics.

The City of San Marcos and SDG&E® selected and arranged for the installation of new LED and induction street lights in a residential neighborhood. In addition to energy efficiency benefits, feedback was solicited from residents, businesses, city departments and local agencies impacted by the street lighting change out by the City.

SDG&E® worked in a collaborative manner with City Departments such as the City Engineer, Public Works as well as the County Sheriff Department to share information and solicit input on the tested street lighting technologies. Meetings with Palomar Observatory and International Dark Sky Association were conducted to take into account the potential impact of the new street lighting technologies on night sky light pollution.

In collaboration with the City of San Marcos, SDG&E® selected and arranged for the installation of new LED and induction street lights in a residential neighborhood. Installation of the streetlights began in November, 2008 and was completed in February, 2009. Quantitative and qualitative lighting and electrical power measurements were taken for both pre and post installation.

Project Background

PROJECT OVERVIEW

The Street Lighting Assessment project was conducted as part of the Emerging Technologies Program of San Diego Gas & Electric Company. The Emerging Technologies program "is an information-only program that seeks to accelerate the introduction of innovative energy efficient technologies, applications and analytical tools that are not widely adopted in California. The information includes verified energy savings and demand reductions, market potential and market barriers, incremental cost, and the technology's life expectancy. Project Management and Methodology was provided by Emerging Technologies Associates, Inc.

The Street Lighting Assessment project studied the applicability of broad spectrum lighting consisting of LED and QL induction luminaires on existing street light poles. Existing LPS luminaires were replaced with new LED and induction luminaires in a neighborhood in San Marcos, CA. The street selected for the assessment was Lindsley Park Drive. The test site allowed for side-by-side comparison of the lighting performance of the base case, LPS and the emerging technologies, LED and QL induction, being assessed. The applicability of the technology was determined by light output, energy and power usage, economic factors and qualitative satisfaction.

TECHNOLOGICAL OVERVIEW

At the time of this assessment, LED and induction broad spectrum lighting were gaining momentum because of the luminaire's ability to provide greater control of light dispersion, greater operating and maintenance savings and desire for higher quality light for exterior use. One such application is street and roadway light luminaires. Currently, the streets in San Diego County, in which San Marcos is located, are illuminated with LPS, HPS and less frequently metal halide (MH). LPS lights are used primarily because of their long rated life and high efficiency relative to other conventional options, but LPS sources also have low color rendition. In San Diego County, ordinances were passed by cities in 1984 requiring LPS street lighting to protect the night sky. New technologies like induction lighting and LEDs have the potential for even longer life than LPS, reduced maintenance, high color rendition, and reduced operating cost including lower energy usage. Currently however, the initial cost of this technology is higher than conventional light sources.

The US Department of Energy reports that LED technology is changing at a rapid pace. Overall, the performance of LED technology is quickly gaining efficiency but the first cost remains a barrier to market entry. However, it should be noted that the costs for LED technology seems to be getting more competitive in the market place with each year that passes and technological advances are applied to street lighting. The induction technology has been in the market since the early 1990s. Therefore, induction has more of a history in numerous outdoor lighting applications including street lighting. For example, the City of San Diego has used induction street lighting in the downtown historic Gas Lamp district for the past ten years with minimal failures.

MARKET OVERVIEW

A report by Navigant Consulting in 2002 estimates that lighting makes up approximately 22% of IOU kWh sales on a national scale. Of that amount roughly 4%, or 1% of total IOU kWh sales, are for roadway lighting. The anticipated escalation rate for electricity is an increasing concern, and energy costs to operate street lighting, especially outdated, inefficient technology, will inevitably increase over time. The market for new energy efficient outdoor light sources will continue to grow due to increasing demand for electricity and the cost to operate and maintain street lighting. Increasing electricity rates and a growing awareness of energy efficiency will increase the economic feasibility of new street lighting technologies in future years.

Project Objectives

The objectives of this project were to examine electrical, lighting, and economic performance of cobra-head LPS luminaires as compared to LED and induction luminaires used in this assessment conducted at the City of San Marcos. The potential electrical demand and energy savings were measured in terms of instantaneous system wattage and estimated annual kWh usage based on SDG&E's LS-2 Rate which assumes 4,165 annual operating hours. Lighting performance was measured in terms of illuminance, uniformity, the scotopic to photopic ratios and Correlated Color Temperature (CCT) measured in Kelvin (K). Additionally, acceptance from residents and community interested parties such as Palomar Observatory and law enforcement authorities was sought by the City of San Marcos officials. Finally, economic performance was calculated as simple-payback for substitution in new installation or replacement scenarios, accounting for lamp life-span, maintenance costs, and electrical costs.

Figure 1: Existing LPS luminaire on Lindsley Park Drive

Methodology

HOST SITE INFORMATION

The site selected for this assessment was Lindsley Park Drive, San Marcos, CA (see Figure 2) a residential area where the existing street lights are 55 W (nominal) LPS cobra-head luminaires. The LPS luminaires are at a height of 26.5 ft. As shown in Figure 1 below, the street makes a U-shape connecting Rees Road to Rock Springs Road. Two street lights were chosen on each side of the street which is marked on the Google Earth satellite photo. It should be noted that all LPS fixtures were replaced in the area with LED and Induction to provide for an assessment area free from other light source trespass which may have affected the data. The natural curvature of the street provided for a "buffer zone" and served as the demarcation between the two technologies. A street view of each light pole fixture chosen for the data collection is shown in Figures 3 and 4.

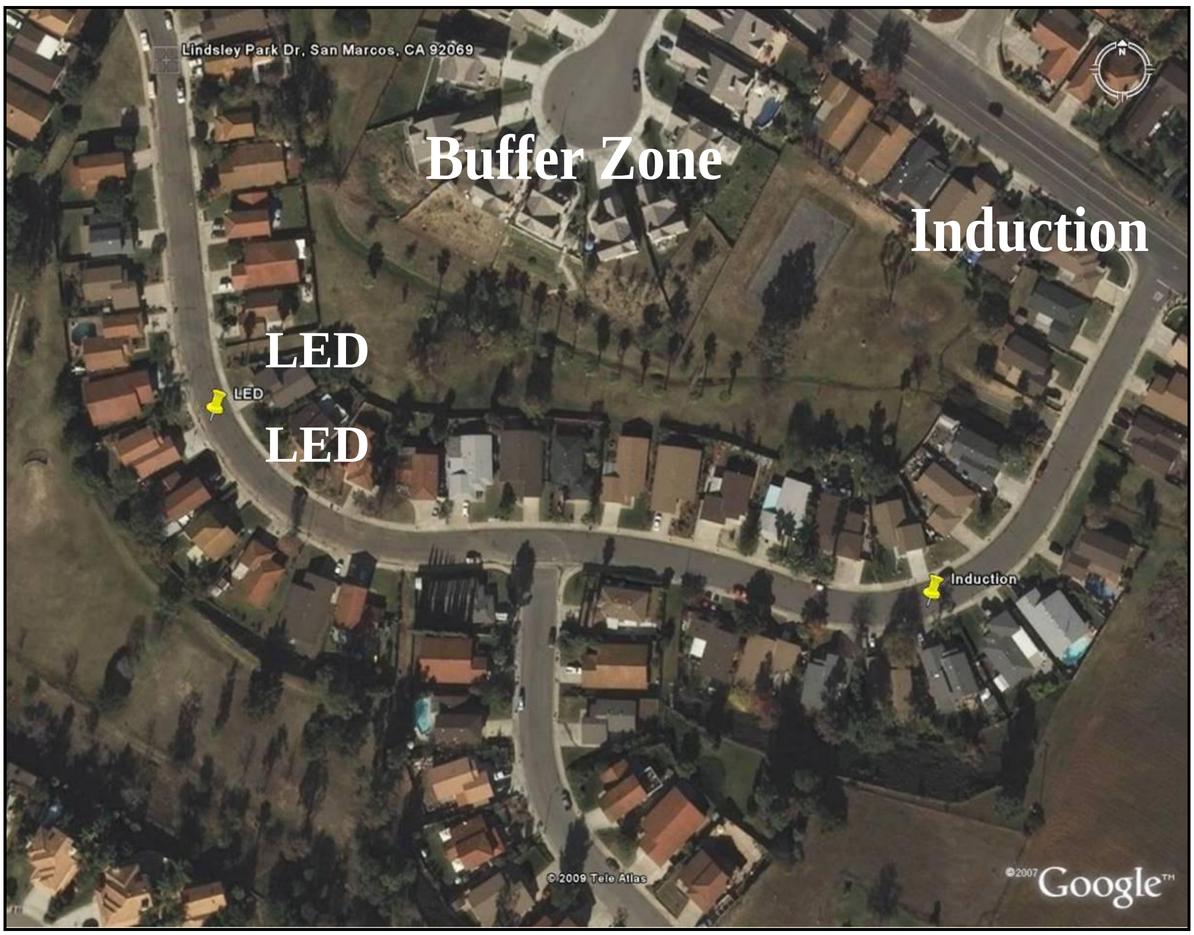


Figure 2: Google Earth satellite image of Lindsley Park Drive

Figure 3: Induction luminaire at Lindsley Park Drive

Figure 4: LED luminaire at Lindsley Park Drive

MEASUREMENT PLAN

The Street Lighting Assessment project studies the suitability and performance of LED and QL induction luminaires in a street lighting application. LPS luminaires were replaced with new LED and induction luminaires along Lindsley Park Drive with the established buffer zone in between the technologies. Quantitative and qualitative light and electrical power measurements were taken.

A measurement plan was developed for this assessment. Pre-installation and post-installation field visits were conducted. The monitoring area was established during the first site visit prior to taking measurements. Meetings with the City Manager's Office and Public Works project team were conducted to ensure that no outstanding issues would preclude the installation of the LED and induction luminaires on San Marcos city streets.

During the pre-installation field visit, data point grids were laid out on the asphalt in accordance with RP-08-00, the methodology recommended by the Pacific Northwest National Laboratory (PNNL) who conducts Gateway demonstrations for the DOE's Solid State Lighting (SSL) Commercialization Initiative.

"RP-08-00 American National Standard Practice for Roadway Lighting is the Recommended Practice provides the design basis for lighting roadways, adjacent bikeways, and pedestrian ways. It deals entirely with lighting and does not give advice on construction. It is not intended to be applied to existing lighting systems until such systems are redesigned. This Practice revises and replaces the previous edition which was published in 1983 and reaffirmed in 1993. Roadway lighting is intended to produce quick, accurate, and comfortable seeing at night that will safeguard, facilitate, and encourage vehicular and pedestrian traffic. The proper use of roadway lighting is also associated here with certain economic and social benefits including a reduction in nighttime accidents, aid to police, facilitation of traffic flow, and the promotion of business during nighttime." (*source:* ANSI/IES RP-08-00 (2005))

To ensure proper documentation of the existing LPS street lighting, the LPS lamps had been replaced with new lamps and the luminaires had been cleaned. The LPS lamps were burned in for approximately 100 hours prior to conducting measurements. All light measurements were taken after dusk.

A two phase measurement plan was undertaken. In Phase 1, pre-installation power readings and light measurements of the LPS fixtures illuminated at both locations were taken. The light measurements that were taken included both photopic and scotopic illuminance readings. Phase 2 of this assessment involved the replacement of the LPS fixtures at both locations with LED and Induction fixtures. During the post-installation visit, power readings and light measurements were taken again on the same grid layout. This allowed for a comparison analysis between the street lighting technologies: the base case LPS, LED and induction.

Photopic and scotopic illuminance measurements were taken on a 50' by 45' grid under two street lights at separate locations on Lindsley Park Drive. The average, maximum, and minimum illuminance levels along with average uniformity ratio were measured in foot candles (fc) for ease of use and understanding.

Figure 5: Typical site grid layout (Lindsley Park Drive)

The luminaires extend up approximately 26.5' above the finished grade, on 6' mounting arms out from metal poles. The illuminance levels were taken with a Solar Light PMA220 meter with photopic and scotopic detectors that were placed directly on the pavement. This meter has a precision of 0.09 fc.

It should be noted that the field measurements differ slightly from those defined in the "Illuminating Engineering Society of North America (IES) Guide for Photometric Measurement of Roadway Lighting Installations." IES recommends that the grid be laid out so that measurements are taken beginning at one-half the grid spacing from the spot directly beneath the luminaire. In this study, the measurement grid was laid out such that the measurements were taken at the predicted maximum and minimum illuminance levels in the test area, corresponding to the areas directly underneath luminaires and at 5' increments between luminaires. This was done to capture the full effect of differing uniformity in the LPS, LED, and Induction luminaires. IES also recommends that care be taken to level the detector before each measurement and that the detector be less than 6" off the ground. The monitoring team determined that the former recommendation was of greater importance, so measurements were taken at ground level. The same procedure was followed for both pre and post measurements.

EQUIPMENT

The following equipment used in the execution of this Measurement Plan was obtained from the Pacific Energy Center:

Illuminance Meter
Solar Light SnP Meter (PMA220) with Photopic Detector (PMA2130) and Scotopic Detector (PMA2131), last calibrated 10/2007

Correlated Color Temperature meter
Konica Minolta Chrome Meter, Model CL-200, last calibrated 10/2007

Consultant owned equipment was used for:

Power Readings
Fluke Clamp Meter, Model 332

Project Results

ELECTRICAL ENERGY AND DEMAND SAVINGS

The LED luminaire used 39% less power than the LPS with an annual reduction of energy usage of 134 kWh. These results are similar to those recorded in other assessments in Oakland, San Jose and San Francisco (see Appendix C). The induction luminaires used 32% less power than the LPS with an annual reduction of 113 kWh. Table 3 contains this data. The energy use is based on 4,165 hours.

Table 3: Energy and Demand Savings

Luminaire	Voltage (V)	System Wattage (W)	Energy (kWh)	Power Savings (W)	Demand Savings (%)	Energy Savings (kWh)
LPS *	240	83	346	-	-	-
LED	240	51	212	32	39	134
Induction	240	56	233	27	32	113

** Base Case*

LIGHTING PERFORMANCE

Both photopic and scotopic illuminance measurements were taken on the 50' x 45' grid described in the above section, "Monitoring Plan." The eye's "photopic response" to light is primarily vision under well-lit conditions such as daytime. The "scotopic response" to light is primarily vision under very low light such as nighttime. Published lumen ratings reflect photopic lumens. A scotopic/photopic meter was used to measure spectral responses following the CIE scotopic and photopic action spectrum. Determining the photopic and scotopic lumens of a particular light source simulates how the human eye perceives light at normal light levels.

Current scientific research is determining that the interplay of scotopic and photopic vision helps us to see under different conditions. Therefore, it is important to record both photopic and scotopic light measurements as a part of the light performance assessment. Dr. Sam Berman in his article, "The Coming Revolution in Lighting Practice," states, "…both cone and rod responses to lighting need to be evaluated. This means knowledge of both photopic and scotopic components of the observed light is necessary to provide optimum lighting for visual performance and brightness perception." (*Source:* www.bluebellgroup.com/62.pdf). Because of the eye's response to lower light levels at night through rod activated vision (scotopic), the scotopic response may be a factor to consider when selecting street light or outdoor luminaires.

1. Average, Minimum and Maximum Illuminance

The average illuminance levels for each test site were calculated and recorded in fc for ease of use. These average illuminance levels, along with the maximum and minimum measured values, were then used to calculate the average- and maximum-to-minimum uniformity ratios. See Appendix A for raw illuminance data and plots.

Table 4 and 5 contain the data which represents a comparison of average, maximum, and minimum illuminance levels as well as uniformity ratios for each street light technology at its respective location.

Table 4: Photopic Illuminance Levels

Luminaire	Illuminance (fc)			Uniformity	
	Avg	Max	Min	Avg to Min	Max to Min
LPS *	0.47	1.2	0.1	4.7:1	12:1
LED	0.53	1.3	0.1	5.3:1	13:1
Induction	0.47	1.2	0.1	4.7:1	12:1

** Base Case*

Table 5: Scotopic Illuminance Levels

Luminaire	Illuminance (fc)			Uniformity	
	Avg	Max	Min	Avg to Min	Max to Min
LPS *	0.23	0.5	0.05	4.6:1	10:1
LED	0.74	2.1	0.1	7.4:1	21:1
Induction	0.66	1.9	0.1	6.6:1	19:1

** Base Case*

It should be noted that due to the layout of the test area and the orientation of the luminaire arms, measurements were not necessarily taken directly under the luminaires. However, this deviation was deemed to be of small enough order to have minimal effect on the overall analysis. In addition, due to the in situ nature of the monitoring, some measurement locations were obstructed. When possible, data for these locations was estimated to be the same as that from nearby points on the grid.

2. Uniformity Ratios

In outdoor lighting uniformity is a measure of how evenly light is distributed across a surface. Typically, the measure is expressed as a ratio of one value to another such as maximum to minimum. Using ratios, perfect uniformity is 1:1.

As indicated in Table 5, photopically, uniformity ratios for the LED luminaire were slightly higher, less uniform, than the LPS luminaire and lower for the induction luminaire. Scotopically, the uniformity ratios were higher for both the LED and induction luminaires. Although the uniformity of light distribution was similar photopically and higher scotopically for the LED and induction luminaires, the difference in distribution is less critical when taking into account the major decrease in overall power and energy usage between the lighting technologies.

3. Scotopic/Photopic Ratios

Dr. Sam Berman, Senior Scientist Emeritus, Lawrence Berkley National Laboratory (LBNL), is a leading scientist conducting research of the effect of lighting on vision. He states, “At different light levels, people exhibit different relative sensitivities to light.” Another important factor to analyze is the S/P ratio. An S/P ratio is the ratio of light measured by the scotopic and photopic light meters. This ratio is important as it determines how well a person can/will perceive something based upon the eye’s sensitivity to different wavelengths of light. The retina, a light sensitive membrane at the back of the eye, contains millions of very tiny light receptors that convert light into electrified signals sent to the vision centers of the brain. The two major categories of light receptors (photoreceptors) are called cones and rods because of their shapes. The very central part of the retina, the fovea, contains only cones. The rest of the retina contains both rods and cones, with the number of rods dominating the cones by about ten to one. Up until now, it is widely accepted that the cones handle day vision while the rods are designed for night vision.

Figure 6 shows the scotopic and photopic sensitivity differences at various wavelengths of light.

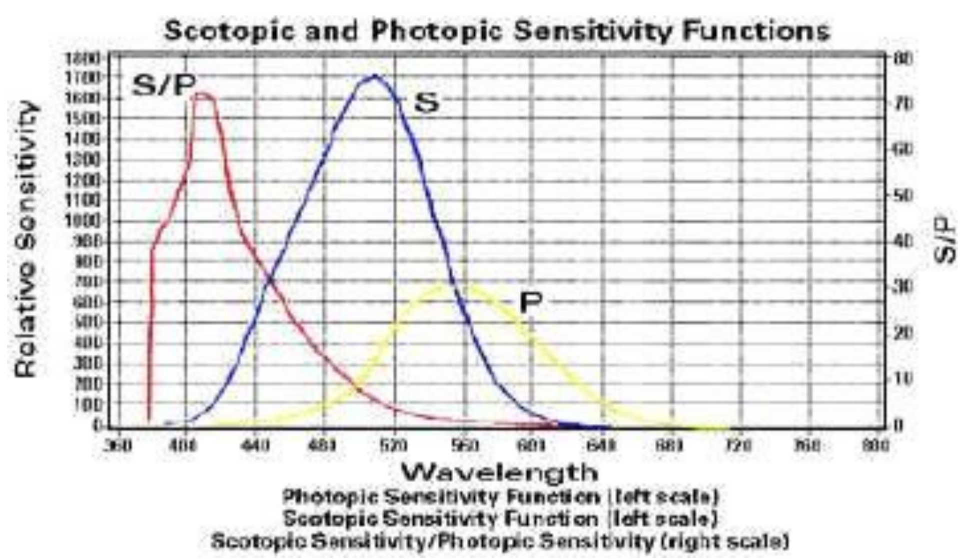


Figure 6: Scotopic and Photopic sensitivity functions

Table 6 below shows the S/P ratios of each luminaire.

Table 6: Average Scotopic and Photopic Illuminance and S/P Ratio

Luminaire	Average Scotopic Illuminance (fc)	Average Photopic Illuminance (fc)	S/P Ratio
LPS *	0.23	0.47	0.49
LED	0.74	0.53	1.40
Induction	0.66	0.47	1.40

** Base Case*

Based on the calculated S/P ratios above, the values discovered for the LED and Induction luminaires are approximately three times as high as that of the LPS luminaires. ***However, recently the IES published a Position Statement (IES PS-02-09) regarding the "Use of Spectral Weighting Functions for Compliance with IES Recommendations." Research has shown that other spectral weighting functions can be useful in evaluating radiation that produces human visual sensation. This realization has led to the development of other possible spectral weighting functions which in turn have misrepresented the true definition of photopic lumens. The IES has determined that at this time, there is no sufficient research to support the application of any alternative to photopic luminous efficiency function. IES 10th edition clarifies that any calculations that modify photopic lumens are not supported as an appropriate calculation method. As a result, lighting calculations and energy savings predictions that use 'modified' lumens (S/P ratio lumens, for example) cannot be used as a basis for comparing the performance of various lighting systems.*** Therefore, it is recommended readers consider the IES position and further research on the S/P ratios when considering broad spectrum lighting for street light and other outdoor lighting applications.

4. Correlated Color Temperature and Color Rendering Index

Correlated Color Temperature (CCT) measurements were taken using a Konica Minolta Chromameter under the LED and induction luminaires. The average color temperature under the LED luminaire was 4,691 K. The average under the induction luminaire was 4,376 K. Because the LED and induction luminaires have a measured average color temperature of over 4,000 K, more along that of natural light, they are able to display the true color of an object or area much more effectively. This can be especially important for busy traffic areas and the safety of neighborhoods. See Appendix C for more details. Figure 7 below illustrates the importance of a color temperature near daylight for law enforcement officials. The top two photos are of induction lighting while the bottom two are of LED lighting. These photos were not taken in the actual assessed areas.

Figure 7: CCT and effect on visibility

Table 7 below gives a summary of average, maximum, and minimum measured color temperatures taken on the same grid used to collect the other project data.

Table 7: Correlated Color Temperature Data

Luminaire	Color Temperature (K)		
	Min	Max	Avg
LED	3,450	4,996	4,691
Induction	4,300	4,435	4,376

Another factor to consider may be the Color Rendering Index (CRI), the measure of the quality of light color, developed by the International Commission on Illumination (CIE). When coupled with the color temperature of a light source near daylight, the higher the CRI the truer the colors of objects. This is particularly important for law enforcement and public safety. Figure 8 below shows the difference between CRI with LPS (CRI – 0) and 3,500 K LED and induction (CRI – 65+).


LPS LED and Induction

Figure 8: CRI - Impact of light source on colors

ECONOMIC PERFORMANCE

It is important to note that the cost and equipment assumptions made in this section apply only to the City of San Marcos. The City was assessing the replacement of the most efficacious (100 – 185 lumens per watt) light source, Low Pressure Sodium. Therefore, readers should consider their specific variables such as maintenance, energy, luminaire efficacy, luminaire costs and type of distribution before drawing any conclusions about the cost effectiveness of LED or induction luminaires. For both LED and induction, luminaire lifetime is a function of the manufacturer's components of the luminaire (LEDs, driver, housing, coatings, etc.), electrical and thermal properties. Therefore, manufacturer claims, with regard to the aforementioned factors, are highly variable. The cost and savings estimates for this section is based upon City of San Marcos to evaluate economic performance of the base case LPS luminaire and the advance street light broad spectrum technologies, LED and induction luminaires, assessed in this project.

1. Energy Cost Estimates

The energy cost for each luminaire is based upon the SDG&E® LS-2 rate schedule as of July 2009. Under this rate schedule, street lights are billed a monthly set rate based on the type and wattage of the lamp assuming 4,165 annual operating hours. The rate is specific to customer-owned street lighting luminaires. This project focused on the replacement of LPS luminaires with both LED and induction technology. Table 8 provides the charges for the street lights based upon the wattages in the City of San Marcos.

Table 8: Energy Cost by Light Source

Luminaire	Actual Power	kWh	UDC ($)	Energy Charge ($)	Monthly Cost ($)	Annual Cost ($)
LPS 55 W *	83	346	1.44	2.13	3.57	42.86
LED 48W	51	212	0.73	1.31	2.04	24.47
Induction 55 W	56	233	0.90	1.44	2.34	28.06

** Base Case*

Simple payback calculations were calculated for retrofit and new construction scenarios. In a retrofit scenario the new technology was installed replacing an existing operational LPS luminaire before end of the useful life and factors the total investment cost and energy savings for both the LED and induction luminaire. The paybacks for a retrofit and new construction are shown in Tables 9 and 10.

Table 9: Simple Payback - Retrofit

Luminaire	Luminaire Cost ($)	Installation Cost ($)	Total Cost ($)	Annual Energy Cost ($)	Annual Energy Savings ($)	Simple Payback (years)
LPS 55W *				43		
LED 48W	366	38	404	24	18	22.0
Induction 55W	289	38	327	28	15	22.1

** Base Case*
Note: The initial investment reflects discounted pricing for 1000 units +

Table 10: Simple Payback – New Construction

Luminaire	Luminaire Cost ($)	Installation Cost ($)	Total Cost ($)	Total Incremental Cost ($)	Annual Energy Cost ($)	Annual Energy Savings ($)	Simple Payback (years)
LPS 55W	316	38	354		43		
LED 48W	366	38	404	50	24	18	2.7
Induction 55W	289	38	327	-27	28	15	-1.8

** Base Case*
Note: The initial investment reflects discounted pricing for 1000+ units.

2. Maintenance and Repair Cost Estimates

The City of San Marcos performs streetlight maintenance when lamps burn out and also as group re-lamping. For this project, City of San Marcos total maintenance cost for LPS luminaires were estimated based upon reported labor and material spending history. A system wide annual maintenance cost was calculated. The rate structure for such maintenance is shown below in Table 11. The table includes estimated costs for the boom truck and provides time for establishing traffic control.

Table 11: City of San Marcos Labor and Truck Rate Schedule

Re-lamping Labor Rates – Loaded ($)				
Time (hrs)	0.25	0.5	0.75	1.0
Labor	14.04	28.08	42.11	56.15
Truck	4.75	9.50	14.25	19.00
Total	18.79	37.58	56.36	75.15

In estimating the labor component of routine maintenance costs, it was assumed that inspection, photocell and cleaning are consistent among all luminaires. Therefore, these were not considered in the maintenance savings calculations.

Cost of each input to determine annualized maintenance cost:

- **Labor and Truck:** $37.58 for all luminaire replacements.
- **Lamp Cost:** Actual LPS cost $15.84/lamp; LED assumed cost based upon 10% failure $36.60 (10% of luminaire cost $366) and induction assumed cost based upon 10% failure $28.90 (10% of luminaire cost $289).
- **Disposal Fee:** The author used the fees assigned in the City of San Diego Assessment project. The fees were assigned by the City of San Diego Environmental Services Department and varied by technology: LPS $4.50, LED $7.50 and induction $25.00.

Table 12: Paybacks with Energy and Maintenance Savings

Luminaire	Total Cost ($)	Total Incremental Cost ($)	Maintenance Cost ($)	Maintenance Savings ($)	Annual Energy Savings ($)	Total Savings ($)	Retrofit Payback (years)	New Constr. Payback (years)
LPS 55W	354	-	14.48	-	-	-	-	-
LED 48W	404	50	6.81	7.67	18.39	26.07	15.5	1.9
Induction 55W	327	-27	3.81	10.67	14.80	25.47	12.8	-1.1

** Base Case*

<u>Example of calculating annualized LED maintenance cost:</u> The total cost of a lamp replacement equals the sum of the labor ($37.58), LED lamp cost based upon 10% failure ($36.60) and the assigned disposal fee ($7.50). This results in $81.68 which is divided by an expected 12 year life yielding an annualized maintenance cost of $6.81. Due to the inability to accurately pinpoint actual factors, this maintenance cost calculation does not take into consideration an inflation factor, escalating energy cost or the future cost of LEDs which is expected to be much less in 10 years.

3. Luminaires and Lamp Life

For the purposes of this project, the end of useful life in hours for each technology is as follows: LPS – 18,000; LED – 50,000; induction – 100,000.

For both the LED and induction technology, a properly designed fixture is required, meaning electrically and thermally, to achieve the life expectancy. If the fixture has poor electrical or thermal design the light source life is adversely affected resulting in a much shorter life.

The manufacturers of the LED luminaires assessed in this project claim life expectancies from 50,000 to 89,000 hours (approximately 12 to 21 years at 4,165 operating hours per year). ***This report uses 50,000 hours, or 12 years in this situation, as the LED life expectancy.*** The base case 55 W LPS lamp has an expected life of 18,000 hours (approximately 4 years). The induction lamp has a stated life of 100,000 hours (approximately 24 years). The induction lamp life was based upon proven life in a properly designed fixture, meaning electrically and thermally.

To determine the maintenance cost it was assumed that LEDs would experience a fractional failure rate of 10% (PG&E Emerging Technology Program, Application Assessment Report 0727, Dec 2008, page 38 http://www.etcc-ca.com/index.php?option=com_content&task=view&id=2841&Itemid=72)

while induction would experience a 10% failure rate before 100,000 hours (Philips QL Induction Lighting Systems, Information for Original Equipment Manufacturers, July 2007 www.**lighting**.**philips**.com/us_en/.../download/ql_oem_guide.pdf*).*

James Brodrick, Lighting Program Manager, US DOE, Building Technologies Program, in a recent article entitled "Lifetime Concerns", when discussing how best to define the longevity of LED luminaires stated: "That's not a simple matter, because it doesn't just involve the LED themselves, but rather encompasses the entire system-including the power supply or driver, the electrical components, various optical components and the fixture housing." ***Therefore, the assumptions for LED life expectancy in this project is based upon 50,000 hours as per the DOE website***

(*source:* http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lifetime_white_leds.pdf)

4. Life Cycle Cost Analysis

As stated in the previous section, to properly assess technology a full life cycle cost analysis is recommended. There are many variables and considerations which are specific to each reader's situation. It is recommended that variables such as labor, cost of materials, maintenance practices, cost of financing, inflation, energy rates, material cost, etc be determined for the specific project under evaluation.

Due to the uncertainty as to future labor, product and other costs, especially for LED technology, readers are recommended to use their judgment regarding the future costs.

Conclusion

This assessment demonstrated that LED and induction broad spectrum lighting technologies deliver superior lighting performance in most areas when compared to LPS. LED and induction street lighting technology exhibited great potential for energy savings 39% and 32%, respectively, and the potential for even better operation and maintenance savings.

The lessons learned from this assessment are as follows:

- testing before adopting new technologies
- further studies required to indemnify cities against potential liability
- street lighting technologies are application and geographic specific
- not to rely on marketing brochures and technical data sheets; full assessment is recommended

While the results of this project attest to the leaps in technological enhancements of both LED and induction luminaires, the high first cost required to retrofit street lights with either LED or induction will be the main barrier to significant market adoption. The significant energy savings and reduce maintenance costs, do not adequately offset this high initial first cost. Performance of the LED and induction luminaires combined with growing industry acceptance of their higher performance versus LPS luminaires may provide early adopters the impetus to invest in the emerging technology.

Due to the as yet proven long life of LEDs, economic and reliability claims are based on the best available information from the manufacturer and DOE reports. James Brodrick, Lighting Program Manager, US DOE, Building Technologies Program, wrote an article in which he states, *"The question of LED luminaire and reliability is a complex one, fraught with nuance and ramification."* On the other hand, induction lighting technology was introduced into the US in 1992. As with LEDs, induction requires proper thermal management to achieve the 100,000 hour stated life. To date, induction lighting has been installed in many applications successfully resulting in induction supporting the claimed life expectancy up to 100,000 hours of operation. It should be noted that the manufacturers provide various warranty periods with their product, usually with a very conservative technology life cycle estimate.

Although the results of this assessment indicate a relatively long payback period for LED and Induction street lighting under current conditions, other performance attributes combined with operating cost savings may be such that longer than typically acceptable commercial payback periods are acceptable. As induction gains acceptance as a viable alternative to existing streetlight technology and LED street lighting technologies advancing at such a fast rate, expectations are that these luminaires will be more economical in the near future. Utility incentives could also help in the short-term to make the luminaires cost-effective for customers fueling earlier adoption of the new technologies.

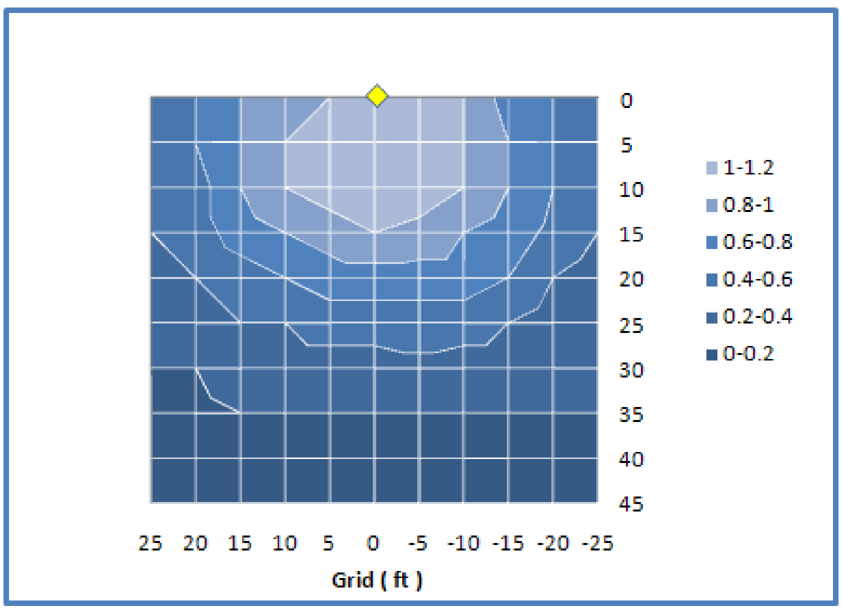
Based upon the findings of this project and others, it is important to note that each situation is different. It is highly recommended that prior to committing to a technology, readers conduct their own pilot or mini assessment of the available options to determine the economic feasibility of their particular project. This recommendation is encouraged by James Brodrick, Lighting Program Manager, US DOE, Building Technologies Program, in one of his recent Postings, stated, *"Outdoor lighting efforts seem to be at the top of the list for many local governments; all their reps are trying to learn about it as fast as they can. As I mentioned a few weeks ago, using LEDs for street lighting is not yet a slam-dunk. Evaluating and selecting street lighting products is a complex process, and learning from others before taking the plunge is highly recommended."*

Appendix A

Raw Illumination Data

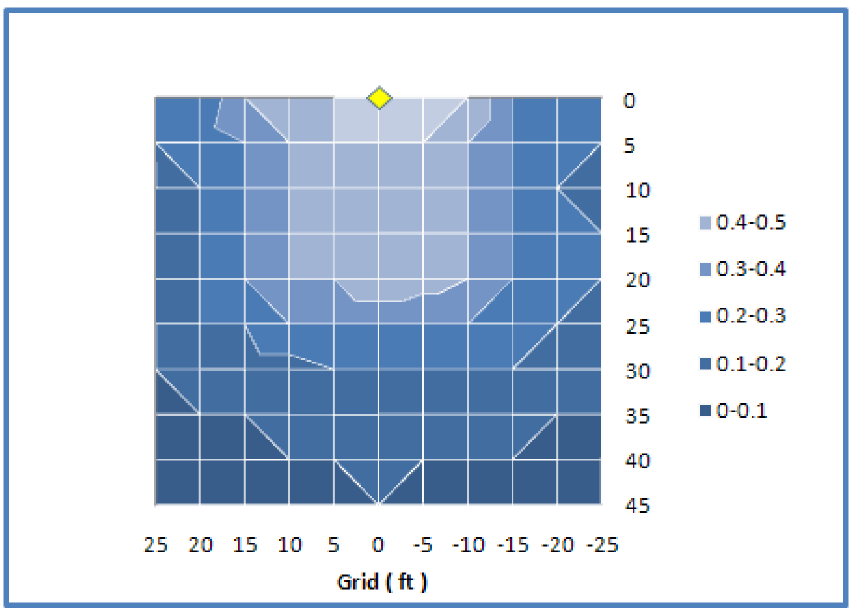
Lindsley Park Drive Light Illuminance Testing

					LPS Photopic FC						
Grid (ft)	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**	**20**	**25**
0	0.4	0.6	0.7	1	1.1	**1.1**	1	0.9	0.8	0.6	0.4
5	0.5	0.6	0.8	1	1.1	1.2	1.1	1	0.8	0.6	0.4
10	0.4	0.6	0.8	1	1.1	1.1	1.1	1	0.8	0.5	0.4
15	0.4	0.55	0.7	0.8	0.95	1	0.9	0.8	0.7	0.5	0.4
20	0.3	0.4	0.6	0.7	0.7	0.7	0.7	0.6	0.5	0.4	0.3
25	0.3	0.3	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0.3	0.2
30	0.2	0.3	0.3	0.3	0.35	0.3	0.3	0.3	0.3	0.2	0.2
35	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.1
40	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
45	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		avg	0.473636	max	1.2	min	0.1				



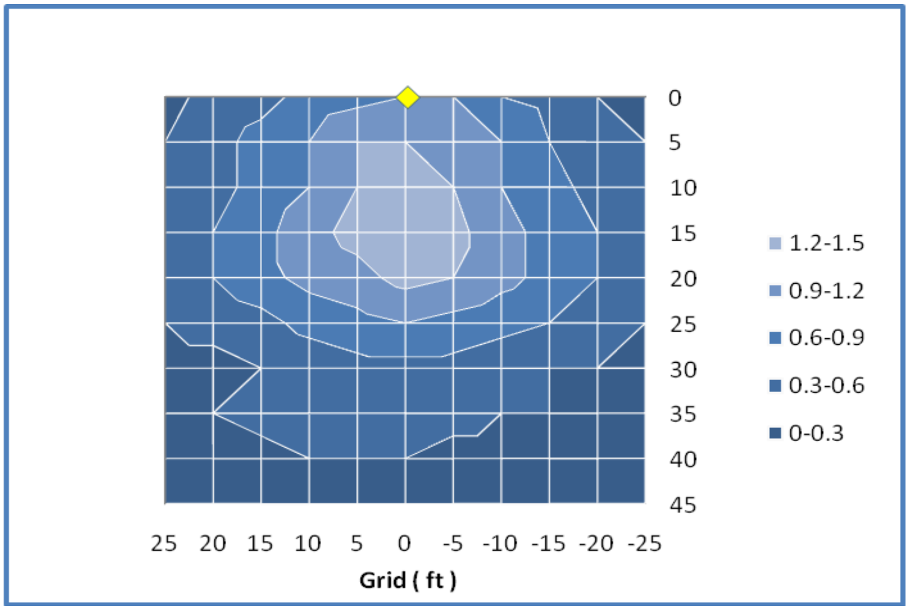
Lindsley Park Drive Light Illuminance Testing

					LPS Scotopic FC						
Grid (ft)	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**	**20**	**25**
0	0.2	0.3	0.3	0.5	0.5	**0.5**	0.5	0.4	0.4	0.2	0.2
5	0.2	0.25	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.25	0.2
10	0.15	0.2	0.3	0.4	0.4	0.45	0.45	0.4	0.3	0.2	0.15
15	0.2	0.25	0.3	0.4	0.45	0.5	0.4	0.4	0.3	0.2	0.15
20	0.2	0.25	0.3	0.4	0.45	0.5	0.4	0.4	0.3	0.2	0.15
25	0.15	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.15
30	0.1	0.15	0.2	0.2	0.2	0.2	0.2	0.15	0.15	0.1	0.1
35	0.1	0.1	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.1	0.05
40	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05
45	0.05	0.05	0.05	0.05	0.05	0.1	0.05	0.05	0.05	0.05	0.05
		avg	0.230455	max	0.5	min	0.05				



Lindsley Park Drive Light Illuminance Testing

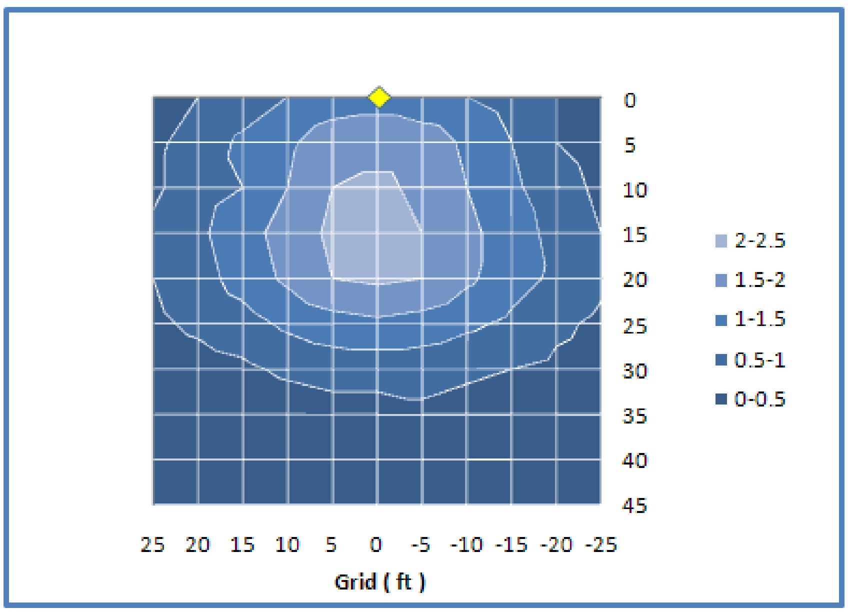
					LED Photopic FC						
Grid (ft)	**-25**	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**	**20**	**25**
0	0.2	0.3	0.5	0.6	0.9	0.9	0.8	0.7	0.5	0.4	0.2
5	0.3	0.4	0.6	0.9	1.1	1.2	1.2	0.9	0.7	0.5	0.3
10	0.3	0.5	0.7	0.9	1.2	1.3	1.2	0.9	0.7	0.5	0.3
15	0.4	0.6	0.8	1	1.3	1.3	1.3	1.1	0.8	0.6	0.4
20	0.4	0.6	0.8	1	1.2	1.3	1.1	1	0.8	0.6	0.4
25	0.3	0.4	0.6	0.7	0.8	0.9	0.8	0.7	0.5	0.4	0.3
30	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2	0.2
35	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.4	0.3	0.2
40	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.1	0.1
45	0	0	0	0.1	0.1	0.1	0.1	0.1	0	0	0
		avg	0.527273	max	1.3	min	0.1				



Lindsley Park Drive Light Illuminance Testing

LED Scotopic FC

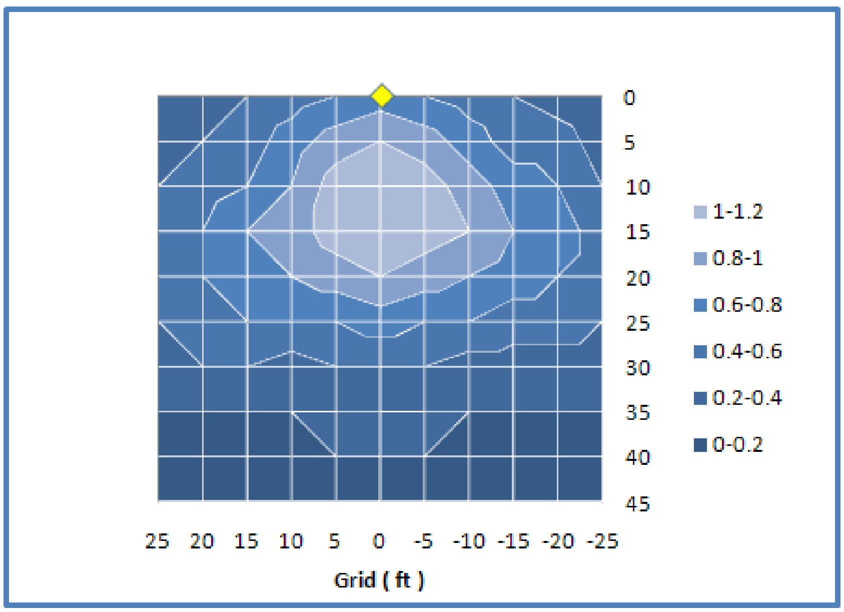
Grid (ft)	-25	-20	-15	-10	-5	0	5	10	15	20	25
0	0.2	0.5	0.8	1	1.1	1.3	1.2	1	0.7	0.5	0.2
5	0.3	0.5	1	1.4	1.8	1.8	1.8	1.4	1.1	0.7	0.4
10	0.4	0.7	1.1	1.5	1.9	2.1	2	1.5	1	0.8	0.4
15	0.5	0.8	1.3	1.6	2	2.1	2.1	1.7	1.3	0.9	0.6
20	0.6	0.9	1.2	1.6	2	2.1	2	1.6	1.2	0.8	0.5
25	0.4	0.6	0.9	1.1	1.3	1.4	1.3	1.1	0.8	0.6	0.4
30	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.6	0.4	0.3	0.2
35	0.1	0.2	0.2	0.3	0.4	0.3	0.3	0.2	0.1	0	0
40	0	0	0	0.1	0.1	0.1	0.1	0.1	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0
		avg	0.74	max	2.1	min	0.1				



Lindsley Park Drive Light Illuminance Testing

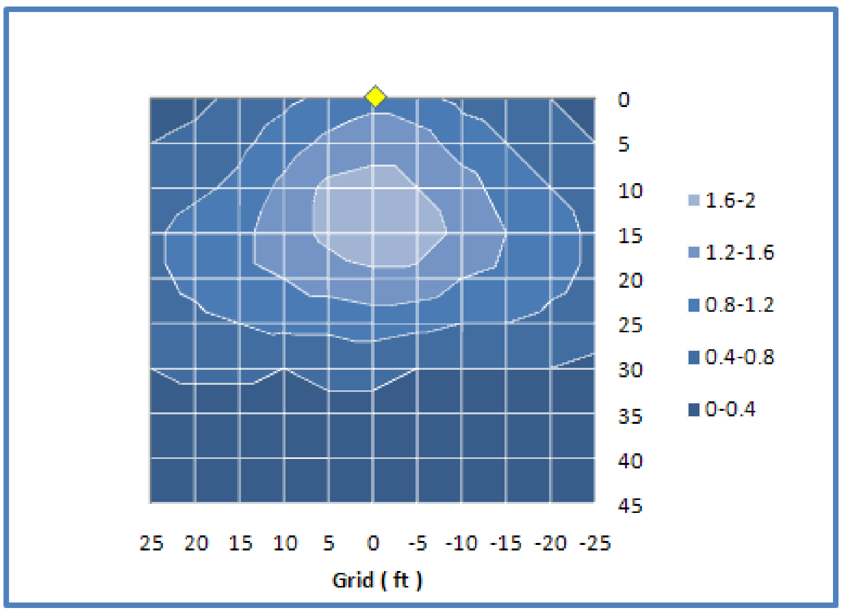
QL Photopic FC

Grid (ft)	-25	-20	-15	-10	-5	0	5	10	15	20	25
0	0.2	0.3	0.4	0.5	0.6	0.7	0.6	0.5	0.4	0.3	0.2
5	0.3	0.5	0.5	0.7	0.9	1	0.9	0.7	0.5	0.4	0.3
10	0.4	0.6	0.7	0.9	1.1	1.2	1.1	0.8	0.6	0.5	0.4
15	0.5	0.7	0.8	1	1.1	1.2	1.1	0.9	0.8	0.6	0.5
20	0.5	0.6	0.7	0.8	0.9	1	0.9	0.8	0.7	0.6	0.5
25	0.4	0.5	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.4
30	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.3
35	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
40	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
45	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
					avg	0.469091	max	1.2	min	0.1	



Lindsley Park Drive Light Illuminance Testing

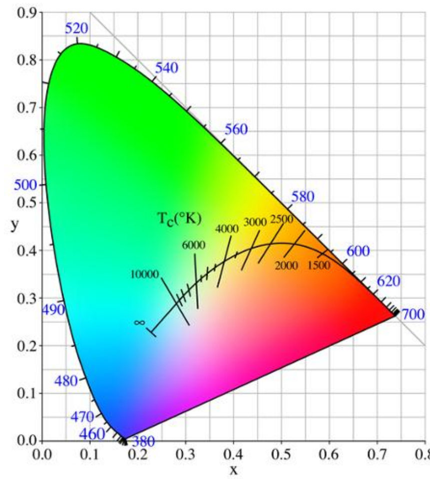
					QL Scotopic FC					
Grid (ft)	-25	-20	-15	-10	-5	0	5	10	15	20	25
0	0.2	0.4	0.6	0.7	0.9	1.1	0.9	0.7	0.5	0.3	0.2
5	0.4	0.6	0.8	1	1.4	1.4	1.3	1	0.7	0.5	0.4
10	0.6	0.8	1	1.4	1.6	1.8	1.7	1.3	0.9	0.7	0.5
15	0.7	1	1.2	1.5	1.8	1.9	1.7	1.4	1.1	1	0.7
20	0.7	0.9	1.1	1.2	1.5	1.5	1.4	1.2	1.1	0.9	0.7
25	0.6	0.7	0.8	0.8	0.9	1	0.9	0.9	0.8	0.7	0.6
30	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.4
35	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
40	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
45	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
					avg	0.661818	max	1.9	min	0.1	



Appendix B

Lighting Characteristic Discussion

Color Temperature



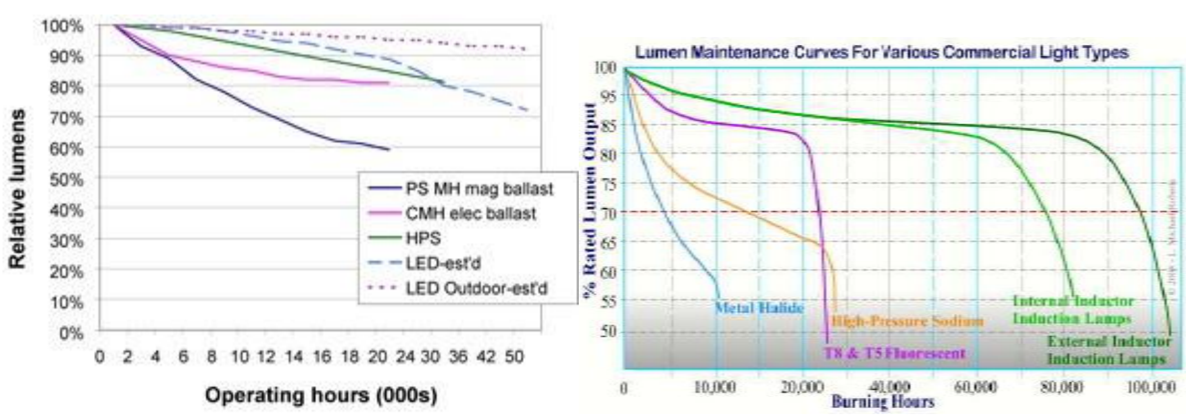
Temperature, or Chromaticity, is a measure in degrees Kelvin that indicates the appearance of a source. If a steel rod were placed into a fire it would first turn red, then orange as it heats up, until it finally turns bluish white. The temperatures of the rod and the color at each temperature describe the color of a source. It may sound like a contradiction, but low color temperature lamps have more red wavelengths, thus creating a warm feeling. High color temperature lamps have more blue wavelengths creating a cool feeling.

The figure to the left shows displays the International Commission on Illumination (CIE) chromaticity space, as well as the chromaticity of black-body light sources of various temperatures and lines of constant correlated color temperature. As the Kelvin Temperature increases from right to left into the chromaticity space, the color temperature changes from red to blue. Monochromatic wavelengths are shown in blue in units of nanometers around the outside of the space.

Lumen Maintenance

LED and induction lumen depreciation is minimal compared to conventional lighting sources. The provided charts below give typical lumen maintenance curves for various light sources corresponding to their estimates of lumen maintenance for burn hours. It should be noted however, that since the expected average annual nighttime temperature is below 25 degrees C, and no comparable luminaire has been operated for over 100,000 hours (nearly 25 years at 4,100 hours per year), no independent data is available to corroborate this figure.

Figure 14: Typical Lumen Maintenance Curves (Sources: www.eere.energy.gov & www.miserlighting.com)



Estimating LED and induction lamp life is problematic because the long projected lifetimes make full life testing impractical, and because the technology continues to evolve quickly, superseding past test results. Most manufacturers define useful life based on the estimated time at which light output will depreciate to 70% of its initial rating; often the target is 50,000 hours for interior luminaires, but some outdoor luminaires are designed for much longer useful lives of 100,000 to 150,000 hours. Luminaire manufacturers typically determine the maximum drive current and junction temperature at which the fixtures will produce greater than 70% of initial lumens for at least the target useful life in hours. If the lamps are driven at lower current and/or maintained at lower temperatures, useful life may be greatly increased.

In general, LEDs and induction lighting in well-designed luminaires are less likely to fail catastrophically than to depreciate slowly over time, so it may be difficult for a utility or maintenance crew to identify when to replace the luminaire. In contrast, poorly designed luminaires may experience rapid lumen depreciation or outright failure.

Thermal management is critical to the long-term performance of the LED, since heat can degrade or destroy the longevity and light output of the LED. The temperature at the junction of the diode determines performance, so heat sinking and air flow must be designed to maintain an acceptable range of operating temperature for both the LEDs and the electronic power supply. For induction lighting, the temperature sensitivity of the generator, which is a solid-state electronic device that can fail prematurely if it gets too hot, is also critical to long-term life. While HID systems can operate at temperatures of 90°C-105°C, induction systems are limited to the 70°C -75°C range. The luminaire manufacturer should provide operating temperature data at a verifiable temperature measurement point on the luminaire, and data explaining how that temperature relates to expected light output and lumen maintenance for the specific technology used.

All light sources experience a decrease in light output (lumen depreciation) over their operating life. To account for this, lighting designers use mean lumens, usually defined as luminous flux at 40% of rated life, instead of initial lumens. For LPS lamps, mean lumens are about 90% of initial lumens. Pulse-start MH mean lumens are about 75% of initial lumens, while ceramic MH lamps have slightly higher mean lumens, around 80% of initial lumens.

Appendix C

Pacific Gas & Electric Project Summaries

LED Street Lighting - Phase II, Oakland, CA

ETCC Project Number PGE 0714

This report summarizes an LED street lighting assessment project conducted to study the applicability of LED luminaires in a street lighting application. In this project, LED lights replaced regular high pressure sodium (HPS) streetlights on several streets in Oakland, California. Side-by-side assessments tested energy consumption, potential cost savings, and lighting quality. Quantitative and qualitative light and electrical power measurements were taken on all streets, and economic costs estimated and qualitative satisfaction gauged with a resident survey.

For more information:

http://www.etcc-ca.com/images/stories/pdf/ETCC_Report_460.pdf

LED Street Lighting - San Francisco

ETCC Project Number PGE 0727

This report summarizes an assessment project conducted to study the performance of light emitting diode (LED) luminaires in a street lighting application. The project included installation of four manufacturers' LED street lights on public roadways in San Francisco, California. Quantitative light and electrical power measurements as well as surface and overhead photographs were taken to compare base case high pressure sodium (HPS) performance with that of the LED replacement luminaires. Estimated economic performance of the LED luminaires as compared to HPS street lights was also calculated and qualitative satisfaction with the LEDs was gauged through a resident survey.

For more information:
http://www.etcc-ca.com/images/stories/et_report_for_led_street_lighting_sf.final.011509.pdf

LED Street Lighting and Network Controls - San Jose

ETCC Project Number PGE 0913

This report summarizes an assessment project conducted to study the performance of light emitting diode (LED) luminaires with network controls in a street lighting application. The project included installation of LED street lights with network controls on public roadways in San Jose, California. Quantitative light and electrical power measurements as well as surface and overhead photographs from a maintenance bucket truck were taken to compare base case low pressure sodium (LPS) performance with that of the LED replacement luminaires. Network controls functionality was also tested and qualitative satisfaction with the system was gauged through a user survey. Estimated economic performance of the network-controlled LED street lighting system was compared to that of the incumbent LPS streetlights.

For more information:
http://www.etcc-ca.com/images/pge_0913_san_jose_efficient_street_light_report_final.pdf