LED Street Lighting

Host Site: City of Sunnyvale

Final Report Prepared in support of the City of Sunnyvale

City of Sunnyvale, California

De Anza College Environmental Studies Department

LED Street Lighting
Sunnyvale, CA

Study Participants:
City of Sunnyvale, California
De Anza College Environmental Studies Department
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Preface

The City of Sunnyvale, California, in accordance with city goals to achieve sustainability, initiated a study to evaluate the replacement of all city streetlights with high-efficiency light-emitting diodes (LED) models. The resulting report is modeled after reports submitted to the DOE Solid-State Lighting GATEWAY Program and on the US Department of Energy Solid-State Lighting GATEWAY Demonstration Program template and studies already published on the GATEWAY site including studies done in San Francisco and Oakland, CA. The city recognized that lighting is a significant fraction of its total electrical usage – 9200 high-pressure sodium (HPS) streetlights drawing between 70 and 200 watts apiece for an average of 11 hours per day – and streetlight efficiency is therefore crucial to the city's progress in sustainability. Pacific Gas and Electric (PG&E) has recognized the importance of LED lighting through its Emerging Technologies programs and the recent establishment of a favorable electrical rate for LED streetlights. The Sunnyvale LED streetlight study culminated in the evaluation of products from three LED lighting vendors compared to existing HPS luminaires installed in a test area located on Fremont Avenue; a 4 - 6 lane roadway with bicycle lane and pedestrian sidewalk in the city. The competitive products evaluated are referred to hereinafter as Vendor A, B, and C, respectively while HPS luminaires are referred to as Vendor D.

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Executive Summary

Two of the three light-emitting diode (LED) streetlight luminaires evaluated for this report showed excellent potential as replacements for existing high pressure sodium (HPS) luminaires.

Project Summary

Three specific LED streetlight luminaires from three different vendors (denoted by Vendor A, Vendor B, and Vendor C) were evaluated as possible replacements for the city's existing HPS streetlights (denoted as Vendor D). Lighting quality, economic, safety, energy savings, and environmental aspects were considered. This is an important project for Sunnyvale in meeting its sustainability objectives: streetlights account for over 2.4 million pounds of CO_2 emissions per year. [1]

To bound the scope of the evaluation, three specific LED Type III streetlight luminaires provided by three different vendors, along with the type of high pressure sodium luminaires in common use within Sunnyvale were field measured and computer modeled for a specific roadway. Aladan+Plus software was used for computer modeling. Once computer models were correlated with field measurements, computer results were primarily used for the technical aspects of the evaluation. The ANSI/IESNA RP-8-00 Roadway Lighting Standard served as the primary evaluation method for rating lighting quality. Controlled digital photography was utilized to evaluate color rendering. Energy savings were field measured. Economic results were based on PG&E electric rates, vendor-supplied information, and current city streetlight practices and labor rates. Sunnyvale citizens provided feedback on the new streetlights via a survey.

Fremont Avenue in Sunnyvale, a 4 - 6 lane roadway with bicycle lane and pedestrian sidewalk with streetlights installed on a central median was chosen for the test site. ANSI/IESNA RP-8-00 recommended measurement practices were followed. Field measurements were performed on two separate nights in March 2009 – one for LED luminaires and one for high pressure sodium.

Readers should note that the evaluation involved specific products in a specific roadway scenario with a specific methodology. Other choices could be made.

Lighting Quality

From a lighting quality standpoint based on the illuminance method of ANSI/IESNA RP-8-00, Vendor A and B LED products were found to be standard conformant in all metrics. The high pressure sodium lights were standard conformant and in several metrics, were seen as greatly over lighting portions of the roadway (with consequent energy expense).Vendor C fell short of standard

[1] Sunnyvale Council Policy Manual 3.7.2 Reduction of Carbon Dioxide Emissions from City Operations

conformance – the particular model evaluated was not a good fit for the Fremont Avenue test area. Type III streetlight distribution pattern was shown to be superior for the test area over Type II.

Light-loss was evaluated utilizing a light-loss factor of 0.63 based on normal LED performance degradation over time, dirt and wear. All vendors remained standard conformant for the roadway through luminaire end of life, however, all LED vendors fell short of sidewalk average illuminance at end of life. LED correlated color temperature (CCT) ranged from 4800K to 5900K compared to 2000K for high pressure sodium. Digital photographs at the test site showed that LED streetlights rendered colors better than high pressure sodium.

Energy Summary

Measured energy savings of LED streetlights over high pressure sodium ranged from 56% to 62% with Vendor B showing the strongest result. Given the city's annual streetlight usage of 5.3GWh, LEDs have huge potential for reducing electrical consumption and resulting CO_2 emissions. Luminaire efficacy of LED streetlights ranged from 47 to 66 lumens/watt with high pressure sodium measured at 60 lumens/watt. Vendor B LED coefficient of utilization (fraction of light actually reaching the roadway area) slightly exceeded high pressure sodium.

Economic Summary

Both new construction and retrofit economics were studied for LED models including 2 additional lower powered models for each vendor. New construction LED economics are good while retrofit economics are satisfactory for LED Vendors A and B. LED products showed significant energy savings and even larger maintenance savings over high pressure sodium with a disadvantage of higher first cost. Expected future price reductions as LEDs mature should further advantage LEDs. Vendor B showed the strongest economic return with simple paybacks in the 0.8 – 3.6 year range for new construction and 4.9 – 6.1 years for retrofit.

Environmental and Safety Summary

LEDs performed well in environmental and safety analysis. LED streetlights emitted far less light at high angles (80-90 degrees vertical) than high pressure sodium, reducing the potential for glare which is an important safety issue. LED products outperformed high pressure sodium in reducing light trespass with Vendor B having an edge. The city of Sunnyvale contributes to overall sky glow affecting the Lick Observatory as well as amateur stargazing – the more efficient LED distribution of light should reduce Sunnyvale's contribution to overall sky glow. Finally, in contrast to LEDs, high pressure sodium lamps must be treated as universal waste due to mercury content.[2]

[2] Managing Universal Waste in California. Page 2, section 3
http://www.dtsc.ca.gov/HazardousWaste/EWaste/upload/HWM_FS_UWR.pdf

Customer Acceptance

Surveys of Sunnyvale citizens who viewed the test area showed 79% preferred or strongly preferred LED streetlights over high pressure sodium with Vendor A receiving slightly higher ratings than the other LED vendors.

Overall Summary

Overall, Vendor A and B LED products demonstrate strong potential as replacements for high pressure sodium streetlights. Vendor B showed the strongest results overall based on good results in all categories and the best results in energy savings. The Vendor C product we evaluated was a mismatch for our particular roadway scenario but may perform well in other situations.

Project Background

Program Overview

The City of Sunnyvale is in the second phase of assessing the feasibility of replacing the current high-pressure sodium (HPS) streetlights with light emitting diode (LED) luminaires. The first phase[3] of this evaluation compared several competitive products against a set of criteria, choosing three of them for further evaluation. The second phase assessment involved the installation of these three products on Fremont Avenue between Hollenbeck and Mary Avenues. A total of six units per product were installed on twin-arm poles. Pole spacing for Vendors A, B and D of the monitored luminaires measured 143 feet apart. Pole spacing for Vendor C measured 137 feet. All monitored luminaires had a mounting height of 31 feet 6 inches. Field-testing was designed to determine if the new LED technology meets the Standard Practice approach for designing a roadway lighting system, meeting ANSI/IENSA RP-8-00 Roadway Standards with an emphasis on pedestrian and bicyclist safety. (IENSA is the Illuminating Engineering Society of North America)**.**

The City of Sunnyvale chose to evaluate LEDs Type III distribution with full cutoff luminaires. LED streetlight performance was evaluated in four areas: Lighting Assessment in conformance with the ANSI/IESNA RP-8-00 Standards, Electrical Energy Use, Safety and Environmental, and Light Pollution.

Technology

An estimated 94% of roadway lighting in the U.S. is High-Intensity Discharge (HID) lamps and 59% of those are HPS lamps.[4] The introduction of LED streetlights has gained momentum over the years as a viable replacement for HID lights such as HPS streetlights because of their low energy usage, long predicted lifetime[5], and reduction in maintenance cost. LEDs also provide improved light quality that enhances road safety. Initial LED cost is higher than HPS, but reduced energy use and lower maintenance costs are a strong argument in favor of LEDs.
An LED is a semi-conducting device that produces light when an electrical current flows through it. It consists of a chip of semi-conducting material treated to create a structure called a p-n (positive-negative) junction. Current flows from the n-side (cathode) to the p-side (anode) when

[3] Appendix E
[4] Navigant Consulting, Inc. (2002). “US Lighting Market Characterization, Volume I.” Table 5-17 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lmc_vol1_final.pdf
[5] "Pre-Qualified LED Fixtures." *ENERGY STAR Qualified Commercial LED Lighting for PG&E Rebate & Incentive Programs*. Version Last Modified: 02/17/2010 http://www.energystar.gov/index.cfm?c=ssl.pr_commercial. ENERGY STAR Solid-State Lighting Luminaire Program Requirements, n.d. Web. 17 June 2010. <www.pge.com/includes/docs/pdfs/

the barrier voltage inherent to the semiconductor materials and the various dopants used in the fabrication of the LED is exceeded. Since very little heat is created, and the voltages and current are relatively small, the resulting emission of photons is efficient compared to the power input. The atomic characteristics of these materials determine the color (frequency) and efficiency of a device. Today, the standard white LED uses a blue LED that acts as a stimulator for its phosphor packaging material. These phosphors are the key to the broad spectrum of light emitted commonly called white light.[6]

Current LED technology has the potential to provide significant electricity savings for streetlights. As will be discussed in this report, depending on lighting luminaire design and how the systems are deployed in the field, an energy savings of 33 to 66 % can be realized.

Advantages:

- ✓ Substantial energy savings.
- ✓ Reduced maintenance and operational costs.
- ✓ Estimated luminaire life of 50,000 hours.
- ✓ Light output can be directed and controlled.
- ✓ Improve light quality for improved visibility and safety.

Project Objectives

The City's objectives for this study were to compare LED Type III distribution / full cutoff luminaires against the performance of the 200W cobra-head style HPS Type II / medium cutoff luminaire lighting with the performance of HPS Type III luminaire as they affect:

- Safety
- Environmental Aspects
- Energy savings
- Conformance with ANSI/IESNA RP-8-00 roadway lighting standards
- Economic performance.

Safety is a primary concern for the City, so assessment included roadway, bike lane and sidewalk illuminance measurements. IESNA guidelines for field measurements were followed, with conditions and exceptions noted. Economic performance was evaluated using a simple payback and NPV methods for both retrofit and new construction values.

Efficient street lighting is part of the City of Sunnyvale's Framework for Environmental Sustainability. City policy mandates the use of efficient street lighting, hence, the need to evaluate the products available to determine the best choice to meet these goals.

[6] HyperPhysics (©C.R. Nave, 2006). Carl R. (Rod) Nave. Department of Physics and Astronomy, Georgia State University http://hyperphysics.phy-astr.gsu.edu/hbase/Electronic/led.html

Lighting Assessment

Consistent with the desire of the city to focus on safety, the ANSI/IESNA RP-8-00 roadway lighting standard was chosen as a primary method of assessing lighting quality. The standard specifies lighting metrics covering a variety of different roadway types and carefully defines a measurement methodology to validate conformance. Because there are so many roadway configurations, each of which has a particular lighting requirement, choices had to be made to bound the study. As a representative roadway configuration, the city chose a particular stretch of Fremont Avenue, a 4 - 6 lane roadway with a median island and center-mounted twin-armed streetlight poles. The evaluation covered only this roadway scenario with specific lighting products provided by the vendors. However, with interpretation, the results are useful for considering other roadway configurations in the city and other lighting product choices.

One additional choice helped bound the study. The ANSI/IESNA RP-8-00 standard allows the choice of three different evaluation methods for determining standard conformance. Although computer modeling was used for all three methods, the illuminance method was chosen for the field evaluation due to instrument availability and simplicity of the measurement process.

Other aspects of lighting quality were also addressed as part of the study. Correlated color temperature was measured. Controlled digital photography was employed to evaluate color rendering differences between the lights.

Electrical Energy Use

The City of Sunnyvale finds the preservation of natural resources through the use of energy-efficient activities to be of great importance to the citizens and businesses of Sunnyvale. Formal City Council policy includes a commitment to "Use energy-efficient streetlight and traffic signal systems."[7] The City also adopted a goal of 20 % CO_2 emissions reduction for City operations from 1990 levels by 2010.

In 2008 the City of Sunnyvale reported the annual electric usage for streetlights was approximately 5.3 GWh. Resulting CO_2 emissions were projected at 1100 metric tons.[8] Streetlight electrical usage is clearly significant.

Actual electrical energy usage was measured for each streetlight and compared as part of the study. The financial cost of energy usage was analyzed based on the new PG&E LS-2 Rate Schedule[9].

[7] Sunnyvale Council Policy Manual 3.5.1 Energy

[8] Sunnyvale Council Policy Manual 3.7.2 Reduction of Carbon Dioxide Emissions from City Operations

[9] Appendix C

Methodology

Host Site Information

Eighteen LED luminaires from three competitive products were installed on Fremont Avenue in Sunnyvale, California, between Mary Avenue and Hollenbeck Avenue. The LED luminaires were installed on streetlight poles in the center median of Fremont Avenue, where the roadway classification type is Local Street and pedestrian classification is low with Low Density Residential. Two luminaires were mounted per pole on eight-foot arms. The roadway in that section of Fremont Avenue is mostly two lanes in each direction, with a short section of three lanes, and includes some turn lanes. The width of the roadway in each direction varies from 34 feet to 43 feet. In addition to the two traffic lanes on each side there is a bicycle lane and a paved sidewalk. Three test areas were established, one for each LED luminaire manufacturer. Each test area consisted of three adjacent poles with Type III full cutoff LED luminaires from the same manufacturer with measurements taken on the westbound lanes of Fremont Avenue. The middle LED test area was subsequently used to test Type III High-pressure Sodium (HPS) semi-cutoff luminaires using the same measurement points.

The luminaires have a height of approximately 31 feet 6 inches above the road surface. Pole spacing is approximately 143 feet in two test areas and 137 feet in the third test area. Luminaires in the test area did not have backlight control. Thus both luminaires on each pole provided light to the westbound lanes where measurements were taken. Sunnyvale typically uses semi-cutoff Type II HPS luminaires. The city has been interested in Type III luminaires for the future and decided to specify Type III luminaire for this test. Photometric plots for the lights studied showed a Type III luminaire light distribution pattern which is fairly square and throws light farther across the street than Type II luminaire distribution which is more rectangular. The difference between Type II and Type III luminaire light distribution patterns for the Fremont Avenue test site will be discussed reporting more detail later in this report.

The test area on Fremont Avenue is typical of comparable streets in Sunnyvale. The section selected provided a fairly consistent roadway where several types of LED luminaires could be evaluated under the same roadway conditions. Very little extraneous light was present from the surrounding area. To minimize headlight interference, traffic was fully blocked from entering westbound lanes and measurements were taken only when eastbound lanes were clear of traffic.

Establishing The Measurement Grid

There were challenges in establishing a measurement grid in the test area. The roadway changed from six lanes to four lanes on the west end, left-turn lanes were present resulting in poles with shorter arms and different offsets from the roadway, and trees caused shading in one test area. The result was that not all luminaires were exactly aligned along the median but were generally within two feet of a line along the center of the median. The varying roadway width was dealt with by assuming a uniform lane width, conforming to the narrowest section of Fremont Avenue. A uniform measurement grid was laid out accordingly to allow a fair comparison of the three

sections of the test area - the major difference being the narrower pole spacing for Vendor C (137' versus 143'). The varying roadway width combined with a uniform measurement grid meant some of the sidewalk measurement points were actually laid out on the roadway.

Monitoring Plan

The Monitoring Plan consisted primarily of illuminance measurements and time series electrical power measurements. These included:

- Horizontal and Vertical Photopic Illuminance
- Correlated Color Temperature
- Voltage, Current, True RMS Power (Watts), RMS Volt-Amps, and Power Factor
- Luminaire temperature
- Controlled digital photographs of objects to illustrate qualitative performance

Measurements were made over two nights. LED luminaires were measured first. Measurements of HPS luminaires were taken on a subsequent visit two weeks later, after luminaires in Vendor A test area were replaced with HPS luminaires.

HPS and LED luminaires were burned-in for a minimum of 100 hours before being tested. The exception was one outside pole LED luminaire from Vendor C that failed, requiring replacement shortly before the scheduled test.

LED luminaires were measured on Thursday March 12, 2009 beginning at 11:30pm following layout of the measurement grid and concluding at 2:00am. The weather was clear, wind was less than 5 mph and the ambient temperature ranged from 41 to 48 degrees F. In an adjacent, dark area the instruments measured an illuminance contribution from waning gibbous moon/sky glow of 0.02 footcandles (fc). The HPS luminaires were tested two weeks later on Thursday March 26,

2009 beginning at 11:00pm and concluding at 12:30am under similar weather conditions, at ambient temperatures ranging from 53 to 58 degrees F, with new moon/sky glow measured at 0.01fc.

Table 1: Instruments

Name	Calibration Date
Konica Minolta Illuminance meter T-1H	6/12/2008
Konica Minolta Chroma Meter CL-200	10/10/2007
Oregon Scientific Digital Thermometer THR-138	Unknown
Fluke 62 Mini-IR Thermometer	Unknown
Nikon D50 Digital SLR Camera	NA

The Pacific Energy Center of Pacific Gas and Electric in San Francisco made available the T-1 Illuminance meter, Chroma meter, tripods, and extension trigger. All measurements of a given type were made with the same light meter and the two light meters agreed within 2-3% for a set of sample illuminance measurements.

Grid Setup

Illuminance measurements were taken in each test area on a grid measuring approximately 150 feet x 42 feet. The mid-point of the grid in the roadway direction was aligned with the middle luminaire of each set of three similar luminaires.

The measurement points in each grid conformed as closely as possible to the requirements of the ANSI /IESNA RP-8-00 measurement standards.[10] In the roadway direction (East-West), the measurement points were set at 1/10 the spacing between luminaires (approximately 14.3' for Vendors A, B and D and 13.7' for Vendor C). In the transverse direction (North-South - across the roadway) the spacing between measurement points was seven feet (half the width of a lane). This provided four rows of measurement points across two lanes with the innermost row beginning 3.5 feet from the median curb. An additional row of measurement points, 35 feet from the first row, was used to measure illuminance at the sidewalk. A total of 50 measurement points within each grid were marked on the roadway and sidewalk (see Appendix B). A 300-foot measuring tape, pre-marked with key intervals was used to establish and mark precise locations for measurements. A laser level and building square were used to establish square and straight lines for marking the grid. To minimize the number of street closures, grid layout and measurement were done on the same night. This required careful preparation and rehearsal to achieve an elapsed time of 45 minutes to complete the layout of each grid section.

[10] See IESNA Publication LM-50-99 Photometric Measurements of Roadway Lighting Installations
The document recommends 3 luminaire cycles - the monitored cycle and one complete cycle on either side. Due to the availability of only 3 luminaires of each type per test area, one full cycle around the center luminaire was monitored, with 1/2 cycle on either side of it.

Horizontal Illuminance

Luminaires were mounted approximately 31feet 6 inches above the roadway on 8-foot mounting arms extending from poles in the roadway median Horizontal illuminance levels were taken with a Minolta T1 Illuminance meter. The meter had a photopic detector mounted on a tripod at a height of 18 inches above ground. It was operated remotely using a 6 foot 6 inches trigger cord. There was no light source behind the operator. The operator, dressed in dark clothing, took readings from a crouched position six feet away from the light meter to minimize any effects on the readings. The meter has a precision of 0.01 foot-candles. The meter was leveled before taking each measurement using the tripod bubble levels. Although the ANSI /IESNA RP-8-00 standard specifies measurements 6 inches above the pavement, due to equipment limitations, we measured at 18 inches. However, modeling shows that measurements at 18 inches should introduce no more than a 1% error in LED average illuminance for purposes of establishing standards conformance.

Vertical Illuminance at Sidewalk

Vertical illuminance levels at the sidewalk were taken with a Minolta Chroma Meter CL200 mounted on a tripod at a height of 4 feet-6 inches as per ANSI /IESNA RP-8-00 standard. The meter was leveled using a bubble level before recording each reading.

Correlated Color Temperature

Correlated Color Temperature (CCT) values were recorded at each luminaire using the Minolta Chroma Meter CL200. The meter was unable to calculate CCT for the high pressure sodium luminaires due to meter limitations in measuring CCT in the range 2000K and below. Instead, for HPS luminaires, X, Y, Z tristimulus values were recorded and later converted to CCT. CCT was measured at three different positions for each luminaire and averaged to obtain the result.

Computer Modeling

The roadway module of the ALADAN+Plus lighting software package was used to model the Fremont Avenue test site. The actual test site has a number of irregularities that could not be modeled by ALADAN+Plus. Experiments showed that these irregularities yielded very small differences and could safely be ignored. ALADAN+Plus calculated all of the ANSI/IESNA RP-8-00 standard metrics for all three standard methods (illuminance, luminance, and small target visibility), with the exception of vertical illuminance for the sidewalk.

Computer modeling of luminance relies on a classification of pavement type to determine the actual reflectance of the pavement. R3 was used to determine the approximate reflectance as suggested by ANSI/IESNA RP-8-00 but was not validated by measurement. Therefore luminance and small target visibility metrics may have a higher degree of error in the calculations than illuminance. Illuminance is independent of pavement characteristics.

Measurement Results

Given the successful correlation between field and modeled results for LED vendors, except for vertical illuminance all results presented below are modeled results unless specifically noted. Vertical illuminance for the sidewalk is always field-measured. Raw field measurements are listed in Appendix A. Vendor A, B, and C products are LED luminaires. The Vendor D product is a high pressure sodium luminaire.

Field measurements were done centered around the middle pole in each test area. However, the software computed results *between* two poles. A simple transposition of locations allows conversion between these two methods. For simplicity, all results are mapped to equivalent locations between two poles.

ANSI/IESNA RP-8-00 Standard Metrics

The ANSI/IESNA RP-8-00 standard lists a variety of metrics required to demonstrate standard conformance for continuously lighted roadways - organized around three different methods, any one of which can be used to demonstrate conformance. ANSI/IESNA RP-8-00 also lists metrics for sidewalk illuminance. Illuminance was chosen as the primary method for this report although the complete listing of metrics are shown for completeness

Table 2 below lists the modeled results for a roadway matching the Fremont Avenue test site. Roadway type is local street and pedestrian classification is low. The ANSI/IESNA RP-8-00 column in the table lists the standard requirement. As can be seen, Vendors A and B are standard conformant. Vendor D (HPS) is standard conformant in all metrics with average illuminance far larger than required for standards conformance. Vendor C underperforms in several of the metrics for the test scenario.

Note: In the tables below, results that meet ANSI/IESNA RP-8-00 standards are green; those that fail to meet red. General guidelines are given for other parameters '>' mean bigger values are better and '<' means smaller values are better. Typically bigger illuminance values are better, while smaller ratios are better, smaller numbers indicate better uniformity.

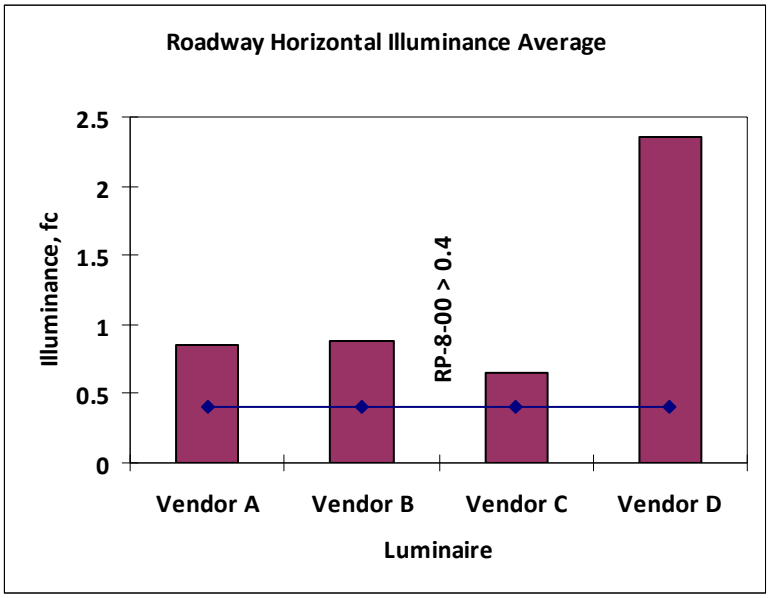
Table 2: ANSI/IESNA RP-8-00 Roadway Metrics

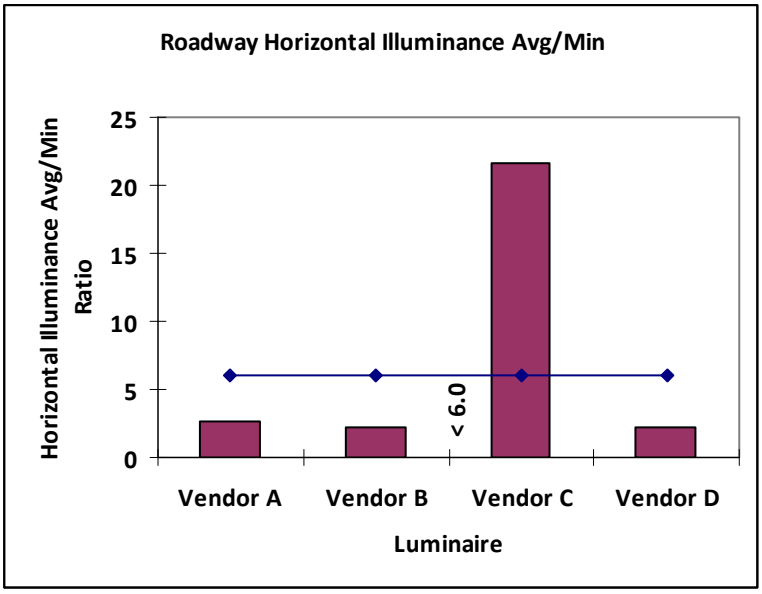
Location on Roadway			Middl	West	East	Midd
Results (model)	**Unit**	**RP-8-00**	**A**	**B**	**C**	**D**
Pole Spacing	**Ft**	**NA**	**143**	**143**	**137**	**143**
Horizontal Illuminance Average	Fc	**>0.4**	**0.85**	**0.88**	**0.65**	**2.35**
Horizontal Illuminance Average/Min		**<6**	**2.59**	**2.21**	**23.02**	**2.20**
Roadway Luminance, Average	cd/m^2	**>0.3**	**0.57**	**0.57**	**0.29**	**2.25**
Roadway Luminance, Average/Min		**<6.0**	**2.11**	**2.32**	**7.91**	**2.63**
Roadway Luminance, Max/Min		**<10.0**	**4.15**	**4.81**	**19.79**	**4.71**
Veiling Luminance Ratio, VL max/L avg.		**<0.4**	**0.26**	**0.28**	**0.15**	**0.28**
Weighting Average Visibility Level		**>1.6**	**2.81**	**2.83**	**3.59**	**3.30**

Key: a > means bigger is better, > x means value must exceed x to be ANSI/IESNA RP-8-00 conformant
Modeled results are initial lumens, RP-8-00 standard mandates maintained lumens (see section on Light Loss)

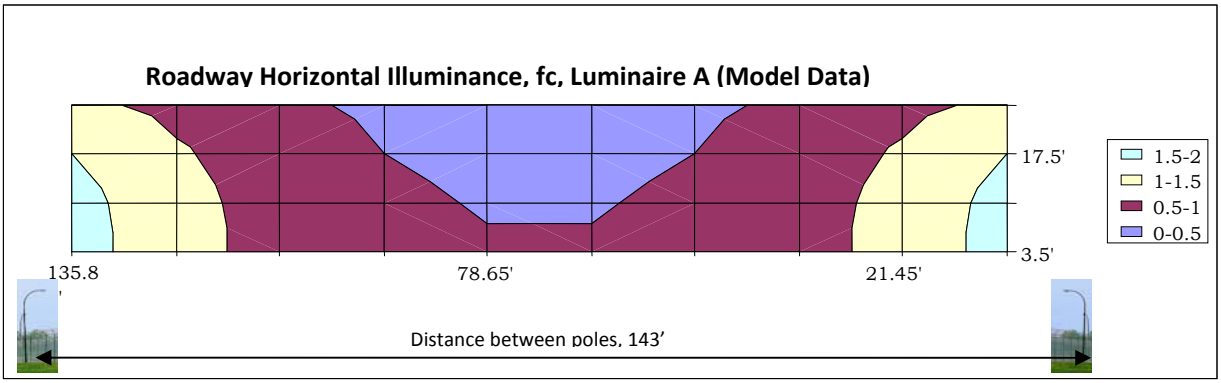
Key results for roadway illuminance are shown graphically below. Both average and uniformity of illuminance are shown. Average illuminance is calculated by averaging the foot-candles of horizontal illuminance across all of the grid points and needs to be above a standard level to maintain adequate visibility. Uniformity is calculated as the ratio of the average horizontal illuminance to the minimum. The standard provides limits on how big the ratio is allowed to be. A smaller uniformity ratio means more uniform lighting across the pavement surface.

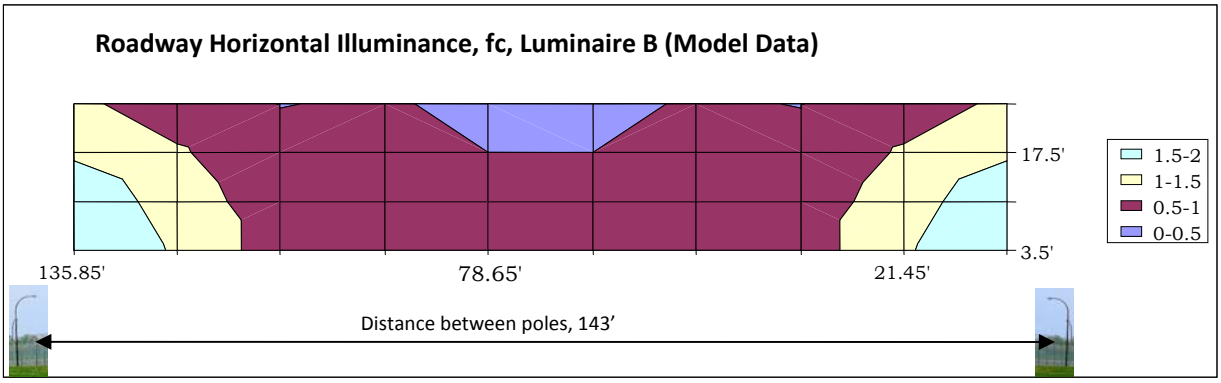
Table 3: Roadway Horizontal Illuminance

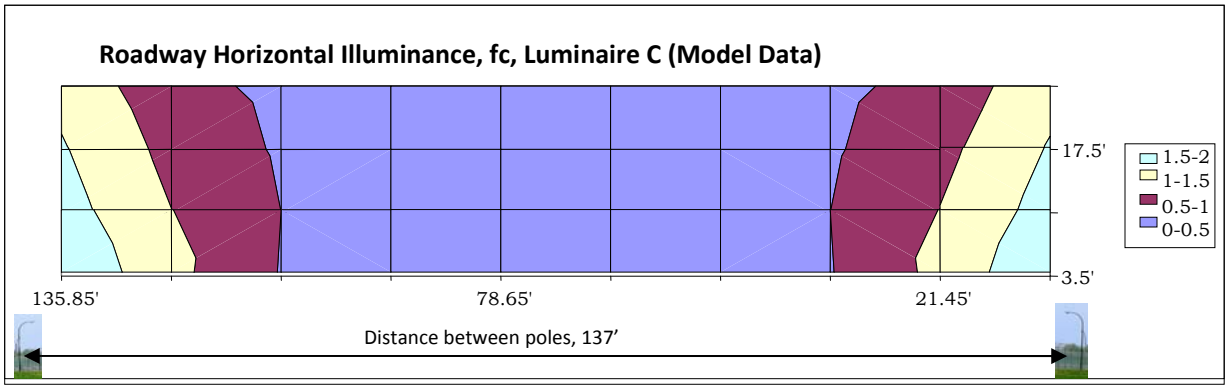


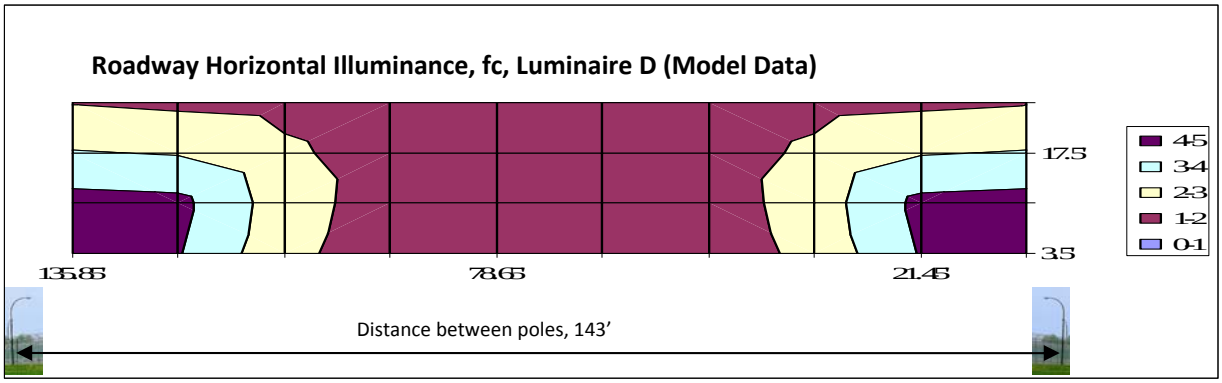


Comparison of the contour plots of roadway horizontal illuminance for all the luminaires indicates that roadway illuminance of LED luminaires (A - C) range from 0 – 2fc, while that of D (high-pressure sodium) range from 1-5fc. Vendor B has the least area less than 0.4fc illuminance. Vendor C has the most area less than 0.4fc among the LEDs measured. IESNA required average is 0.4fc.









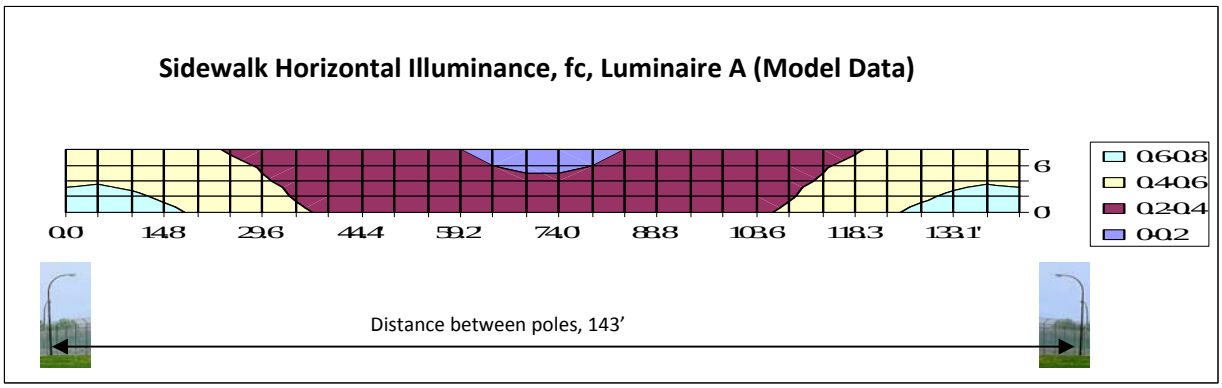
Pedestrian Safety

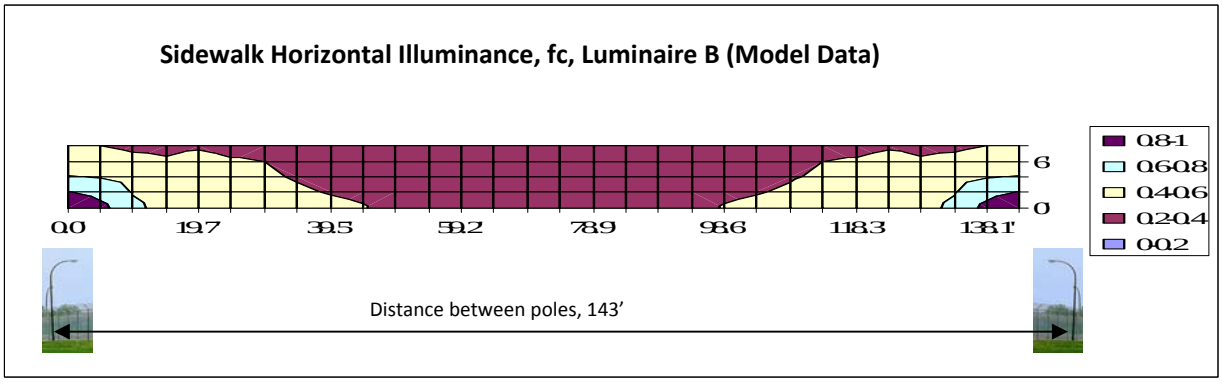
Pedestrian safety is an important aspect for roadway street lighting for the City. Sidewalk illumination was therefore evaluated. ANSI/IESNA RP-8-00 specifies standard metrics for the sidewalk, including horizontal and vertical illuminance. Table 4 below lists modeled ANSI/IESNA RP-8-00 metrics for the sidewalk. Low Pedestrian Conflict and Low Residential Density are assumed

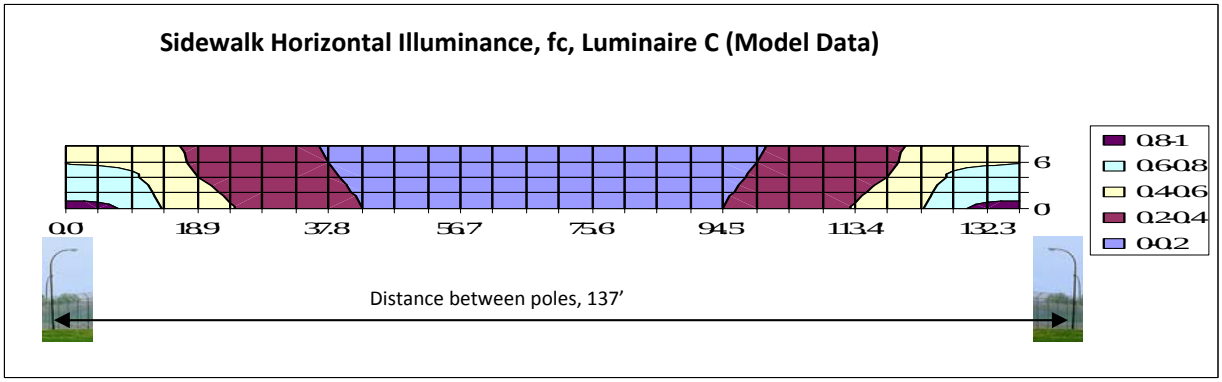
Table 4: Sidewalk Illuminance

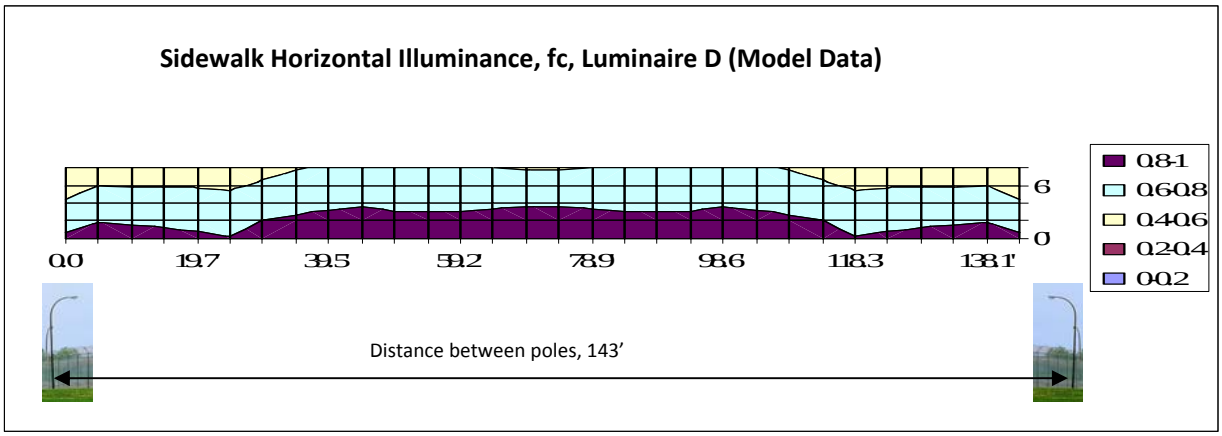
Results	Unit	RP-8-00	A	B	C	D
Sidewalk Horiz. Illuminance Average	fc	**>0.3**	**0.39**	**0.40**	**0.32**	**0.73**
Sidewalk Horiz. Illuminance Average/min		**<6.0**	**2.17**	**1.82**	**3.56**	**1.62**
Sidewalk Vertical Illuminance, min	fc	**>0.08**	**0.25**	**0.39**	**0.11**	**0.75**

Based on the results obtained all vendors are in conformance with ANSI/IESNA RP-8-00 values for sidewalk illuminance.




Sidewalk Horizontal Illuminance, fc, Luminaire B (Model Data)
0.0
19.7
39.5
59.2
78.9
98.6
118.3
138.1'
6
0
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2
Distance between poles, 143'


Sidewalk Horizontal Illuminance, fc, Luminaire C (Model Data)
0.0
18.9
37.8
56.7
75.6
94.5
113.4
132.3
6
0
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2
Distance between poles, 137'


Sidewalk Horizontal Illuminance, fc, Luminaire D (Model Data)
0.0
19.7
39.5
59.2
78.9
98.6
118.3
138.1'
6
0
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2
Distance between poles, 143'

Correlation Between Field and Modeled Results

ALADAN+Plus software was used to model the roadway with the photometric data provided by the vendors. Horizontal illuminance data from the computer model and field were compared for all the vendors. In the case of Vendor B, field data was modified by replacing the data affected by tree shading with data from symmetric measurements.

Goodness of fit (R-sq or R^2)* between the measured roadway horizontal illuminance data and the model was calculated since for every data point in the model the corresponding field (measured) data was available. The goodness of fit, average, standard deviation and the coefficient of variation (ratio of standard deviation to the mean) are given in Table 5 for the roadway horizontal illuminance.

Table 5 is a comparison of model and field data for roadway and sidewalk illuminance. It can be seen from Tables 3 and 4 that field data matches the model for all three LED vendors. However, the fit is not as good for Vendor D (high-pressure sodium).

Table 5: Goodness of Fit Between Model & Field Roadway Horizontal Illuminance

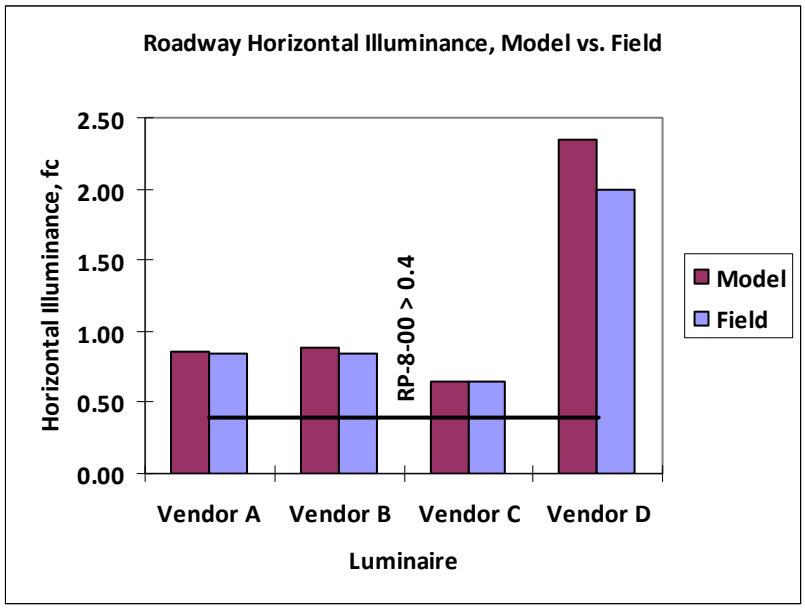
Luminaire	Goodness of Fit, R^2	**Average Illumination, fc**		**Standard Deviation, fc**		**Coefficient of Variation**	
		Model	Field	Model	Field	Model	Field
Vendor A	0.963	0.85	0.84	0.42	0.47	0.49	0.56
Vendor B	0.967	0.88	0.84	0.47	0.47	0.53	0.56
Vendor C	0.995	0.65	0.65	0.60	0.57	0.92	0.88
Vendor D	0.85	2.35	2.00	1.17	1.11	0.50	0.56

* The goodness of fit, R-sq (R^2), is calculated using the formula: $R^2 = 1- SS_{err}/SS_{tot}$ SS_{err} is the sum of squares of the residuals (difference between the field and the model, i.e., error). SS_{tot} is the sum of the squares of the difference between the data point and the mean of the data points. An R-sq of "1.0" means that the difference between the model and the experimental value (residual) is zero or *the fit is excellent*. Typically, an R-sq value >0.95 is considered very good, and >0.8 acceptable.

It should be noted that the correlation effort revealed that Vendor A luminaires installed in the test area were non-standard lights – not in the manufacturer's catalog. The closest comparable light from the Vendor A catalog was used for computer modeling. *This reinforces the value of conducting both field measurement and computer modeling studies to validate results.*

Table 6: Model vs. Field Data Comparison

Field Vs. Model Comparison		Vendor A		Vendor B		Vendor C		Vendor D	
		Model	Field	Model	Field	Model	Field	Model	Field
Horizontal Illuminance Average	fc	0.85	0.84	0.88	0.84	0.65	0.65	2.35	2.00
Horizontal Illuminance Min	fc	0.33	0.31	0.40	0.41	0.03	0.02	1.07	0.84
Horizontal Illuminance Max	fc	1.71	1.98	1.96	1.90	1.93	1.89	4.95	4.73
Horizontal Illuminance Max/Min		5.18	6.39	4.90	4.63	64.33	94.50	4.63	5.63
Horizontal Illuminance Avg/Min		2.58	2.71	2.20	2.05	21.67	32.50	2.20	2.38
Sidewalk Hor. Illuminance Average	fc	0.39	0.35	0.39	0.38	0.32	0.32	0.72	0.66
Sidewalk Horizontal Illuminance Min	fc	0.21	0.22	0.25	0.29	0.09	0.10	0.62	0.56
Sidewalk Horizontal Illuminance Avg/Min		1.86	1.59	1.56	1.31	3.56	3.20	1.16	1.18



The fit between model and field data validates the model for LED vendors and gives us confidence that modeling can be used for roadway/luminaire optimization and selection.

Coefficient of Utilization

One measure of luminaire efficiency is the coefficient of utilization (CU) that quantifies how much of the light emitted by a luminaire reaches its intended target – in this case, the roadway and sidewalk. The higher the CU, the more light that actually reaches its target and the lower the wasted light and power. Due to limitations in software tools, we computed the CU for only vendors B and D shown in the table below.

Vendor B scored slightly higher than vendor D.

Table7: Coefficient of Utilization

	Vendor B	Vendor D
Coefficient of Utilization	0 .43	0.41

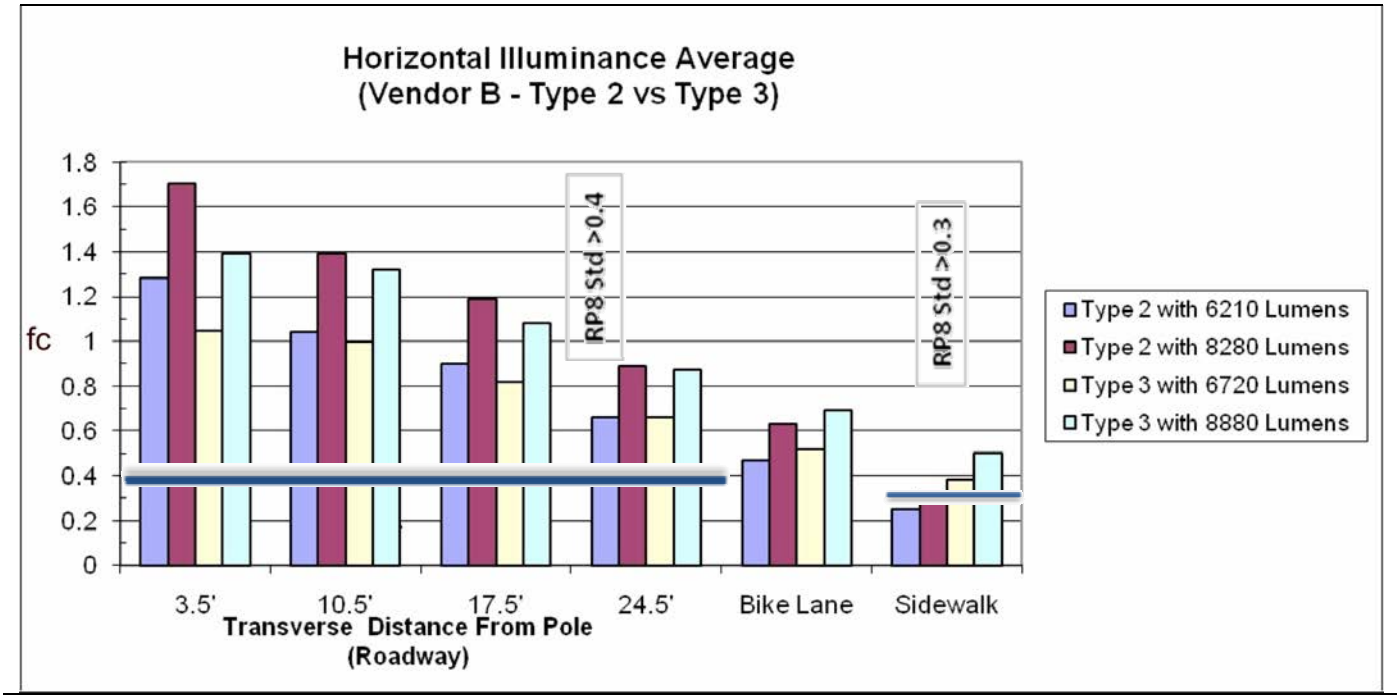
Type II vs. Type III Streetlights

Although Type III streetlights were measured in the test area, it is important to understand whether Type II streetlights might have improved visibility. Photometric plots of the two types of lights showed that the Type III light distribution pattern was square with greater range extending across the road and Type II more rectangular with greater range extending down the road. In Table 8 below, equivalent Type II luminaires for Vendor B were modeled and compared to Type III luminaires.

Since the choice of Type II or Type III streetlights affects sidewalk illumination which is the furthest point from the streetlight, additional modeling of a more powerful light in Vendor B's catalog was done to illustrate the benefits that could be achieved on sidewalk Illuminance by choosing the best light distribution pattern for the area under consideration. Of the two models evaluated for each type, the left entry represents the model evaluated in the field or its equivalent Type II model, the right entry represents the next most powerful model in Vendor B's catalog.

Table 8: Vendor B – Type II and Type III Comparison Summary

Luminaire Type/ Lumens	Unit	RP-8-00	Type 2	Type 2	Type 3	Type 3
			6210	8280	6720	8880
Horizontal Illuminance Average	fc	> 0.4	0.97	1.29	0.88	1.16
Horizontal Illuminance Avg/Min (Uniformity Ratio)		< 6.0	2.31	2.31	2.21	2.21
Roadway Luminance Average	cd/m^2	> 0.3	0.72	0.96	0.57	0.78
Roadway Luminance Avg/Min (Uniformity Ratio)		< 6.0	2.45	2.45	2.32	2.63
Roadway Luminance Max/Min (Uniformity Ratio)		< 10.0	5.95	5.95	4.81	6.1
Veiling Luminance Ratio, Max/Roadway Luminance, Avg		< 0.4	0.28	0.28	0.28	0.27
Small Target Visibility		>1.6	2.89	3.2	2.83	3.08
Pedestrian Grid (Sidewalk) Horizontal Illuminance Avg	fc	> 0.3	0.26	0.35	0.4	0.53
Pedestrian Grid (Sidewalk) Horizontal Illuminance Avg/Min		< 6.0	2.89	2.69	1.82	1.83



Both models of Type II and Type III luminaires meet the ANSI /IESNA RP-8-00 standard for horizontal illuminance on the roadway. Type II has higher roadway average illuminance but Type III has better roadway uniformity and sidewalk illuminance (and by extension bicycle lane illuminance). Only the lower-powered Type II luminaire failed ANSI /IESNA RP-8-00 standard requirements for sidewalk illuminance. Type III luminaires have an advantage over Type II luminaires in sidewalk and bike lane illuminance for the test area studied as they show higher illuminance and a better uniformity ratio.

Light Loss

Street light lumen maintenance varies over time due to a variety of factors. Light output from LEDs gradually declines over time based on the specific LED product, average nighttime temperature, and driver loss. LED lifetimes are quoted as L70[11] thousands of hours before light output degrades to 70% of initial output (see page 36)*

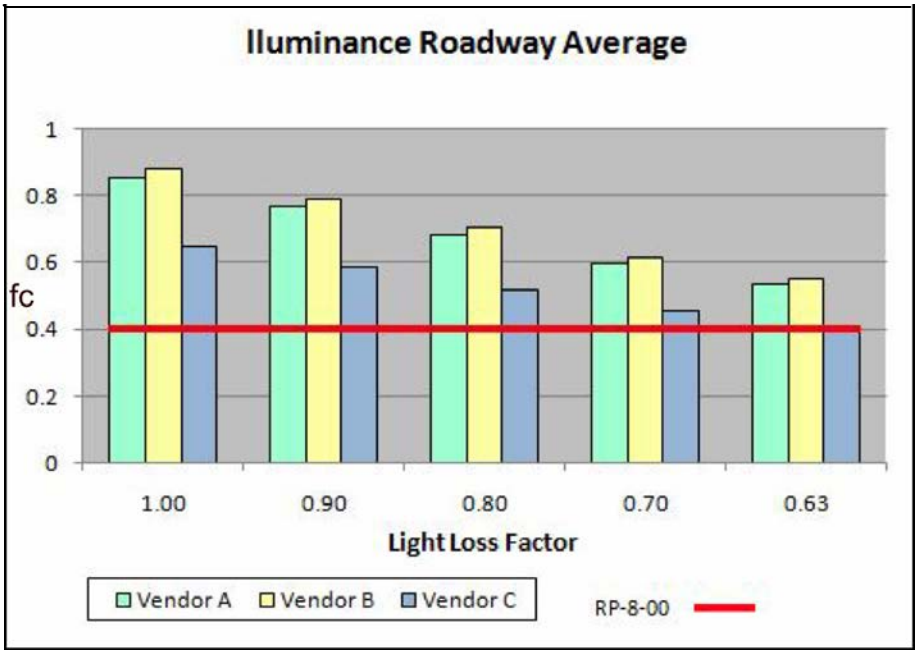
In addition to LED lumen maintenance, other degradations can occur which will impact lighting effectiveness including dirt, luminaire wear, tree shading, etc. In the Fremont Avenue test area, we would expect a 10% degradation over time from dirt and wear.

[11] IES LM-80-08 , **Measuring Lumen Maintenance of LED Light Sources ,** Illuminating Engineering Society

* See page 36 in the economic section **Estimated LED Maintenance and Installation Option Costs** for assumptions on how L70 maps to hours

It is important to understand how an LED luminaire will perform over its entire lifetime (maintained lumens) vs. the ANSI/IESNA RP-8-00 standard. For our analysis we combined the end of life luminaire depreciation factor (0.7) and "very clean" dirt depreciation factor (0.9) and produced 0.63 (0.9*0.7) as our total light loss factor.[12] All LED vendors met average horizontal illuminance requirements in the roadway through end of life, however all of the LED vendors failed to meet average horizontal illuminance requirements for a portion of their lifetime for the sidewalk. In addition Vendor C failed to meet requirements for vertical illuminance for sidewalk end of life. A choice will need to be made between higher power LED luminaires or sacrificing some level of standards conformance on the sidewalk for the final portion of the estimated LED luminaire lifetime.

The chart below shows the impact of % degradations in lighting power over time versus the ANSI/IESNA RP-8-00 standard. This chart does not attempt to correlate light loss per thousand hours – we did not have enough data from vendors to do that accurately. However, we know that light loss degradation is not a linear function – it degrades most rapidly near the end of the luminaire lifetime.



Light loss is an industry issue that needs to be tracked carefully over time to improve accuracy in sizing a luminaire for a particular roadway situation. Work is underway in the industry to improve confidence in estimating lifetime and light loss. LED lifetimes, LED light loss factors, and LED

[12] Kauffman, Rick. "Calculating Light Loss Factors." *Municiple Solid-State Street Lighting Consortium*. US Department of Energy, 2011. <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/msslc-se2011_kauffman.pdf>

dirt/wear loss factors along with rapid advances in LED quality and efficacy must be continually reevaluated as more product experience is built.

Table 9: LED Luminaire End of Life Illuminance Assuming 0.63 Light Loss Factor

Light Loss Results	RP-8	Vendor A	Vendor B	Vendor C
Roadway Avg Illuminance fc	>0.4	.54	.55	.41
Sidewalk Avg Horiz. Illuminance fc	>0.3	.25	.25	.20
Sidewalk Min Vertical Illuminance fc	>0.08	.16	.25	.07

Correlated Color Temperature Results

All three of the LEDs had significantly higher correlated color temperatures (CCT) than the high-pressure sodium – much closer to daylight conditions. This helps explain improved color rendering of the LED luminaires versus the high-pressure sodium luminaire as shown below in the section on digital photography.

Table 10: Correlated Color Temperature

Correlated Color Temperature	LED A	LED B	LED C	HPS
Measured Average (K)	4812	5993	5560	2000*

Meter unable to calculate CCT due to limitations in its CCT algorithm in the range of 2000k and below. CCT for this case was computed from tristimulus values (XYZ = 5.19, 4.13, 0.54; xyz = 0.53, 0.42, 0.05) plotted against the Planckian Locus in the CIE 1931 x,y Chromaticity Space.

Luminaire Operating Temperature

Temperatures were recorded using an infrared thermometer. Ambient temperatures the nights these were recorded were relatively low (40-50 degrees F). Operating temperatures will be higher in the summer. Operating temperatures influence the expected lifetime of LEDs.

Table 11: Luminaire Temperature Results

Operating Temperature	LED A	LED B	LED C	HPS
Heatsink Temperature (degrees F)	90.5	88.0	116.0	145
Face Temperature	59.5	84.5	67.5	170

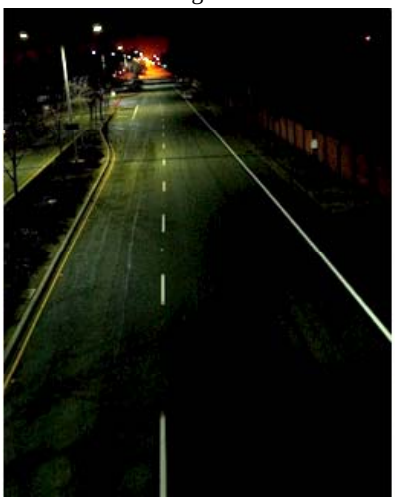
Controlled Digital Photography

Controlled digital photography was utilized to make qualitative comparisons of the lights. In some cases, a daylight photo of the object was taken for comparison. Photos of objects and street scenes were taken with a Nikon D50 SLR digital camera in raw mode, presented in this report without color adjustment, unprocessed, except for an exposure level adjustment to make the photos visible. For object photos, camera position relative to the streetlights, tripod height, and distance to the object were the same. Exposure adjustment was made equally for streetlight object photos to compensate for night shooting, with a different adjustment for daylight pictures. Aerial street scenes were taken from a basket truck utilizing different exposure adjustments, but illustrate the difference in the lights.

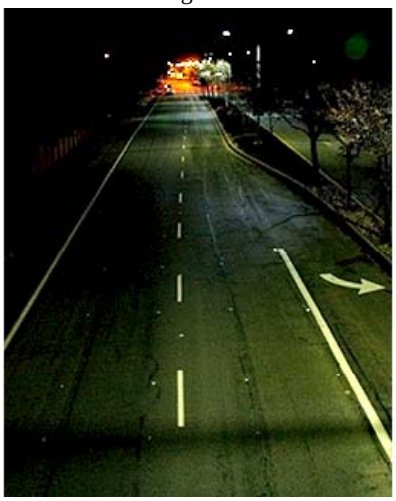
As can be seen from the photos, there is significant variation in color rendering between LED and HPS lights. Qualitative comparison is very subjective. Participants in the study generally found color rendering far better with LED lighting than with HPS. White, blue, green, and red generally reproduced better with LEDs. HPS favored yellow. In street scenes, the boundary between LED and HPS lights was a striking contrast in colors.

VENDOR A

Looking east



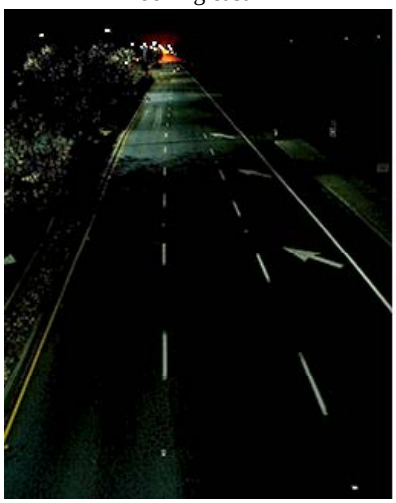
Looking west



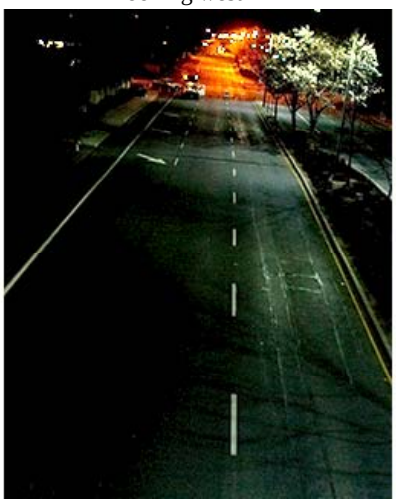
Looking down

VENDOR B

Looking east



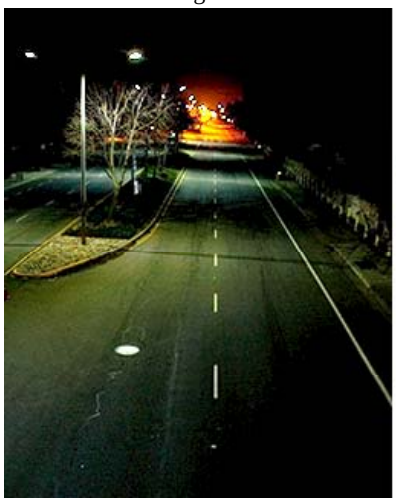
Looking west



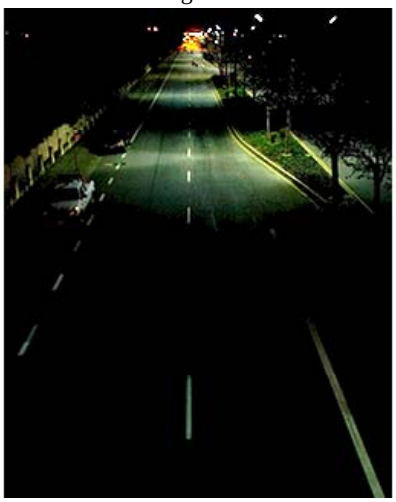
Looking down

VENDOR C

Looking east



Looking west



Looking down

VENDOR D

Looking east

Looking west

Looking down

WHITE: Day
A
B
C
D
GREEN: Day
A
B
C
D
YELLOW: Day
A
B
C
D
RED: Day
A
B
C
D
BLUE: Day
A
B
C
D

SUITCASE, COOLER, AND YELLOW JACKET

A **B** **C** **D**

A **B** **C** **D**

WHITE CAR BACK/FRONT

A **B** **C** **D**

WHITE CAR SIDE

A **B** **C** **D**

Electrical Use and Energy Savings

Measured electrical data is presented below. LED wattage relative to HPS for products evaluated ranged from 38% to 44% with Vendor B showing the lowest usage. This translates directly to Greenhouse Gas (GHG) reduction. However these savings do not directly translate to financial savings – streetlights are often unmetered and charged a flat rate by the local utility (see economic analysis).

Combining field measured electrical usage and laboratory total measured lumen output emitted by each luminaire (photometric data listed in Appendix E), the luminous efficacy of each luminaire was calculated in lumens/watt. HPS Vendor D luminaire efficacy was negatively affected by the 27% of lumen output trapped inside the luminaire. In practical terms, Vendor D efficacy is overstated below given its higher percentage of lumen output at high vertical angles. High-angle light can be wasted because it falls outside the roadway and above potential objects on the roadway and sidewalk. In our field test area, light emitted straight across the roadway above the 65 degree angle is wasted. Light emitted down the length of the roadway at angles higher than 80 degrees contributes very little useful illumination and can be a cause of glare. Vendor B showed the highest efficacy.

Table 12: Electrical Use and Efficacy

Electrical and Efficiency Data	Vendor A	Vendor B	Vendor C	Vendor D
Average Voltage	237.2V	236V	239.2V	232.7V
Average Amps	0.61V	0.50A	0.51A	1.17A
Average Power Factor	0.81	0.85	0.87	0.98
Average Watts	119W	101W	105W	269W
Luminous Efficacy of Luminaire	52.5 lm/W*	66.5 lm/W	47.3 lm/W	60.1 lm/W
Lumen Output	6649	6720	4969	16159

* *Given the nonstandard Vendor A light installed in the test area, rated wattage was used for this metric*. Laboratory testing results are listed in Appendix G

Fitted Target Efficacy

The ENERGY STAR® program has proposed a new metric called Fitted Target Efficacy (FTE) which will be applied to outdoor lighting including streetlights when finalized (as of this writing Draft 1.2 was under review).[13] Pacific Northwest National Laboratory (PNNL) provides a tool

[13] Overview of Fitted Target Efficacy (FTE) for Outdoor Pole-Mounted Area and Roadway Luminaires US Department of Energy, ENERGY STAR for SSL Luminaires. July 1, 2009
http://www.energystar.gov/index.cfm?c=revisions.ssl_luminaires

that computes the FTE for a given luminaire using standard photometric files. Full results from version Beta version B.1.1 of the tool are listed in Appendix H. Summary results are listed below in Table 13.

The FTE metric computes a lumens/watt efficacy value for the luminaire under evaluation. Lumens are summed within an area which meets a uniform light distribution requirement. Only lumens from within the area of uniform light distribution are counted for computing the metric and the rest of the lumens are discarded. Furthermore, an algorithm is applied to the remaining uniform light distribution which discounts non-rectangular lighting distributions. The resulting lumens are divided by the luminaire power consumption in watts to compute the fitted target efficacy metric.

The FTE metric is application-independent which broadens its usefulness. However, ultimately the uniform lighting distribution area established by the FTE metric must be compared to the actual roadway lighting area to evaluate the appropriateness of a luminaire for a particular roadway. To assist in this evaluation, the PNNL tool denotes the maximum sized rectangle which fits within the uniform distribution area. This "uniform rectangle" can be divided into forward and backward rectangles based upon orientation to the luminaire position and used for comparison with a target roadway scenario.

Looked at as an application-independent metric, LED vendors A and B rate the highest in FTE with vendor B having the edge. LED Vendor C and HPS Vendor D are far behind. Specifically for the Fremont Avenue test site, the FTE forward uniform rectangle should cover a 43' transverse and 143' longitudinal rectangle (transverse width of roadway/sidewalk is 43' and longitudinal distance between poles is 143'). None of the products actually covers this area with their forward uniform rectangle but Vendor D (HPS) came the closest. Of LED vendors, vendor B covers the area the best with vendor A close behind. Vendor C trails significantly.

The ENERGY STAR® draft standard defines a minimum FTE based on a categorization of luminaires by overall lumen output and backlight characteristics. As of this writing, none of the vendor products evaluated in this report meet the standard. In addition to FTE, ENERGY STAR® defines other criteria including percentage of light in the forward very high 80-90 degree vertical zone (FVH). Light emitted from a luminaire at this high angle causes glare. Vendor D (HPS) fails this metric. All of the LED vendors pass this requirement.

Table 13: Fitted Target Efficacy (FTE)

	Vendor A	Vendor B	Vendor C	Vendor D
FTE lumens/watt	**37**	**40**	**32**	**33**
Forward Uniform Rectangle Transverse x Longitudinal	**63' x 72'**	**60' x 75'**	**57' x 51'**	**48' x 96'**

Summary of Measured Results

Performance of LED lights from three different vendors was compared to that of standard high-pressure sodium lamps installed on the test roadway. The choice of test roadway and specific vendor products was one of many the city might have chosen to evaluate. Other choices may have led to different results. However, the results presented here are useful in understanding the potential of moving ahead to replace HPS streetlights with LEDs.

The data shows that two of the three LED luminaires (Vendors A and B) meet the roadway and sidewalk illuminance criteria for the test area. Vendor C failed to meet the roadway standard for the test area. Type III streetlight distribution pattern was shown to be superior for the test area over Type II.

The HPS luminaire proved to be standard conformant in every metric – in some cases greatly exceeding the required ANSI/IESNA RP-8-00 metrics (at substantial cost in electrical power). Although we did not study the possibility, a lower powered HPS luminaire might have been sufficient for the test roadway.

Light loss over time is an important factor. All vendors remained standard conformant for the roadway through luminaire end of life, however, ***all LED vendors fell short of sidewalk average illuminance at end of life.*** Higher power luminaires would be necessary to maintain ANSI /IESNA RP-8-00 conformant lighting levels for the sidewalk through end of life.
LED luminaires outperform HPS lights by a substantial margin on electrical usage. Energy savings by the three LED vendors versus High Pressure Sodium models studied ranged from 56% to 62%. Vendor B showed the strongest performance in this category, with lowest electrical usage and highest luminous efficacy.

Overall, both Vendors A and B showed strong potential as replacements for HPS. Vendor B showed the strongest results overall based on good results in all categories and the best results in energy savings.

Economic Performance

Economic performance is evaluated through the simple payback and net present value (NPV) analysis using the cost and savings estimates. The savings are calculated using the maintenance costs for both group replacement and spot replacement scenarios as well as energy cost. Refer to Appendix D for detailed energy cost-savings and maintenance cost-savings estimates. The economics of new construction as well as retrofit scenarios are calculated in Appendix D.

Estimated Energy Costs

The 2009 PG&E LS-2 rate schedule is used to estimate the energy cost for each HPS luminaire. As per this rate structure, the 240 volt, 70 watt, 150 watt and 200 watt HPS luminaries are billed at the rate of $4.150, $8.422 and $9.887 per month respectively. The comparable replacement LED luminaires for each of the HPS luminaires as recommended by the vendors included in this report, are also billed per the published rates in the 2009 PG&E LS-2 rate schedule for LED luminaires.

The monthly fixed charge for the HPS and the comparable replacement LEDs includes only the energy charge per lamp per month and not the facility charge. Including the facility charge will not affect the estimated energy savings cost since the facility charge is the same for HPS and LEDs. For simplicity, the facility charge is not included in the calculation.

The annual operating hours are 4100 hours per year as assumed in the PG&E LS-2 rate-schedule. Annual energy savings per luminaire for LEDs are shown in table EP-1 below.

Table: EP-1 Annual Energy Savings for LED Lamps

Vendor	LED Lamps	Annual Energy Savings
Vendor A	70W	$26.08
	150W	$62.24
	200W	$57.28
Vendor B	70W	$28.56
	150W	$52.28
	200W	$59.90
Vendor C	70W	$6.00
	150W	$57.26
	200W	$59.90

Estimated HPS Maintenance Costs

The maintenance cost for streetlights is estimated for both categories: group replacement as well as burnout replacement.

Group replacement is a scheduled replacement of lamps. Burnout replacement is the replacement of specific lamps due to lamp or any other component failure. In this report, the total annual maintenance per HPS luminaire is estimated based on labor and material cost per replacement, and annual replacement frequency. Cost is obtained from the City maintenance contractor for group and burnout replacement scenarios. The data on monthly system-wide streetlight replacement through group and burnout maintenance, provided for the same period, is used to estimate the annual replacement frequency.

The mercury present in the HPS lamps requires treating the removed lamps as universal waste. Therefore, an additional disposal charge per lamp is added to calculate the total annual maintenance cost per luminaire.

Estimated LED Maintenance and Installation Option Costs

The total annual maintenance cost per LED luminaire is estimated based on the rated life of the luminaire, the warranty and the cost of the luminaire provided by the manufacturer. The rated life of the LED luminaires ranges from 10 to 30 years, which is significantly longer than the HPS lamp rated life of five to seven years. Still, the LED lamps will require some level of maintenance in case of catastrophic failure, as well as periodic cleaning, inspection, and photocell repair. Since catastrophic failure of the LED luminaires is rare, the rated life of the luminaire is the amount of time the LED source takes to depreciate to 70% of its initial lumen output, commonly known as L70. For this report the luminaire life is assumed to be 50,000 hours (12.2 years) as per the PG&E requirements.[14]

Since the life of all the LED luminaires is greater than the term of analysis considered for this report (10 years), end-of-life replacement costs are not included in this analysis. However, it is assumed that a small percentage (10%) of LED luminaires will fail before the end of the rated luminaire life. The annual replacement frequency for LED luminaires is estimated based on the probability of failure within the warranty period, as well as outside the warranty period. The cost of replacing an LED luminaire within the warranty period will include only the installation cost, while replacement outside the warranty period will include luminaire cost in addition to the installation cost.

The cost of LED luminaires is based on bulk purchase rate estimates obtained from each LED manufacturer. Since there is a downward trend in LED luminaires costs, the future replacement costs can be reasonably lower. Without enough information on projected cost reductions, LED luminaire replacement cost is held constant. If luminaires were purchased individually or in small

[14] "Pre-Qualified LED Fixtures." *ENERGY STAR Qualified Commercial LED Lighting for PG&E Rebate & Incentive Programs*. Version Last Modified: 02/17/2010 http://www.energystar.gov/index.cfm?c=ssl.pr_commercial. ENERGY STAR Solid-State Lighting Luminaire Program Requirements, n.d. Web. 17 June 2010. <www.pge.com/includes/docs/pdfs/

number, it would result in higher luminaire costs than those used in this analysis, thereby lengthening the simple payback period and decreasing the net present value.

The estimated total annual costs (energy + maintenance) and total annual savings per luminaire are shown in Table EP-2. The maintenance of HPS luminaires accounts for 54% of the total annual cost for a 70W luminaire, 37% for a 150W luminaire and 34% for a 200W luminaire. In the case of luminaires from three different vendors, the values are 42%, 44% & 27% of total annual cost for LEDs equivalent to 70 W HPS, 32%, 27% & 27% for LEDs equivalent to 150W HPS and 24%, 24% &22% for LEDs equivalent to 200 W HPS respectively. These values will vary depending on the luminaire cost and the manufacturer's warranty.

Table EP-2: Total Annual Costs and Savings per Luminaire

Total Annual Costs and Savings per Luminaire							
Vendor	**Luminaire Type**	**Annual Maintenance Cost**	**Annual Maintenance Savings**	**Annual Energy Cost**	**Annual Energy Savings**	**Total Annual Cost**	**Total Annual Savings**
HPS	70W	$58.34	-	$49.80	-	$108.14	-
	150W	$59.97	-	$101.06	-	$161.04	-
	200W	$61.60	-	$118.64	-	$180.25	-
Vendor A	70W	$17.23	$41.12	$23.72	$26.08	$40.95	$67.19
	150W	$18.02	$41.96	$38.82	$62.24	$56.84	$104.20
	200W	$19.01	$42.60	$61.37	$57.28	$80.37	$99.87
Vendor B	70W	$16.68	$41.66	$21.24	$28.56	$37.92	$70.22
	150W	$18.08	$41.90	$48.78	$52.28	$66.86	$94.18
	200W	$18.35	$43.25	$58.74	$59.90	$77.09	$103.16
Vendor C	70W	$16.22	$42.12	$43.80	$6.00	$60.02	$48.12
	150W	$16.22	$43.75	$43.80	$57.26	$60.02	$101.02
	200W	$16.46	$45.15	$58.74	$59.90	$75.20	$105.05

Two economic scenarios: (i) new construction and (ii) retrofit are considered for the comparison between the LED and base case HPS options. Please refer to Appendix D for further details on the scenarios presented in the simple payback and Net Present Value (NPV) calculation tables.

New Construction Economics

In new construction scenarios, the comparable replacement LED luminaires are installed instead of the standard 70W, 150W and 200W HPS luminaires. Thus, the incremental cost of installing the LED luminaires is the difference in material costs between HPS luminaires and equivalent LED luminaires provided. The cost of installation is assumed to be the same for both luminaire types. The simple payback years are estimated based on the incremental cost and the total annual savings for each luminaire. The NPV for each luminaire was estimated based on the assumed

project analysis period of 10 years, escalation rate for all costs of 3% annually and real discount rate of 5%. Refer Appendix D for details on the simple payback and NPV calculations.

As seen in Table EP-3 below, the simple payback length in years for the LED luminaires from Vendor A, ranges from 2.5 to 5 years. The 10-year NPV ranges from $395 to $624.

For the LED Luminaires from Vendor B, the simple payback years range from 0.8 to 3.6 years. The 10-year NPV ranges from $521 to $577.

Vendor C simple payback ranges from 4.7 to 10 years and $330 to $438. The *negative value* of 10-year NPV for LED luminaire equivalent to 70 W from Vendor C suggests it is not an economic option.

Table EP-3: New Construction Economics

New Construction Economics						
	Luminaire Type	**Initial Investment**	**Incremental Cost**	**Annual Savings**	**Simple Payback (yrs)**	**10-yr NPV**
HPS	70W	$270.00	-	-	-	-
	150W	$280.00	-	-	-	-
	200W	$290.00	-	-	-	-
Vendor A	70W	$435.00	$165.00	$67.19	2.5	$440.40
	150W	$595.00	$315.00	$104.20	3.0	$623.84
	200W	$795.00	$505.00	$99.87	5.1	$394.86
Vendor B	70W	$325.00	$55.00	$70.22	0.8	$577.62
	150W	$607.00	$327.00	$94.18	3.5	$521.56
	200W	$662.00	$372.00	$103.16	3.6	$557.46
Vendor C	70W	$752.35	$482.35	$48.12	10.0	-$48.77
	150W	$752.35	$472.35	$101.02	4.7	$437.81
	200W	$905.81	$615.81	$105.05	5.9	$330.69

Retrofit Economics

In the retrofit scenario, the comparable replacement LED luminaires are installed in place of the existing and fully functional 70W, 150W and 200W HPS luminaires. Thus, there is no initial investment in the HPS luminaires and the incremental cost of the LED installation is the total of estimated cost of the LED luminaire plus the estimated installation costs minus the PG&E rebate for streetlight retrofit. The simple payback years and the NPV are estimated in the same manner as in the new construction scenario.

Table EP-4: PG&E Rebate for Streetlights Retrofit

Rebate Amount Per Eligible LED Replacement	
Fixture/Watt with new LED Fixture	**Rebate Amount**
70 W	$50.00
150 W	$100.00
200 W	$125.00

Table EP-5 shows that the simple payback in years for Vendor A LED luminaires ranges from 5.4 to 7.4 years, and the 10-year NPV ranges from $153 to $376. For the LED luminaires from Vendor B, the simple payback ranges from 4.9 to 6.1 years, and the 10-year NPV ranges from $274 to $325. Vendor C luminaires is from 7.1 to 16.0 years and $98 to $190. The 10-year NPV for one of the options is *negative* suggesting it is not economically feasible.

In new construction and retrofit scenarios, the higher values of NPV for the LED luminaires from Vendor B suggests these luminaires will add more value to the project. Also, the payback in years and the initial investment cost for the LED luminaires from Vendor B are much less compared to those from Vendor A and C. This suggests the initial project cost will be compensated for sooner if LED luminaires from Vendor B are used.

Table EP-5: Retrofit Economics (Includes Rebates)

Retrofit Economics						
	Luminaire Type	**Initial Investment**	**Incremental Cost[1]**	**Annual Savings**	**Simple Payback (yrs)**	**10-yr NPV**
HPS	70W	-	-	-	-	-
	150W	-	-	-	-	-
	200W	-	-	-	-	-
Vendor A	70W	$435.00	$452.50	$67.19	6.7	$152.90
	150W	$595.00	$562.50	$104.20	5.4	$376.34
	200W	$795.00	$737.50	$99.87	7.4	$162.36
Vendor B	70W	$325.00	$342.50	$70.22	4.9	$290.18
	150W	$607.00	$574.50	$94.18	6.1	$274.06
	200W	$662.00	$604.50	$103.16	5.9	$324.96
Vendor C	70W	$752.35	$769.85	$48.12	16.0	-$336.27
	150W	$752.35	$719.85	$101.02	7.1	$190.31
	200W	$905.81	$848.31	$105.05	8.1	$98.19

[1] Initial investment + Installation cost for group installation-PG&E rebate[15]

[15] PG&E Rebate program

Figures EP-1 through EP-4 show simple payback and net present value for LED luminaires at estimated annual maintenance savings for new construction and retrofit scenarios.

Figure EP-1

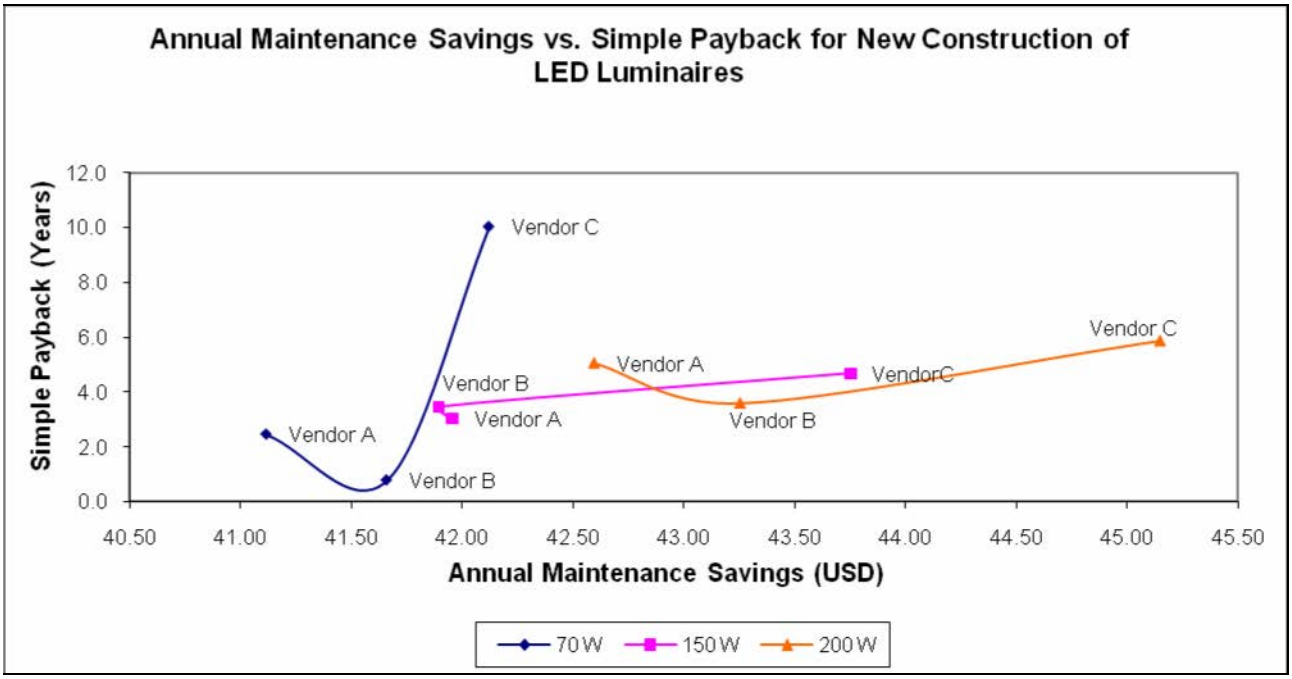


Figure EP-2

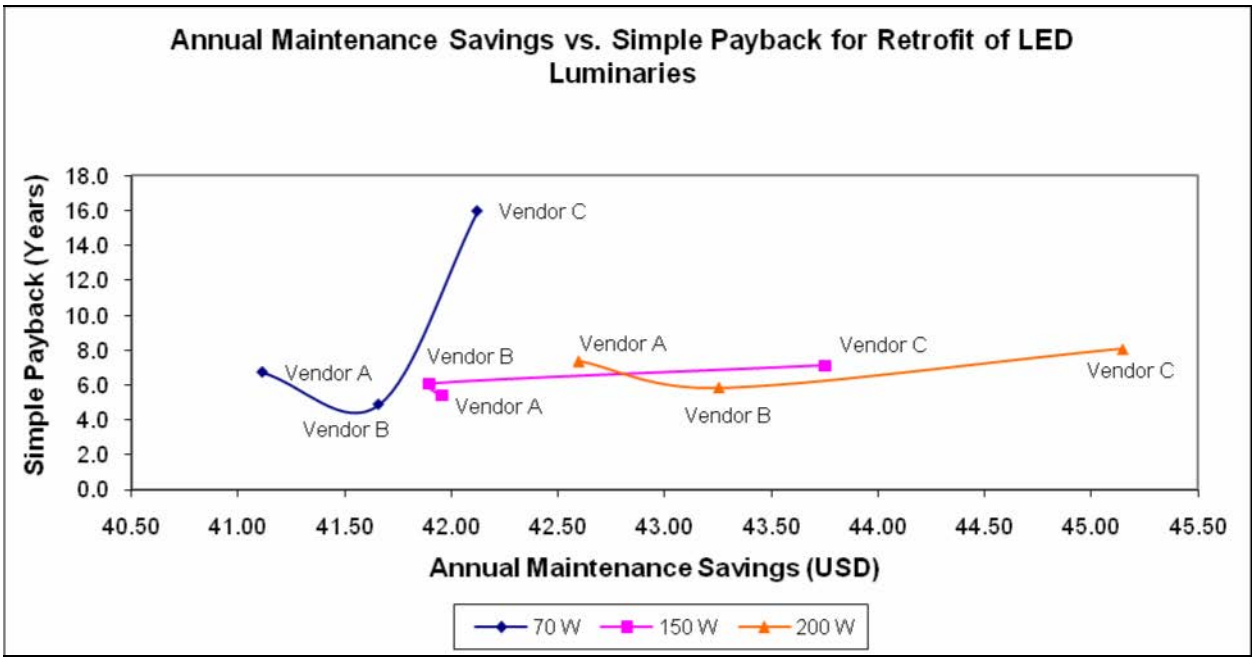


Figure EP-3

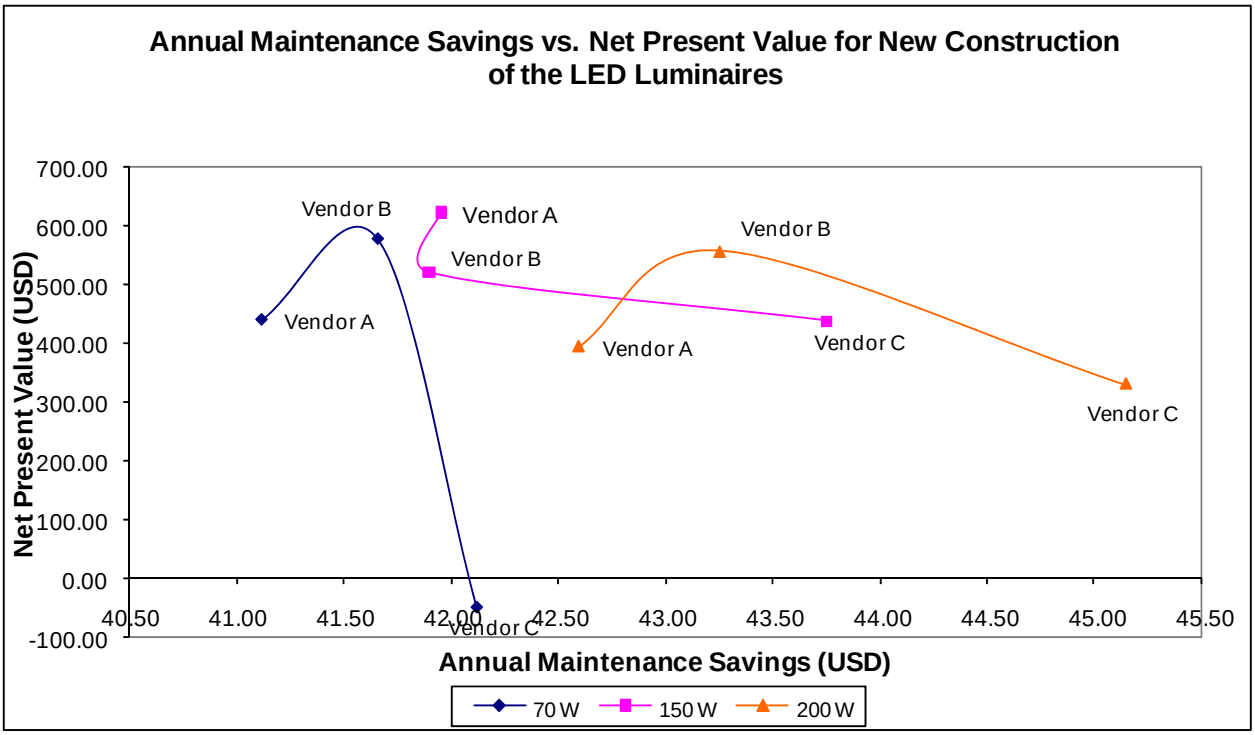
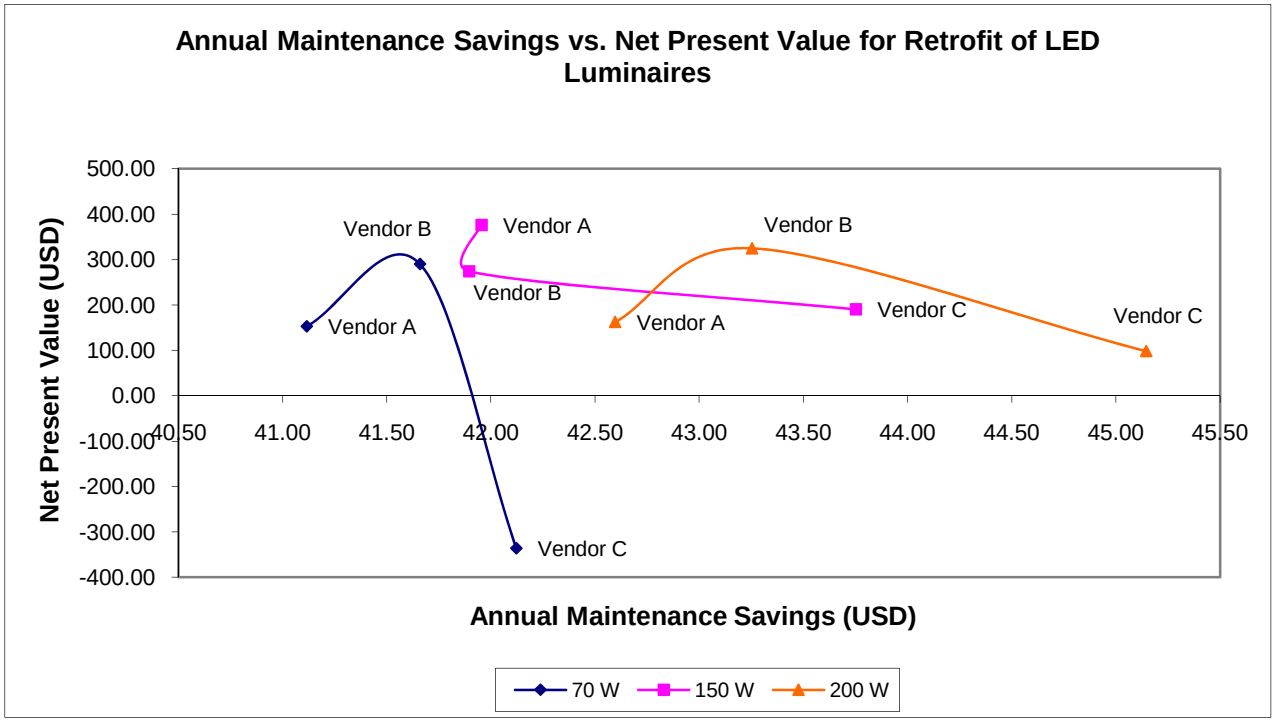


Figure EP-4



Economic Feasibility

The LED luminaires are relatively high in initial cost compared to the standard HPS luminaires. As a result, the adoption of LED luminaires for street lighting on a larger scale will depend not only on the lighting and energy performance but also the economic feasibility and competitiveness for new construction and retrofit scenarios. Though savings in energy and maintenance costs compensate for the high initial cost of the LEDs, the influence of this factor will depend on the extent of savings for a particular product and location. Thus it is required to compare the simple payback of the LED and the HPS for new construction and retrofit scenarios.

For a new construction scenario the expected simple payback years after including the estimated energy and maintenance savings are, 0.8 to 2.5 years for 70-Watt, 3 to 4.7 years for 150-Watt and 3.6 to 5.9 years for 200-Watt equivalent LED luminaires. For a retrofit scenario these values are, 4.9 to 6.7 years for 70-Watt, 5.4 to 7.1 years for 150-Watt, and 5.9 to 8.1 years for 200-Watt equivalent LED luminaires.

A five-year period is typically selected for payback analysis. For the lowest cost luminaires to meet a payback threshold of 5 years or less in the retrofit scenario, the LED luminaire cost would need to drop by over $45 per luminaire, or total savings improve by $10 per year per luminaire for 150-Watt and a cost drop of $95 per luminaire, or total savings improve by $20 per year per luminaire for 200-Watt luminaires over current estimates.

In addition to simple payback calculations, this analysis includes net present value (NPV) calculations for investments on LED streetlights. Simple payback is insufficient to make an economic decision. The NPV calculations are highly sensitive to the specifics of the project, such as estimated total annual costs, discount rate, escalation rate, and term of analysis.

As per the assumptions made in this analysis, the 10-year NPV for new construction ranges from $440 to $577 for 70W, $437 to $623 for 150W, and $330 to $557 for 200W equivalent luminaires. The 10-year NPV for retrofit ranges from $153 to $290 for 70W, $190 to $376 for 150W and $98 to $325 for 200W equivalent LED luminaires. These 10-year NPV values are equivalent to an internal rate of return of 42% to 135% for 70W, 20% to 35 % for 150W, and 14% to 28% for 200W equivalent luminaires in case of new construction. For retrofit scenario the internal rate of return are 11% to 19% for 70W, 10% to 17% for 150W and 9% to 16% for 200W equivalent luminaires.

The result suggests that LED luminaires are economically feasible for a new construction scenario. The results for retrofit scenarios are also satisfactory. The 10-year NPV and the IRR for the LED luminaires are less and the payback period is more for retrofit scenario than in new construction. (See Appendix D) The downward trend of the LED luminaire cost may further reduce the payback period and increase the 10-year NPV and IRR.

Safety and Environmental Concerns

The Illuminating Engineering Society of North America (IESNA) is the authoritative source of general lighting specifications and evaluating public safety and the effect of lighting. According to the ANSI/IESNA RP-8-00 standard practices:

- The principal purpose of roadway lighting is to produce quick, accurate and comfortable visibility at night. These qualities of visibility may safeguard, facilitate and encourage vehicular and pedestrian traffic. [16]

- Research data from IESNA shows increased hazards occur in darkness. They report that accidents on unlighted roadways have three times the rate of fatalities compared to daytime fatality rate. "This ratio can be reduced, when properly fixed lighting is installed, since fixed lighting systems reveal the environment beyond the range of the vehicles headlights." [17]

The choice of good streetlights should increase visibility and should not in itself become a distraction. The following three considerations enhance streetlight performance: *Limit glare, proper installation, and site maintenance for tree and foliage control.*

- *Limit Glare* - Glare causes the effect of a curtain of darkness around a brightly illuminated point. It is a safety concern since it affects the ability of pedestrians and drivers to perform visual tasks. Veiling luminance is one measure of glare and is reported as part of the metrics in the lighting quality section of this report. The IESNA Luminaire Classification System (LCS) gives additional information in quantifying potential glare issues. The LCS categorizes light output for a luminaire in zones corresponding to vertical angles. Light in the forward and backward very high zone (80-90 degree vertical angle) is problematic for glare. Photometric reports (see Appendix A) show that vendor D emits significantly more of its light in the glare-producing very high zone: 5.5% versus 1.1% for vendor A, 0.5% for vendor B, and 0.4% for vendor C. All of the LED luminaires evaluated in this report outperformed HPS in this metric and should improve safety. Two types of glare are important. Disability glare reduces the ability to see, but does not often cause discomfort.[18] Discomfort glare makes the eyes uncomfortable; yet does not affect visibility. It isn't possible to eliminate glare completely. However, good planning and the correct downward-illuminating fixture will minimize the amount of glare.

- *Proper Installation* - Proper installation of streetlights is critical to realize the desired benefits. Poor installations with horizontal and vertical misalignment can produce glare and light trespass. Light trespass is lighting that does not stay within the desired area and either causes glare or interferes with the surroundings and is discussed below.

[16] See IESNA Publication Roadway Lighting RP-8-00 Reaffirmed 2005, pg 1 paragraph 1.2
[17] See IESNA Publication Roadway Lighting RP-8-00 Reaffirmed 2005, pg 2 paragraph 1.4
[18] See IESNA Publication Roadway Lighting RP-8-00 Reaffirmed 2005, pg 2 paragraph 1.5

- *Site Maintenance* - A critical long-term consideration when choosing lighting is maintaining tree and foliage growth with ongoing maintenance. This regimen keeps lighting functioning as planned. Trees foliage was an issue in our test area and substantially degraded light quality for one of our test grids.

Personal Safety

An additional aspect of public street lighting is the effect on personal safety. Too much lighting can encourage vandalism and graffiti as unintended consequences.[19] In addition, inappropriate lighting can attract criminal behavior, if deep shadows are cast that offer concealment.

Light Pollution

Sky Glow

Urban sky glow is the result of outdoor lighting used in cities and causes a brightening of the sky that reduces the visibility of the natural night sky.[20] Sky glow is based on an urban population's use of light. Excess light in the sky has an adverse impact not only on the environment in general but deprives citizens of a natural view of the universe. Sky glow is a major contributor to light pollution. It is wasted light that does not help to increase nighttime safety, utility, or security. According to the International Dark-Sky Association (IDA)[21] effective mediation strategies are to use night lighting only when necessary and focus light downward. Turn off lights when not necessary or use the correct amount of light needed. More is not always better. The use of effective placement and practically designed fixtures can provide light control and reduce wasted light.

IDA mandates the use of luminaires with no uplight – no light emitted above the 90 degree vertical angle. All luminaires in the study performed well in this regard. Vendor B and vendor D emitted no uplight at all. Vendors A and C emitted only about 0.1% of total light upward which is considered negligible by the DOE.

Using IDA's "Estimation of Sky Glow," the approximate contribution of three of Silicon Valley's cities to nighttime sky glow is evaluated below. This estimation is based on the direct distance from the University of California's Lick Observatory located on Mount Hamilton. In this evaluation the location of Sunnyvale relative to the observatory, as well as its population, creates just over 12% increase in sky glow to the natural night sky. In comparison to the closest city to the observatory, San Jose, with nearly nine times the population of Sunnyvale the contribution to sky glow is minimal. San Jose has a much more significant affect on sky glow and thus provides much more hindrance to the observations made at Lick.[22]

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[19] International Dark Sky Association Information Sheet: #24 "Security Lighting: Let's Have Real Security: Not Bad Lighting"
[20] "The Problem with Light Pollution" International Dark-Sky Association – Information Sheet #1
[21] Light Pollution" NLPIP Lighting Answers, Lighting Research Center, Volume 7 Issue 2 March 2003 http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/abstract.asp
[22] Laurie Hatch, Lick Observatory Strategic Planning Committee Inaugural Meeting, 2007, http://www.ucolick.org/lospc/bolte1.pdf

Other Observatories that may be affected are the Chabot Science Center, the Foothill College Observatory, and the observatory on Sky Line Blvd operated by the Peninsula Astronomical Society. There are also many private observatories in the area.

Table 14: Estimation of Sky Glow

	City of San Jose		City of Santa Clara		City of Sunnyvale	
	Population	Distance	Population	Distance	Population	Distance
	1,006,892	22.53 Km	108,518	35.41 Km	138,826	41.84 Km
Sky Glow (I)	4.1787		0.1455		0.1226	
% increase	417.87 %		14.55 %		12.26 %	

Based on Walkers Law: I = 0.01Pd^-2.5
Where I = Sky Glow, P = population, d = Distance from observation site
Populations are rough estimates from year 2000

Light Trespass

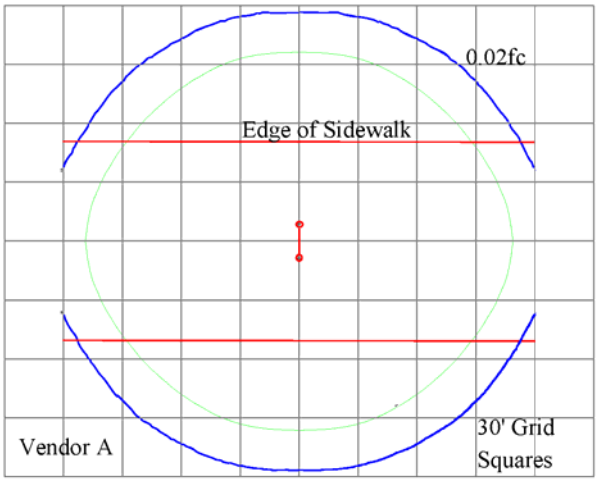
Light Trespass is the occurrence of light being cast where it is not wanted or needed. For example, light trespass can be considered when spill light from a streetlight or floodlight enters through window, illuminates an indoor area, or falls on private property. [23] It is essential that the appropriate light is used to illuminate the desired area and that unnecessary light is not created. Although light trespass can be a subjective issue based upon property limits and personal opinion, it is important to consider that reducing and preventing light trespass aids in decreasing light pollution.

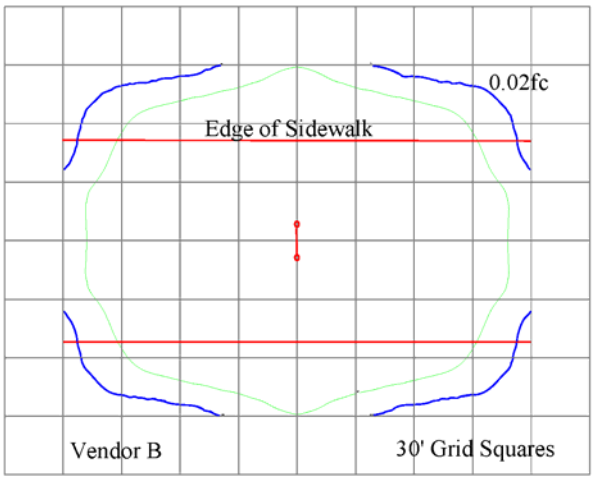
Each of the Vendor products emits a unique light distribution footprint. ALADAN photometric light distribution footprints are shown below. A 0.02 foot-candle contour (similar in intensity to full moon illumination) is shown on a grid of 30’ squares for a single luminaire and represents the farthest reach of each of our four luminaires. The contour at the top of each grid shows the maximum reach into the neighborhood adjoining the roadway. Light extending beyond 43’ from the luminaire is a possible source of light trespass in our test area.

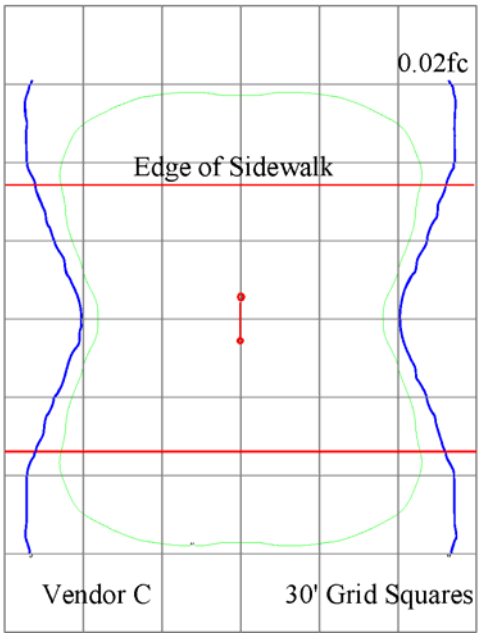
1. Vendor A has a light distribution pattern reaching about 110 feet across the roadway from the luminaire in a circular shape.
2. Vendor B reaches about 95 feet in a square shape.
3. Vendor C reaches 110 feet in a square shape.
4. Vendor D reaches about 120 feet in a rectangular shape.

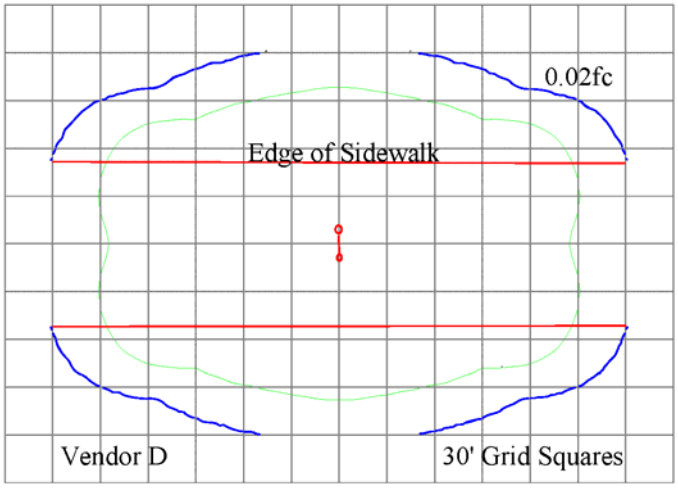
[23] “Light Pollution” NLPIP Lighting Answers, Lighting Research Center, Volume 7 Issue 2 March 2003
http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/abstract.asp

Vendor B has the most desirable light distribution pattern for minimizing light trespass in our test area.









Customer Acceptance

The citizens of Sunnyvale were asked to participate on an opinion poll conducted through a survey consisting of the following questions. Results are listed following each question.

1. Have you noticed that new streetlights were installed on Fremont between Mary and Hollenbeck in March 2009?

Answer Options	Response Percent
Yes	72.2%
No	27.8%

2. Do you feel that the new streetlights installed March 2009 have improved or not improved visibility for you as a DRIVER?

Answer Options	Response Percent
Strongly improved	36.8%
Somewhat improved	31.6%
No change/ about the same	21.1%
Somewhat not improved	5.3%
Strongly not improved	5.3%
Don't know/ not applicable	0.0%

3. Do you feel that the new streetlights installed this March 2009 have improved visibility for you as a PEDESTRIAN?

Answer Options	Response Percent
Strongly improved	31.6%
Somewhat improved	21.1%
No change/ about the same	31.6%
Somewhat not improved	0.0%
Strongly not improved	5.3%
Don't know/ not applicable	10.5%

4. Do you feel the new streetlights installed March 2009 have made it easier or more difficult to recognize people at night under the streetlights?

Answer Options	Response Percent
Much easier	15.8%
Somewhat easier	26.3%
No Change/ About the same	26.3%
Somewhat more difficult	0.0%
Much more difficult	5.3%
Don't know/ not applicable	26.3%

5. Do you feel that the new streetlights installed this past March create less glare of more glare?

Answer Options	Response Percent
Much less glare	15.8%
Somewhat less glare	21.1%
Somewhat more glare	15.8%
Much more glare	10.5%
About the same as the old lights	21.1%
Don't know/ not applicable	15.8%

6. Do you feel that the new streetlights installed March 2009 give off the right amount of light or are they too bright or too dim?

Answer Options	Response Percent
Right amount of light	66.7%
Much too bright	0.0%
Somewhat too bright	11.1%
Somewhat too dim	16.7%
Don't know/ not applicable	5.6%

7. Next, we'd like to get more specific details on the new streetlights installed this past March and how they may have affected different aspects of the test site. * *X,Y,Z are interchangeable with B,A,C respectively.* *(See page 14)*

The test site's overall appearance						
Answer Options	Strongly improved	Somewhat improved	Somewhat not improved	Strongly not improved	No change	Don't know
Lights closer to Mary (X)	33.3%	27.8%	11.1%	5.6%	11.1%	11.1%
Lights closer to Pome (Y)	35.3%	29.4%	5.9%	5.9%	23.5%	0.0%
Lights closer to Hollenbeck (Z)	23.5%	35.3%	5.9%	5.9%	11.8%	17.6%

The test site's night time safety						
Answer Options	Strongly improved	Somewhat improved	Somewhat not improved	Strongly not improved	No change	Don't know
Lights closer to Mary (X)	22.2%	33.3%	0.0%	5.6%	22.2%	16.7%
Lights closer to Pome (Y)	29.4%	29.4%	0.0%	5.9%	29.4%	5.9%
Lights closer to Hollenbeck (Z)	17.6%	35.3%	0.0%	5.9%	23.5%	17.6%

The test site's night time visibility						
Answer Options	Strongly improved	Somewhat improved	Somewhat not improved	Strongly not improved	No change	Don't know
Lights closer to Mary (X)	27.8%	33.3%	5.6%	5.6%	16.7%	11.1%
Lights closer to Pome (Y)	41.2%	29.4%	0.0%	5.9%	23.5%	0.0%
Lights closer to Hollenbeck (Z)	35.3%	29.4%	0.0%	5.9%	17.6%	11.8%

8. How important is it for you to see the stars at night from your street?

Answer Options	**Response Percent**
Very Important	15.8%
Somewhat Important	57.9%
Slightly Important	10.5%
Not Important at all	15.8%

9. Which of the new streetlights allow you to best see the stars in the sky above?

Answer Options	Response Percent
Vendor X -Lights closer to Mary Ave	20.0%
Vendor Y- Lights closer to Pome Ave	0.0%
Vendor Z- Lights closer to Hollenbeck Ave	20.0%
I can see the stars equally with each Vendor	33.3%
I can't see the stars with any of vendor's streetlights	20.0%
I don't care about seeing the stars	6.7%

10. When all things are considered, do you prefer the New streetlights that were installed last March of do you prefer the Old streetlights they replaced?

Answer Options	Response Percent
Strongly prefer the new streetlights	47.4%
Somewhat prefer the new streetlights	31.6%
Somewhat prefer the old streetlights	0.0%
Strongly prefer the old streetlights	5.3%
There is not much difference	10.5%
Don't know/ not applicable	5.3%

11. Are you a resident of the City of Sunnyvale?

Answer Options	Response Percent
Yes	90.0%
No	10.0%

12. Do you have any children under the age of 18 living at home?

Answer Options	Response Percent
Yes	30.0%
No	70.0%

Conclusion

In 1998 the City of Sunnyvale initiated the transition to LED technology by retrofitting the traffic signals with LED modules. The city enlisted the services of KEMA, Inc. to capture the energy savings.[24] This effort showed a significant energy savings and thus opened the door to consider more efforts to achieve energy savings and greenhouse gas (GHG) emissions reduction.

Recognizing the advances made in LED technology over the past several years the city initiated an effort to look into the feasibility of retrofitting its High-Pressure Sodium streetlights with LED models. Seven LED luminaire vendors were evaluated during the first phase of the project, and preliminary testing was conducted. Based on the results three LED products were selected to proceed with a second phase of the project and a more comprehensive analysis was undertaken. The results of the second phase LED demonstration project reinforced the results obtained in 1998 that LED technology has the potential for energy savings, greenhouse gas emission reduction and also enhancing the safety of pedestrians, bicyclists and drivers by providing better illumination on the sidewalks and roadways.

For the specific demonstration project chosen, ***two of the three LED products showed excellent lighting quality, environmental and safety benefit, and positive citizen feedback, while providing significant economic savings over high pressure sodium luminaires*** currently used by the city. As LED technology continues to be developed and demand for this technology increases these advantages are expected to continue to grow. At the same time, industry ability to accurately predict LED lifetime and light loss factors needs to improve as LED technology matures.

In addition to its longstanding energy conservation policy, Sunnyvale's Council has set a City target for GHG emissions reductions, pledging to reduce CO_2 emissions from City operations to 20% below 1990 levels by 2010. The Council also authorized the Mayor to sign the U.S. Mayor's Climate Protection Agreement and directed that the City become a reporting member of the California Climate Action Registry. In support of these efforts, in October 2006 the community developed a sustainability vision ratified by the Council in May 2007. City staff work in support of this leadership direction has included several studies around the issue of GHG emissions and related sustainability practices, and development of a Framework for Sustainability that identifies the City services, policies, and partnerships that enable achieving the sustainability goals. As the Framework suggests, significantly reducing energy consumption and achieving sustainability will require a high level of interdepartmental planning, collaboration, and coordination.

To meet the City's goal of reducing CO_2 emissions 20% by 2010, the City will need to reduce CO_2 emissions by 3,832,180 lbs. Analysis of City energy use and emissions through Fiscal Year

[24] KEMA Inc." City of Sunnyvale Climate Action Plan – City Operations" June 2007. http://sunnyvale.ca.gov/NR/rdonlyres/C36B4290-CC7D-4554-B218-BD8C022EF4B4/0/SunnyvaleClimateFinalReport62007.pdf

2007/08 shows the City has reduced its emissions by 7 percent or 1,316,041 lbs. since 1990. The 1990 Baseline energy use from Streetlights was 4,774,623 kWh and 2,721,535 lbs. of CO_2 emissions. 2008 data indicates Streetlights consumed 5,268,965 kWh of electricity and produced 3,351,062 lbs of CO_2 emissions[25]. This represents a 21.3% increase from the baseline year. It is estimated that replacing Streetlights with LEDs can save Sunnyvale an additional 2,956,917 kWh per year and 1,549,425 lbs of CO_2 per year[26]. These reductions will move the city toward its goal of 20% reduction by 2010.

The Sunnyvale LED Street Light Demonstration project was limited in scope to make the project feasible. A specific roadway, a small number of specific products, and a particular methodology were used to objectively evaluate the potential of LED products to replace High-Pressure Sodium luminaires. However, no single study can cover all of the variables and scenarios applicable. The reader is advised to look at how other cities have approached the same type of project, their methodologies and their decision making for product choice.

[25] "SustainableSiliconValley2008AnnualReport." *http://www.sustainablesv.org/sites/default/files/dms/media-kitssv-2008-annualreport.pdf*. Sustainable Silicon Valley, n.d. Web. 30 July 2011. <www.sustainablesv.org/sites/default/files/dms/media-kitssv-2008-annualreport.pdf>.

[26] Pacific Gas and Electric Company Carbon Footprint Calculator Assumptions <http://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf>

Appendix A: Monitoring Data

Raw illuminance data measured at the streetlight test area is included below. Longitudinal distance along the roadway is given in the first column. Transverse distance across the roadway measured from median curb is given across the top. Sidewalk measurements, both horizontal and vertical illuminance, are shown in the last two columns.

Vendor A Raw Field Data (foot-candles)

	3.5'	10.5'	17.5'	24.5'	horizontal sidewalk	vertical sidewalk
135.9'	1.78	1.72	1.40	1.01	0.22	0.26
121.6'	1.14	1.14	0.97	0.74	0.24	0.32
107.3'	0.72	0.72	0.61	0.48	0.31	0.45
93.0'	0.55	0.50	0.44	0.34	0.41	0.60
78.7'	0.42	0.46	0.36	0.31	0.51	0.77
64.4'	0.59	0.49	0.37	0.31	0.52	0.78
50.1'	0.62	0.60	0.48	0.38	0.46	0.66
35.8'	0.87	0.84	0.73	0.57	0.34	0.48
21.5'	1.33	1.32	1.10	0.82	0.25	0.33
7.2'	1.98	1.88	1.50	1.05	0.23	0.25

Vendor B Raw Field Data (foot-candles) [affected by shading on the left side]

	3.5'	10.5'	17.5'	24.5'	horizontal sidewalk	vertical sidewalk
135.9'	1.86	1.74	1.37	1.02	0.34	0.39
121.6'	0.84	1.29	0.65	0.71	0.38	0.51
107.3'	0.33	0.15	0.46	0.38	0.32	0.47
93.0'	0.17	0.18	0.27	0.24	0.39	0.53
78.7'	0.21	0.25	0.31	0.36	0.59	0.96
64.4'	0.55	0.54	0.49	0.45	0.77	1.12
50.1'	0.48	0.41	0.43	0.46	0.40	0.65
35.8'	0.56	0.60	0.61	0.46	0.36	0.55
21.5'	1.46	1.33	1.03	0.82	0.35	0.40
7.2'	1.90	1.74	1.36	1.11	0.29	0.53

Vendor C Raw Field Data (foot-candles)

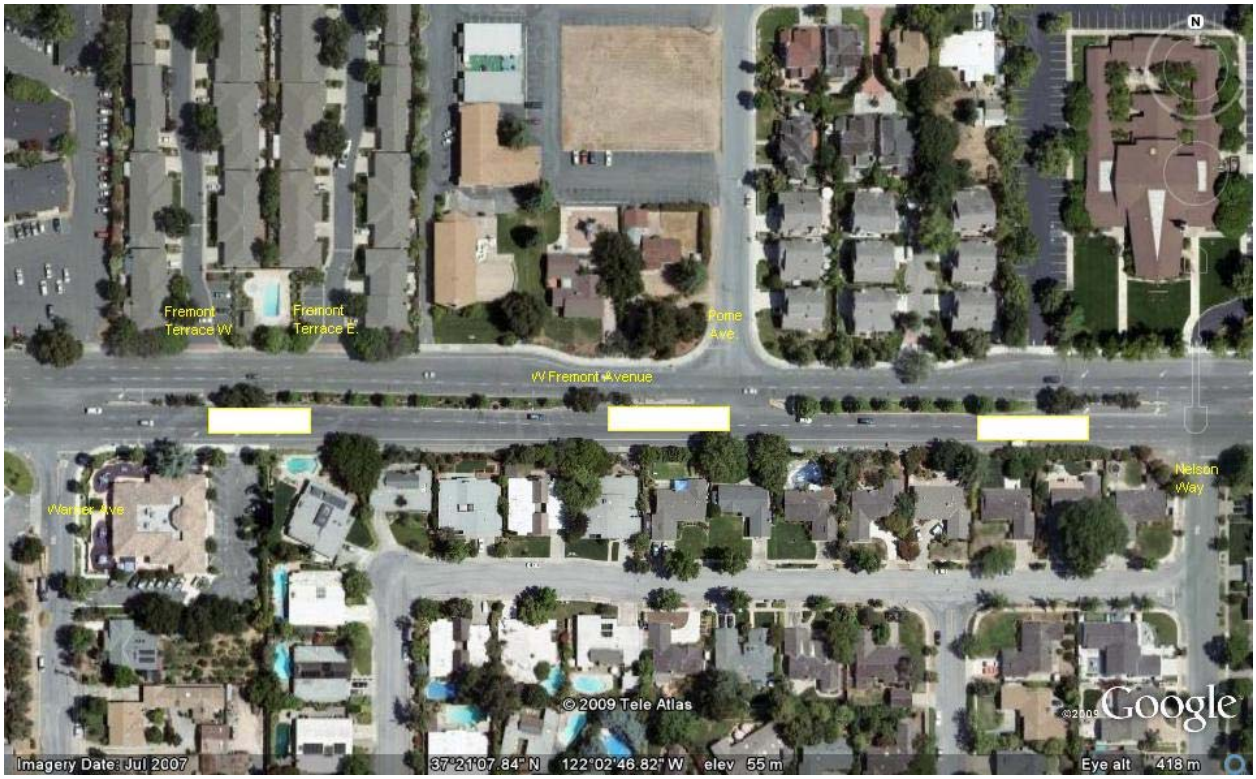
	3.5'	10.5'	17.5'	24.5'	horizontal sidewalk	vertical sidewalk
130.2'	1.83	1.67	1.51	1.32	0.10	0.11
116.5'	1.16	1.00	0.86	0.68	0.15	0.21
102.8'	0.45	0.48	0.43	0.36	0.25	0.34
89.1'	0.19	0.22	0.21	0.20	0.37	0.52
75.4'	0.02	0.05	0.07	0.09	0.67	0.95
61.7'	0.04	0.04	0.06	0.09	0.70	0.99
48.0'	0.17	0.23	0.33	0.21	0.38	0.52
34.3'	0.54	0.51	0.44	0.39	0.27	0.37
20.6'	1.13	1.03	0.85	0.66	0.18	0.24
6.9'	1.89	1.72	1.40	1.29	0.15	0.15

Vendor D Raw Field Data (foot-candles)

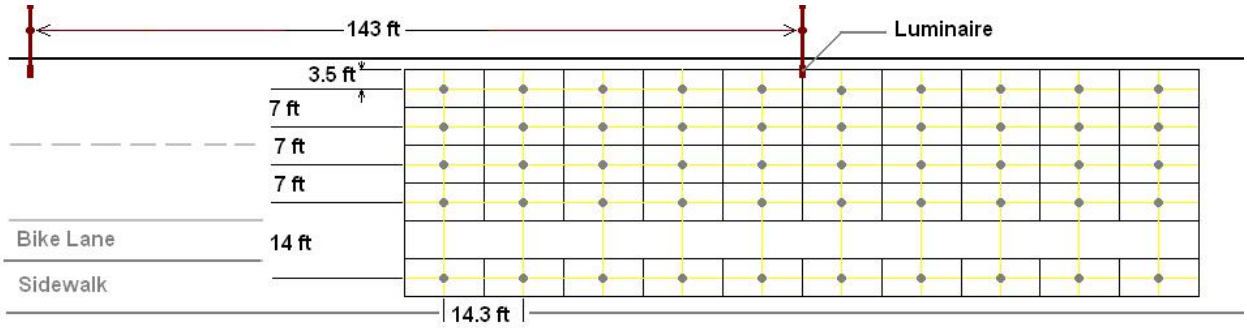
	3.5'	10.5'	17.5'	24.5'	horizontal sidewalk	vertical sidewalk
135.9'	4.73	4.23	2.57	1.66	0.78	0.97
121.6'	3.64	3.43	2.29	1.41	0.70	0.90
107.3'	1.67	1.66	1.53	1.23	0.70	0.96
93.0'	1.25	1.30	1.24	1.10	0.60	0.86
78.7'	0.84	1.01	1.10	1.10	0.63	0.91
64.4'	1.09	1.22	1.23	1.12	0.59	0.86
50.1'	1.26	1.36	1.33	1.19	0.56	0.75
35.8'	2.16	2.20	1.89	1.36	0.66	0.91
21.5'	4.07	3.39	2.07	1.22	0.70	0.91
7.2'	4.70	3.78	2.52	1.66	0.71	0.91

Appendix B: Monitoring Layout

Location of the three grid measurement areas on Fremont Avenue is shown below.



Detail for Vendor A, B, and D grids are shown below. Vendor C grid is similar but has a pole spacing of 137'.



Appendix C: PG&E LED Street Light Rate

PG&E has a published electric rate for streetlights – part of its LS-2 Customer Owned Street and Highway Lighting rate. A fixed rate per day per streetlight is based on the rated wattage of the LED light. Assumptions for this report are based on the LS-2 rate effective as of May 1, 2009. PG&E's LS-2 rate can be found at: http://pge.com/tariffs/tm2/pdf/ELEC_SCHEDS_LS-2.pdf

See Following pages: 59, 60, and 61

Pacific Gas and Electric Company
Rate Schedule LS-2
Customer-Owned Street and Highway Lighting

Rates Effective:
May 1, 2009, to September 30, 2009

CLASS	A	C**
	PG&E supplies energy and service only.	PG&E supplies the energy and maintenance service as described in Special Condition 8
Facilities Charge Per Lamp Per Month	$0.187	$2.688

Energy Charge Per Lamp Per Month
All Night Rates

Nominal Lamp Rating: Lamp Watts	kWh per Month	Average Initial Lumens*	Per Lamp Per Month: All Classes	Half-Hour Adjustment
Incandescent Lamps:				
58	20	600	$2.441	$0.111
92	31	1,000	3.784	0.172
189	65	2,500	7.934	0.361
295	101	4,000 **	12.328	0.560
405	139	6,000 **	16.966	0.771
620	212	10,000 **	25.877	1.176
860	294	15,000 **	35.886	1.631
Mercury Vapor Lamps:				
40	18	1,300	$2.197	$0.100
50	22	1,650	2.685	0.122
100	40	3,500	4.882	0.222
175	68	7,500	8.300	0.377
250	97	11,000	11.840	0.538
400	152	21,000	18.553	0.843
700	266	37,000	32.468	1.476
1,000	377	57,000	46.017	2.092
High Pressure Sodium Vapor Lamps:				
120 Volts				
35	15	2,150	$1.831	$0.083
50	21	3,800	2.563	0.117
70	29	5,800	3.540	0.161
100	41	9,500	5.004	0.227
150	60	16,000	7.324	0.333
200	80	22,000	9.765	0.444
250	100	26,000	12.206	0.555
400	154	46,000	18.797	0.854

Pacific Gas and Electric Company
Rate Schedule LS-2
Customer-Owned Street and Highway Lighting

Rates Effective:
May 1, 2009, to September 30, 2009

Nominal Lamp Rating:			Energy Charge Per Lamp Per Month All Night Rates Per Lamp Per Month	
Lamp Watts	kWh per Month	Average Initial Lumens*	All Classes	Half-Hour Adjustment
High Pressure Sodium Vapor Lamps:				
240 Volts				
50	24	3,800	$2.929	$0.133
70	34	5,800	4.150	0.189
100	47	9,500	5.737	0.261
150	69	16,000	8.422	0.383
200	81	22,000	9.887	0.449
250	100	25,500	12.206	0.555
310	119	37,000	14.525	0.660
360	144	45,000	17.577	0.799
400	154	46,000	18.797	0.854
Low Pressure Sodium Vapor Lamps:				
35	21	4,800	$2.563	$0.117
55	29	8,000	3.540	0.161
90	45	13,500	5.493	0.250
135	62	21,500	7.568	0.344
180	78	33,000	9.521	0.433
Metal Halide Lamps:				
70	30	5,500	$3.662	$0.166
100	41	8,500	5.004	0.227
150	63	13,500	7.690	0.350
175	72	14,000	8.788	0.399
250	105	20,500	12.816	0.583
400	162	30,000	19.774	0.899
1,000	387	90,000	47.237	2.147
Induction Lamps:				
40	14	2,200	$1.709	$0.078
55	19	3,000	2.319	0.105
80	27	4,500	3.296	0.150
85	30	4,800	3.662	0.166
120	42	8,500	5.067	0.230
150	51	10,900	6.225	0.283
165	58	12,000	7.079	0.322

Light Emitting Diode (LED) Lamps: 120-240 Volts

Lamp Watts****	kWh per Month*****	A Only	Half-Hour Adjustment
0.00-5.00	0.9	$0.110	$0.005
5.01-10.00	2.6	0.317	0.014
10.01-15.00	4.3	0.525	0.024
15.01-20.00	6.0	0.732	0.033
20.01-25.00	7.7	0.940	0.043
25.01-30.00	9.4	1.147	0.052
30.01-35.00	11.1	1.355	0.062
35.01-40.00	12.8	1.562	0.071
40.01-45.00	14.5	1.770	0.080
45.01-50.00	16.2	1.977	0.090
50.01-55.00	17.9	2.185	0.099
55.01-60.00	19.6	2.392	0.109
60.01-65.00	21.4	2.612	0.119
65.01-70.00	23.1	2.820	0.128
70.01-75.00	24.8	3.027	0.138
75.01-80.00	26.5	3.235	0.147
80.01-85.00	28.2	3.442	0.156
85.00-90.00	29.9	3.650	0.166
90.01-95.00	31.6	3.857	0.175
95.01-100.00	33.3	4.065	0.185
100.01-105.00	35.0	4.272	0.194
105.01-110.00	36.7	4.480	0.204
110.01-115.00	38.4	4.687	0.213
115.01-120.00	40.1	4.895	0.223
120.01-125.00	41.9	5.114	0.232
125.01-130.00	43.6	5.322	0.242
130.01-135.00	45.3	5.529	0.251
135.01-140.00	47.0	5.737	0.261
140.01-145.00	48.7	5.944	0.270
145.01-150.00	50.4	6.152	0.280
150.01-155.00	52.1	6.359	0.289
155.01-160.00	53.8	6.567	0.299
160.01-165.00	55.5	6.774	0.308
165.01-170.00	57.2	6.982	0.317
170.01-175.00	58.9	7.189	0.327
175.01-180.00	60.6	7.397	0.336
180.01-185.00	62.4	7.617	0.346
185.01-190.00	64.1	7.824	0.356
190.01-195.00	65.8	8.032	0.365
195.01-200.00	67.5	8.239	0.375

Appendix D: Economic Data and Calculations

Table D1: Annual Energy Cost per Luminaire

ESTIMATED ANNUAL ENERGY COSTS

70 Watt HPS (5362 no.)		
Monthly Fixed Charge[1]	4.15	$/fixture
Annual Cost[2]	49.80	$/yr

200 Watt HPS (3429 no.)		
Monthly Fixed Charge	9.887	$/fixture
Annual Cost[2]	118.64	$/yr

150 Watt HPS (141 no.)		
Monthly Fixed Charge[1]	8.422	$/fixture
Annual Cost[2]	101.06	$/yr

Annual Cost for HPS	**70 W**	**150 W**	**200 W**	
	49.80	**101.06**	**118.64**	**$/yr per fixture**

LED	**Vendor A**			**Vendor B**			**Vendor C**			
Lamp Watts[3] (HPS)	70 W	150 W	200 W	70 W	150 W	200 W	70 W	150 W	200 W	
LED Stated Wattage	48 W	80 W	125 W	42 W	99 W	117 W	86 W	86 W	120 W	
Monthly Fixed Charge[1]	1.977	3.235	5.114	1.77	4.065	4.895	3.65	3.65	4.895	$/fixture
Annual Cost[2]	23.72	38.82	61.37	21.24	48.78	58.74	43.80	43.80	58.74	$/yr
Estimated Annual Energy Savings[4]	**26.08**	**62.24**	**57.28**	**28.56**	**52.28**	**59.90**	**6.00**	**57.26**	**59.90**	**$/yr per fixture**

[1]As per PG&E LS-2 2009 Rate Structure. Only Energy Charge per Lamp per Month is used. Facility Charge per Lamp per Month not included

[2]Monthly fixed charge x 12

[3]Lamp Watts as obtained from the Vendors

[4]Annual Cost for HPS - Annual Cost for LED

Table D2: Annual Maintenance Cost per HPS Luminaire

HPS Luminaire Maintenance Cost Estimates							
Details							
	Maintenance Category						
	Group			Burnout			
	70 W	**150 W**	**200 W**	**70 W**	**150 W**	**200 W**	
Cost per Replacement[1]	337.5	347.5	357.5	367.5	377.5	387.5	$/fixture
Annual Replacement Frequency[2]	8.2	8.2	8.2	8.1	8.1	8.1	%/yr
Annual Replacement Cost[3]	27.675	28.495	29.315	29.768	30.578	31.388	$/yr

	70 W	**150 W**	**200 W**
Annual Replacement Cost per Luminaire[4]	$57.44	$59.07	$60.70
Annual Hazardous Disposal Cost per Lamp[5]	$0.90	$0.90	$0.90
Total Annual Maintenance Cost per Luminaire[6]	**$58.34**	**$59.97**	**$61.60**

[1]From City Maintenance Contractor. Includes Labor and Material Cost, does not include Adminiatrative Overhaed

[2]Assumed based on past City records

[3]Cost per replacement x Annual replacement Frequency

[4]Sum of annual replacement cost for each wattage in each maintenance category

[5]HID lamps incur hazardous waste disposal costs. The Cost obtained from the City Public Work Supervisor

[6]Total Annual maintenance cost based on sum of annual replacement cost for lamps in group and burnout categories

Table D3: Annual Maintenance Cost per LED Luminaire

LED Luminaire Maintenance Cost Estimates

Assumptions	
Rate of Failure before end of rated lamp life[1]	10%
Luminaire Operating Hours	4100 hr/yr
Emergency Replacement Labor Cost[2]	$187.50
Routine Service Labor Cost[3]	$67.50
Routine Service Interval (yr)	5
Luminaire Life	50000 hrs

Replacement Frequency and Manufacturer's Warranty Details	Vendor A			Vendor B			Vendor C			
	eq.70 W	eq. 150 W	eq. 200 W	eq.70 W	eq. 150 W	eq. 200 W	eq.70 W	eq. 150 W	eq. 200 W	
Luminaire Life	50000	50000	50000	50000	50000	50000	50000	50000	50000	hr
	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	yr
Manufacturer Warranty	5	5	5	5	5	5	10	10	10	yr
Annual Probability of Failure[4]	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	%
Probability of Failure Within Warranty[5]	4.23	4.23	4.23	4.23	4.23	4.23	8.28	8.28	8.28	%
Probability of Failure Outside of Warranty[6]	6.03	6.03	6.03	6.03	6.03	6.03	1.88	1.88	1.88	%

Economic Details	Vendor A			Vendor B			Vendor C			
	eq. 70 W	eq. 150 W	eq.200 W	eq.70 W	eq. 150 W	eq.200 W	eq. 70 W	eq. 150 W	eq. 200 W	
Luminaire Cost (Bulk Rate)	435	595	795	325	607	662	752.35	752.35	905.81	$/luminaire
Annual Cost of Failure Within Warranty[7]	0.65	0.65	0.65	0.65	0.65	0.65	1.27	1.27	1.27	$/luminaire
Annual Cost of Failure Outside of Warranty[8]	3.08	3.87	4.86	2.53	3.93	4.20	1.45	1.45	1.68	$/luminaire
Total Annual Cost of Failure	3.73	4.52	5.51	3.18	4.58	4.85	2.72	2.72	2.96	$/yr
Total Annual Cost of Routine Service[9]	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	$/yr
Total Annual Maintenance Cost	17.23	18.02	19.01	16.68	18.08	18.35	16.22	16.22	16.46	$/yr

[1]Assumption based on some fraction of luminaires will fall catastrophically before LED lamp failure due to normal wear and tear

[2]Cost equal to cost of labor only for emergency HPS lamp replacement. Material cost not included.

[3]Cost equal to cost of labor only for routine group HPS lamp replacement. Material cost not included.

[4]Based on luminaire life and assumed failure rate: 1 - (1 - Failure rate) ^ (1/luminaire life in yrs)

[5]Based on annual probability of failure and length of warranty: 1 - (1 - Annual probability of failure) ^ (Length of Warranty)

[6]Based on annual probability of failure, luminaire life and length of warranty: 1 - (1 - Annual probability of failure) ^ (luminaire life - length of warranty)

[7](Emergency replacement cost) * Probability of failure within warranty/ luminaire life in years

[8](Emergency replacement cost + luminaire cost) * Probability of failure outside warranty /luminaire life in years

[9]Cost based on routine service cost * (1/Routine service interval)

TableD4: Simple Payback for New Construction and Retrofit Scenarios

Simple Payback Calculations

New Construction Scenario

Incremental Costs and Savings	Vendor A			Vendor B			Vendor C			
	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	
Incremental Cost	165.00	315.00	505.00	55.00	327.00	372.00	482.35	472.35	615.81	$/fixture
Annual Energy Savings	26.08	62.24	57.28	28.56	52.28	59.90	6.00	57.26	59.90	$/fixture
Annual Maintenance Savings	41.12	41.96	42.60	41.66	41.90	43.25	42.12	43.75	45.15	$/fixture
Simple Payback[1]	2.5	3.0	5.1	0.8	3.5	3.6	10.0	4.7	5.9	yr

Retrofit Scenario

Incremental Costs and Savings	Vendor A			Vendor B			Vendor C			
	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	
Incremental Cost	452.50	562.50	737.50	342.50	574.50	604.50	769.85	719.85	848.31	$/fixture
Annual Energy Savings	26.08	62.24	57.28	28.56	52.28	59.90	6.00	57.26	59.90	$/fixture
Annual Maintenance Savings	41.12	41.96	42.60	41.66	41.90	43.25	42.12	43.75	45.15	$/fixture
Simple Payback[1]	6.7	5.4	7.4	4.9	6.1	5.9	16.0	7.1	8.1	yr

[1]Incremental Cost/ (annual Energy Cost + Annual Maintenance Cost)

Table D5: Net Present Value for New Construction and Retrofit Scenarios

Net Present Value Calculations

New Construction Scenario

Economics	Vendor A			Vendor B			Vendor C			
	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	
Real Discount Rate[1]	5	5	5	5	5	5	5	5	5	%/yr
Cost Escalation	3	3	3	3	3	3	3	3	3	%/yr
Term of Analysis	10	10	10	10	10	10	10	10	10	yr
Equivalent Discount Rate[2]	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	%/yr
PVF[3]	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	
NPV[4]	440.40	623.84	394.86	577.68	521.56	557.46	-48.77	437.81	330.69	$

Retrofit Scenario

Economics	Vendor A			Vendor B			Vendor C			
	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	eq.70 W	eq.150 W	eq. 200 W	
Real Discount Rate[1]	5	5	5	5	5	5	5	5	5	%/yr
Cost Escalation	3	3	3	3	3	3	3	3	3	%/yr
Term of Analysis	10	10	10	10	10	10	10	10	10	yr
Equivalent Discount Rate[2]	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	%/yr
PVF[3]	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	
NPV[4]	152.90	376.34	162.36	290.18	274.06	324.96	-336.27	190.31	98.19	$

[1]Expected rate of return on large capital investments as estimated by municipal or utility scale customer

[2](Real Discount Rate - Cost Escalation) / (1 + Cost Escalation)

[3](((1 + Equivalent Discount Rate)^y) - 1) / (Equivalent Discount Rate x ((1 + Equivalent Discount Rate)^y)

[4]((Annual Energy Savings + Annual Maiantenance Savings) x PVF) - Incremental Cost

Table D6: Internal Rate of Return for New Construction and Retrofit Scenarios

Internal Rate of Return								
Vendor A			Vendor B			Vendor C		
eq. 70 W	eq. 150 W	eq. 200 W	eq. 70 W	eq. 150 W	eq. 200 W	eq. 70 W	eq. 150 W	eq. 200 W
New Construction								
42%	35%	18%	135%	30%	28%	-	20%	14%
Retrofit								
11%	17%	9%	19%	14%	14%	-	10%	16%

Appendix E: Photometric Report

Vendor A Photometric Report (closest matching product, supplied by vendor)

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

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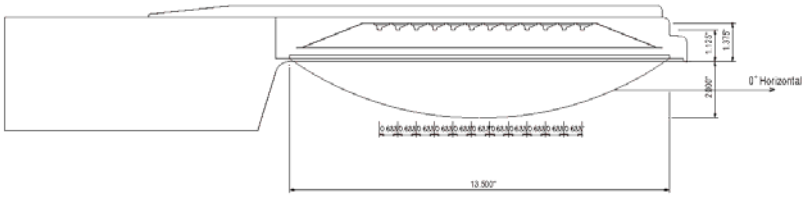
LTL NUMBER: 13629 DATE: 07-25-2008
PREPARED FOR: LEOTEK ELECTRONICS USA CORP
CATALOG NUMBER: SL-320W1M3-FX (FX4-120W1M3M-0)
LUMINAIRE: CAST ALUMINUM HOUSING, MOLDED GRAY PLASTIC REFLECTOR,
CLEAR PLASTIC ENCLOSURE.
LAMP: 120 WHITE LEDS
LED POWER SUPPLY: ONE LEOTEK LP1090-24-GG-170
ELECTRICAL VALUES: 120.0VAC, 1.0685A, 126.7W
LUMINAIRE EFFICACY: 52.5 LUMENS/WATT
POWER FACTOR: 0.9881
NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED
PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*

#13629



IES CLASSIFICATION: **TYPE III**
LONGITUDINAL CLASSIFICATION: **MEDIUM**
CUTOFF CLASSIFICATION: **CUTOFF****

**CUTOFF DESIGNATION IS NOT DEFINED FOR ABSOLUTE PHOTOMETRIC TESTS. THIS CUTOFF RATING IS BASED ON THE MAXIMUM CANDELA READING PER LUMINAIRE RATED AT 1000 LUMENS.

FLUX DISTRIBUTION

LUMENS	DOWNWARD	UPWARD	TOTALS
HOUSE SIDE	2834.08	0.00	2834.08
STREET SIDE	3815.63	3.56	3819.19
TOTALS	6649.71	3.56	6653.27

Approved By: MG

*DATA WAS ACQUIRED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY. A UDT MODEL #211 PHOTODETECTOR AND UDT MODEL #S370 OPTOMETER COMBINATION WERE USED AS A STANDARD. A SPECTRAL MISMATCH CORRECTION FACTOR WAS EMPLOYED BASED ON THE SPECTRAL RESPONSIVITY OF THE PHOTODETECTOR AND THE SPECTRAL POWER DISTRIBUTION OF THE TEST SUBJECT.

TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.
TEST ANGULAR INCREMENTS AND REPORT FORMATTING WAS BASED ON IES LM-31-95.

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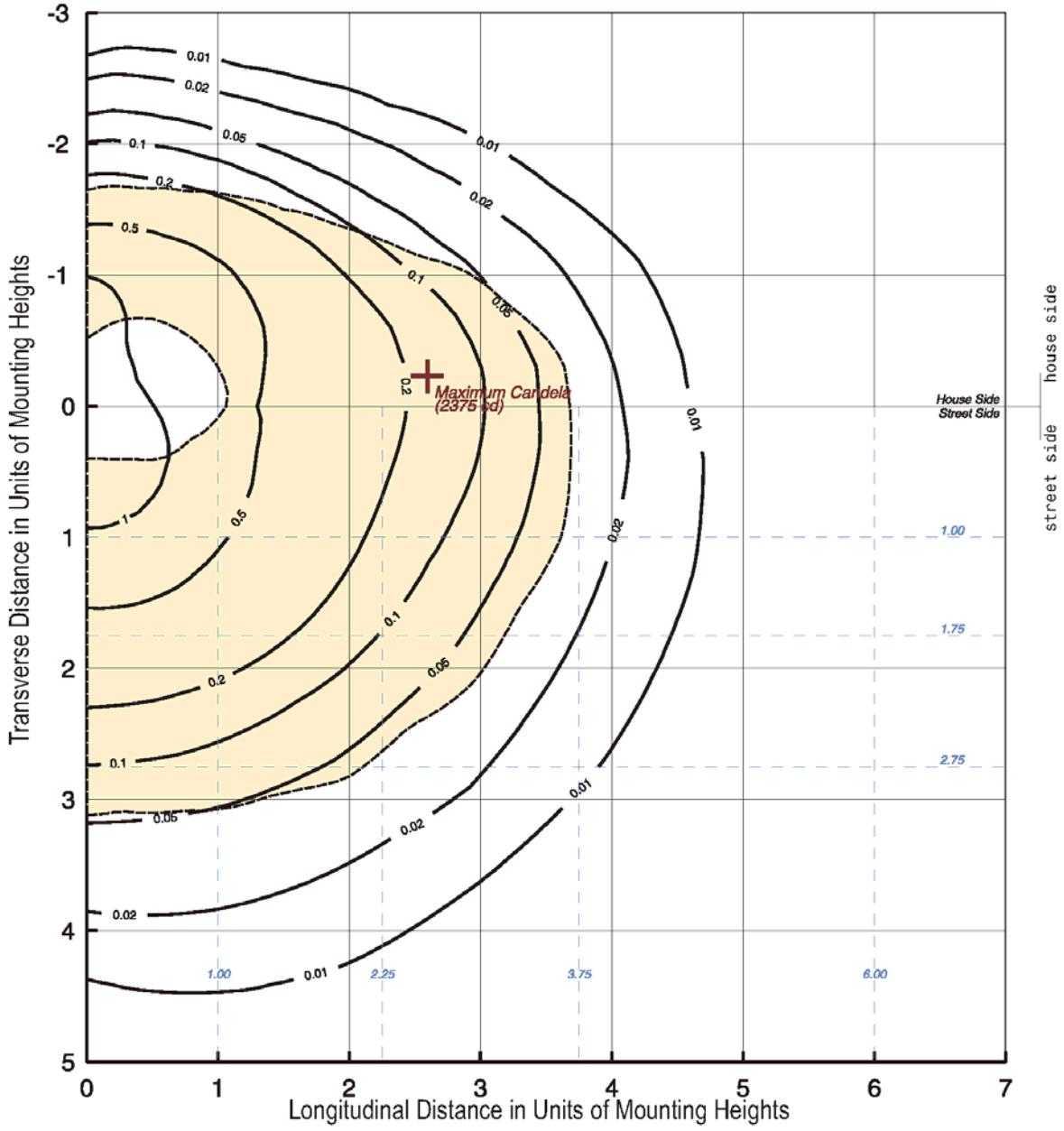
ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION
VALUES BASED ON 25.00 FOOT MOUNTING HEIGHT



PROJECTION OF HALF-MAX CANDELA CONTOUR

PAGE 2-LTL NUMBER 13629

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CANDELA DISTRIBUTION

	0	5	15	25	35	45	55	65	75	85	90
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	3	3	3	3	7	7	9	7	3	0	0
90	22	19	19	19	16	15	15	19	12	3	0
87.5	19	16	16	19	18	18	16	18	15	16	13
85	31	27	28	37	46	37	45	27	25	18	18
82.5	121	131	200	230	230	180	236	227	210	167	118
80	266	330	456	468	477	462	522	502	525	425	335
77.5	523	584	684	725	753	769	810	807	817	771	678
75	842	883	939	977	1014	1093	1108	1127	1203	1154	1127
72.5	1156	1160	1190	1276	1321	1351	1446	1504	1677	1829	1803
70	1550	1507	1563	1567	1600	1700	1764	1826	2019	2271	2324
69	1662	1646	1659	1680	1715	1825	1880	1938	2034	2272	2365
67.5	1855	1822	1861	1897	1956	2022	2037	2031	2083	2232	2280
65	2051	2065	2087	2198	2175	2192	2123	2090	2056	2047	2093
62.5	2052	2055	2064	2137	2147	2102	2056	2010	1967	1967	1944
60	2003	2008	2077	2064	2044	1947	1894	1855	1816	1861	1868
57.5	1985	2016	1977	1967	1919	1826	1759	1676	1661	1673	1739
55	1870	1889	1947	1871	1819	1741	1664	1591	1531	1512	1522
52.5	1791	1816	1806	1765	1741	1691	1603	1503	1472	1427	1381
50	1728	1744	1716	1688	1661	1627	1546	1463	1351	1296	1314
47.5	1664	1673	1674	1627	1585	1563	1485	1400	1285	1246	1199
45	1618	1630	1615	1586	1539	1497	1424	1351	1257	1181	1153
40	1554	1552	1513	1479	1428	1363	1308	1254	1169	1084	1035
35	1443	1439	1421	1385	1327	1255	1194	1123	1054	983	939
30	1351	1351	1327	1294	1252	1187	1123	1060	989	932	892
25	1250	1251	1233	1203	1167	1118	1069	1018	963	908	880
20	1164	1161	1154	1127	1105	1074	1035	999	963	923	898
15	1076	1075	1069	1057	1039	1012	983	959	933	901	889
10	1012	1012	1008	997	983	971	950	927	911	892	883
5	938	939	935	930	926	918	911	904	895	886	883
0	884	884	884	884	884	884	884	884	884	884	884

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CANDELA DISTRIBUTION

	95	105	115	125	135	145	155	165	175	180
180	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0
87.5	9	6	0	0	0	0	0	0	0	0
85	22	19	12	10	7	0	0	0	0	0
82.5	106	130	76	46	25	18	4	0	0	0
80	325	291	160	94	58	37	18	7	0	0
77.5	644	499	291	170	98	58	27	22	13	6
75	1085	795	473	285	152	84	37	24	22	24
72.5	1789	1288	757	461	271	160	89	63	46	24
70	2347	1889	1175	728	465	298	209	176	149	119
69	2375	2035	1378	865	562	371	273	236	213	176
67.5	2321	2157	1633	1144	747	531	416	355	330	286
65	2160	2195	1907	1570	1145	902	732	626	593	531
62.5	1992	2096	2037	1882	1519	1248	1033	910	883	817
60	1876	1980	1970	1923	1749	1488	1305	1170	1118	1056
57.5	1774	1801	1873	1882	1880	1691	1491	1393	1358	1291
55	1546	1651	1719	1771	1835	1810	1654	1583	1506	1470
52.5	1421	1460	1566	1640	1733	1779	1753	1668	1703	1691
50	1282	1317	1422	1534	1601	1664	1734	1809	1800	1756
47.5	1202	1214	1312	1402	1479	1548	1633	1727	1798	1810
45	1117	1136	1187	1278	1349	1422	1497	1624	1713	1750
40	1000	975	996	1047	1127	1214	1314	1427	1554	1586
35	901	859	857	887	959	1038	1139	1255	1357	1393
30	859	820	804	822	874	932	1020	1136	1208	1235
25	854	814	799	813	856	898	962	1060	1129	1148
20	872	847	823	829	862	899	956	1003	1056	1068
15	874	850	836	841	857	890	918	939	959	954
10	880	866	860	860	866	874	883	892	898	889
5	884	877	872	872	869	868	866	868	869	862
0	884	884	884	884	884	884	884	884	884	884

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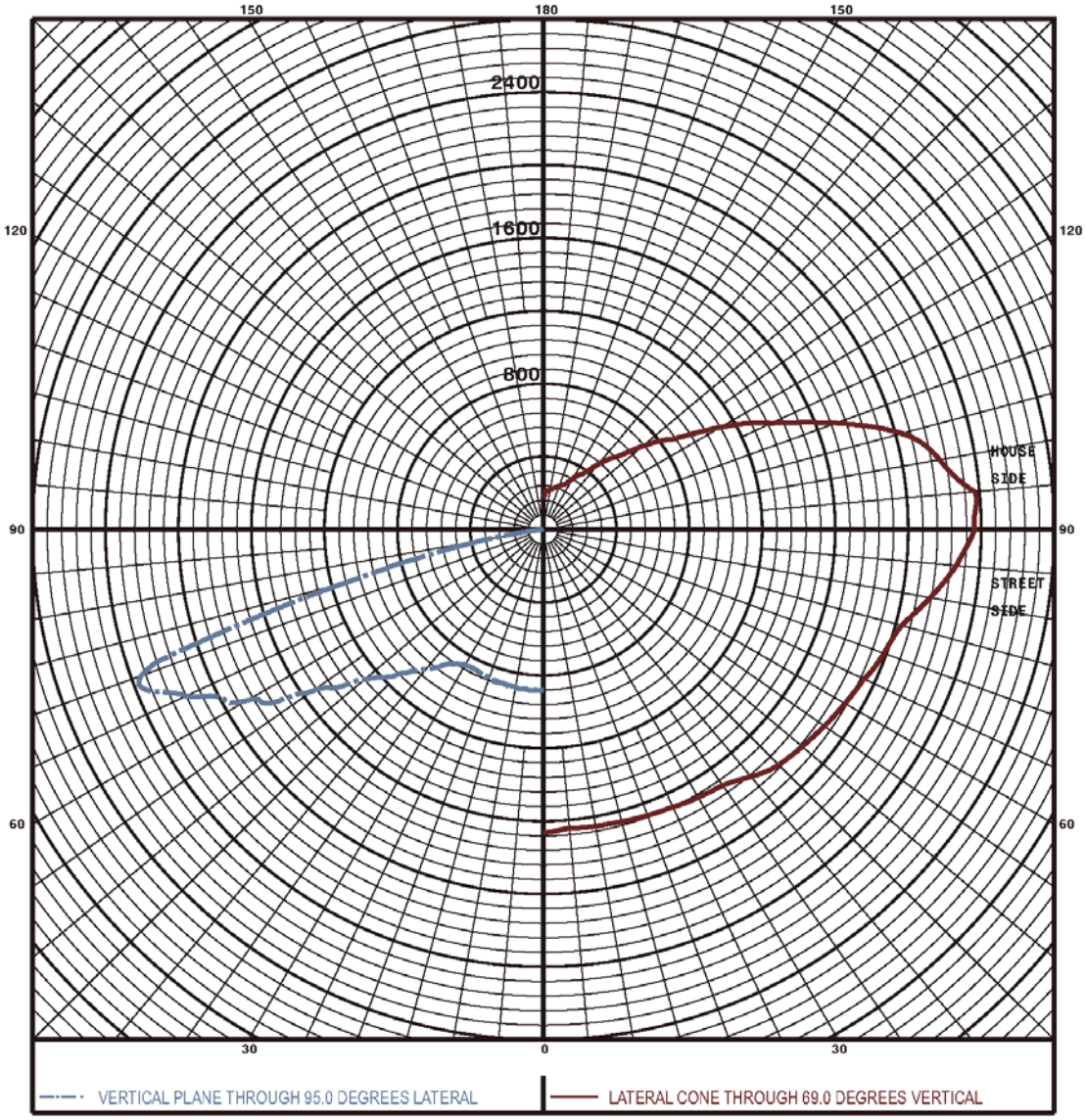
MAXIMUM PLANE AND CONE PLOTS OF CANDELA



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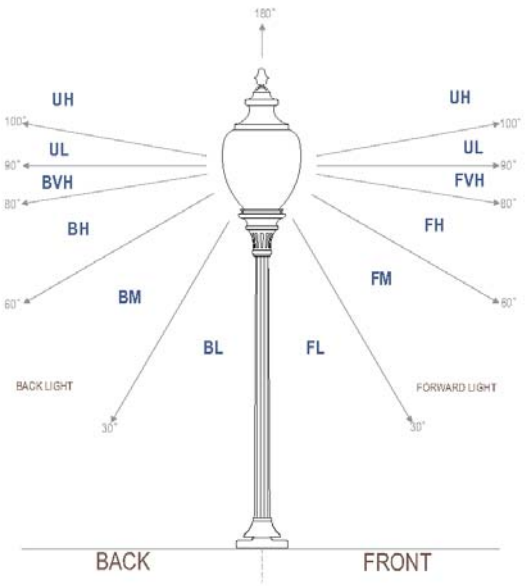
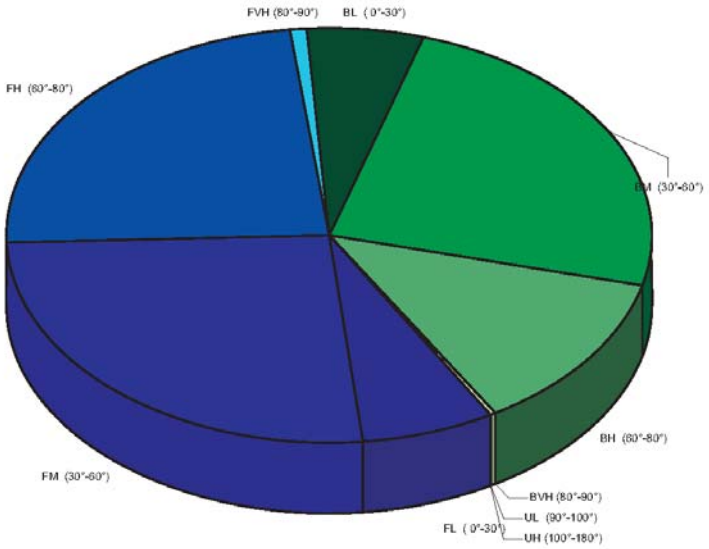
FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



ZONE	FLUX LUMINAIRE LUMENS	FLUX % OF LUMINAIRE LUMENS
FORWARD LIGHT	3816	57.3
FL (0°-30°)	445	6.7
FM (30°-60°)	1739	26.1
FH (60°-80°)	1569	23.6
FVH (80°-90°)	63	1
BACK LIGHT	2834	42.6
BL (0°-30°)	380	5.7
BM (30°-60°)	1605	24.1
BH (60°-80°)	836	12.6
BVH (80°-90°)	14	0.2
UPLIGHT	4	0.1
UL (90°-100°)	4	0.1
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



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Vendor B Photometric Report (supplied by vendor) – scaling is required to match the 60 LED model

IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

DESCRIPTIVE INFORMATION (From Photometric File)

IESNA:LM-63-2002
[TEST]ITL61067
[TESTLAB]INDEPENDENT TESTING LABORATORIES, INC.
[ISSUEDATE]09/25/08
[MANUFAC]BETA LIGHTING, INC.
[LUMCAT]BLD-STR-T3-__-025-LED-B-525 (BXSL03025B-U)
[LUMINAIRE] Type III 30 LED LEDWay operating at 525mA
[MORE]THREE CIRCUIT BOARDS EACH WITH 10 LEDS AND CAST GRAY PAINTED
[MORE]METAL TRIM PLATE, ONE CLEAR PLASTIC NON-INTEGRAL LENS BELOW
[MORE]EACH LED.
[LAMP]THIRTY WHITE LIGHT EMITTING DIODES (LEDS), EACH WITH CLEAR
[MORE]HEMISPHERICAL INTEGRAL LENS, VERTICAL BASE-UP POSITION.
[OTHER]TOTAL INPUT WATTS = 58.9 AT 277.0 VOLTS
[_LEDDRIVER]ADVANCE LEDINTA1400C50F30M
[_NOTE]DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT
[MORE]VOLTAGE (277VAC) TO THE LED DRIVER.

CHARACTERISTICS

IES Classification	Type III
Longitudinal Classification	Short
Cutoff Classification (deprecated)	Full Cutoff
Total Rated Lamp Lumens	3413
Maximum Candela	1922
Maximum Candela Angle	62H 63V
Maximum Candela At 90 Degrees Vertical	0 (0.0% Lamp Lms)
Maximum Candela from 80 to <90 Degrees Vertical	336 (9.8% Lamp Lms)
Downward Total Efficiency	100.0%
Total Luminaire Watts	59
Ballast Factor	1.00

Photometric Toolbox Professional Edition (c) copyright 1995-2008 by Lighting Analysts, Inc.
Calculations based on published IES Methods and recommendations, values rounded for display purposes.
Results derived from content of manufacturers photometric file.

IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

LUMINAIRE CLASSIFICATION SYSTEM (LCS)

	Lumens	% Lamp	% Luminaire
FL - Front-Low (0-30)	273.5	8.0	8.0
FM - Front-Medium (30-60)	921.9	27.0	27.0
FH - Front-High (60-80)	722.5	21.2	21.2
FVH - Front-Very High (80-90)	10.2	0.3	0.3
BL - Back-Low (0-30)	239.5	7.0	7.0
BM - Back-Medium (30-60)	873.5	25.6	25.6
BH - Back-High (60-80)	364.8	10.7	10.7
BVH - Back-Very High (80-90)	7.6	0.2	0.2
UL - Uplight-Low (90-100)	0.0	0.0	0.0
UH - Uplight-High (100-180)	0.0	0.0	0.0
Total	3413.5	100.0	100.0

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Calculations based on published IES Methods and recommendations, values rounded for display purposes.
Results derived from content of manufacturers photometric file.

IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

CANDELA TABULATION

Vert. Angles	Horizontal Angles									
	0	5	15	25	35	45	55	62	65	75
0.0	604	604	604	604	604	604	604	604	604	604
2.5	590	588	590	591	591	593	594	597	597	599
5.0	573	571	575	580	584	588	590	592	593	591
7.5	563	561	567	576	583	588	587	587	587	585
10.0	555	554	558	568	576	580	577	576	577	579
12.5	542	541	549	558	566	571	570	574	576	584
15.0	532	531	544	555	563	577	586	595	598	608
17.5	534	534	552	563	571	598	618	631	636	645
20.0	564	564	576	576	591	633	664	682	687	700
22.5	625	622	616	598	623	670	710	735	744	765
25.0	674	673	653	614	650	697	739	767	776	801
27.5	713	715	680	623	661	706	743	773	783	807
30.0	762	763	699	631	661	695	733	761	771	802
32.5	864	864	755	662	657	673	708	737	748	784
35.0	997	993	827	734	686	651	674	703	714	754
37.5	1113	1107	886	799	750	673	640	659	668	697
40.0	1184	1169	907	854	812	739	637	617	623	634
42.5	1170	1144	847	833	859	807	694	605	600	591
45.0	1363	1285	822	791	821	865	740	630	603	577
47.5	1500	1426	878	727	772	816	724	632	607	570
50.0	1398	1340	949	657	658	708	664	603	594	567
52.5	1025	1042	935	801	642	673	703	630	617	586
55.0	903	854	844	996	877	834	816	730	696	643
57.5	988	905	683	1032	1120	1127	1158	926	830	721
60.0	1129	1041	716	955	1207	1234	1627	1498	1277	801
62.5	1110	1045	749	856	1126	1217	1611	1920	1797	1123
63.0	1058	990	724	821	1097	1221	1528	1922	1845	1261
65.0	896	843	623	689	970	1188	1349	1705	1736	1500
67.5	681	630	476	510	712	1033	1298	1452	1461	1458
70.0	481	437	337	360	454	807	1225	1334	1292	1185
72.5	281	263	212	219	268	521	1009	1121	1039	800
75.0	115	120	122	117	149	275	716	822	738	384
77.5	48	51	64	65	79	131	442	498	404	110
80.0	27	27	32	36	41	60	223	209	132	34
82.5	16	16	17	18	20	27	83	58	35	16
85.0	7	7	7	8	8	9	25	13	9	7
87.5	1	1	1	1	1	1	3	3	3	2
90.0	0	0	0	0	0	0	0	0	0	0

Vert. Angles	Horizontal Angles									
	85	90	95	105	115	125	135	145	155	165
0.0	604	604	604	604	604	604	604	604	604	604
2.5	603	602	604	603	606	606	606	609	610	612
5.0	593	592	594	593	597	598	601	606	608	613
7.5	589	590	592	593	597	594	592	593	593	594
10.0	587	590	593	593	589	578	567	560	555	555
12.5	595	598	598	588	572	549	529	516	506	504
15.0	614	611	605	582	553	522	499	481	465	461
17.5	642	632	617	575	535	509	494	474	449	432
20.0	691	673	646	572	523	516	508	482	442	409
22.5	759	737	703	602	552	552	530	494	440	394
25.0	800	785	763	705	686	632	573	527	464	409

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Results derived from content of manufacturers photometric file.

CANDELA TABULATION - (Cont.)

27.5	809	798	787	807	857	766	654	588	509	457
30.0	810	804	802	867	958	890	757	645	552	514
32.5	800	801	816	922	1000	962	822	668	591	576
35.0	776	790	831	973	1033	974	807	667	623	651
37.5	727	762	834	1014	1054	939	752	654	681	755
40.0	656	708	813	1015	1049	871	695	669	778	850
42.5	603	659	764	963	976	783	645	745	857	900
45.0	588	644	739	889	872	693	663	841	916	928
47.5	592	654	737	835	773	626	763	932	949	904
50.0	610	677	750	792	682	641	891	951	896	759
52.5	644	711	765	776	629	758	934	910	716	580
55.0	679	722	750	743	644	904	912	728	474	459
57.5	716	717	710	735	710	947	818	430	379	417
60.0	795	766	716	802	862	905	566	404	430	429
62.5	904	838	760	919	1045	833	376	364	324	291
63.0	973	877	788	957	1086	791	342	322	281	232
65.0	1191	1053	929	1054	1111	616	252	210	153	100
67.5	1336	1224	1103	1140	961	250	98	71	64	69
70.0	1150	1126	1112	1213	735	71	49	51	49	49
72.5	746	811	867	1112	557	42	39	38	34	35
75.0	323	414	550	929	412	31	31	27	25	26
77.5	78	118	227	670	237	23	22	18	19	19
80.0	29	44	96	336	83	15	13	13	13	11
82.5	16	20	39	94	16	8	6	7	5	4
85.0	7	7	9	10	4	3	2	1	0	0
87.5	2	2	2	2	1	0	0	0	0	0
90.0	0	0	0	0	0	0	0	0	0	0

Vert. Angles	**Horizontal Angles**	
	175	**180**
0.0	604	604
2.5	611	610
5.0	614	614
7.5	596	596
10.0	555	555
12.5	505	506
15.0	463	464
17.5	427	427
20.0	396	395
22.5	374	372
25.0	384	381
27.5	433	429
30.0	500	496
32.5	577	575
35.0	681	682
37.5	791	793
40.0	873	872
42.5	907	905
45.0	903	895
47.5	828	813
50.0	669	657
52.5	552	546
55.0	479	479
57.5	439	439
60.0	419	414

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Results derived from content of manufacturers photometric file.

IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

CANDELA TABULATION - (Cont.)

62.5	256	251
63.0	199	195
65.0	100	102
67.5	77	78
70.0	54	55
72.5	39	40
75.0	30	31
77.5	23	23
80.0	13	13
82.5	4	4
85.0	0	0
87.5	0	0
90.0	0	0

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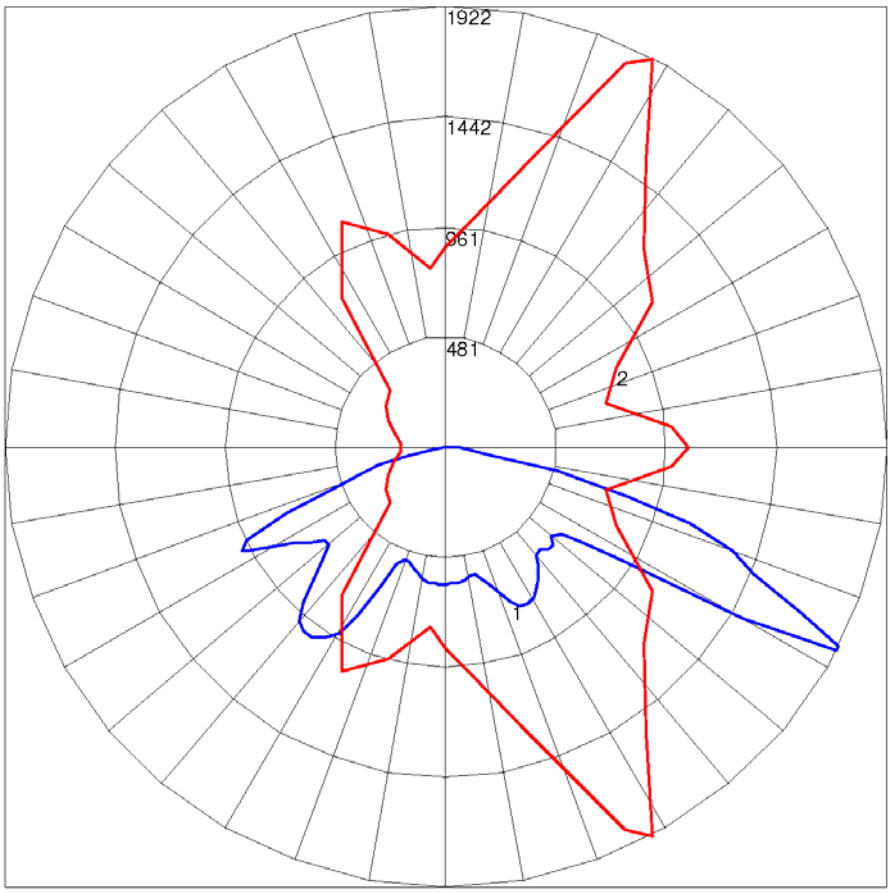
IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

POLAR GRAPH



Maximum Candela = 1922 Located At Horizontal Angle = 62, Vertical Angle = 63
1 - Vertical Plane Through Horizontal Angles (62 - 242) (Through Max. Cd.)
2 - Horizontal Cone Through Vertical Angle (63) (Through Max. Cd.)

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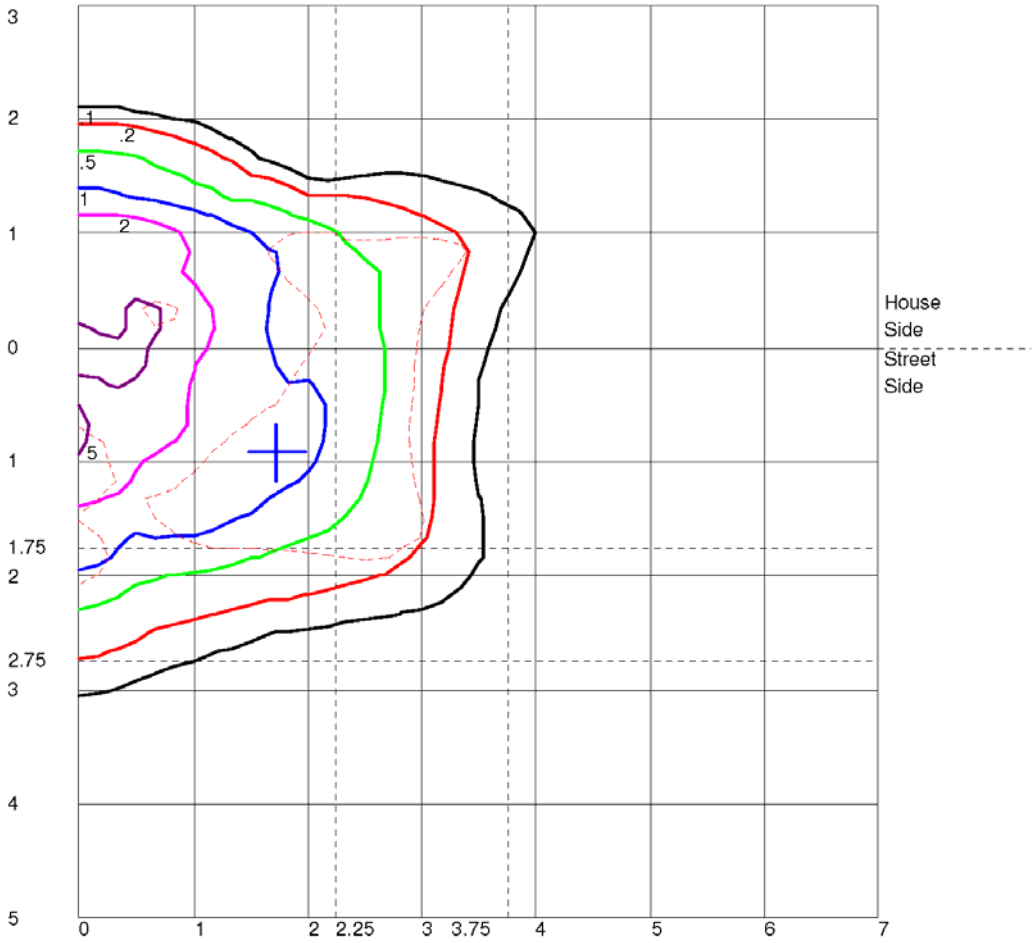
Results derived from content of manufacturers photometric file.

IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINANCE



Distance In Units Of Mounting Height
Values Based On 10 Foot Mounting Height
1/2 Maximum Candela Trace Shown As Dashed Curve
(+) = Maximum Candela Point

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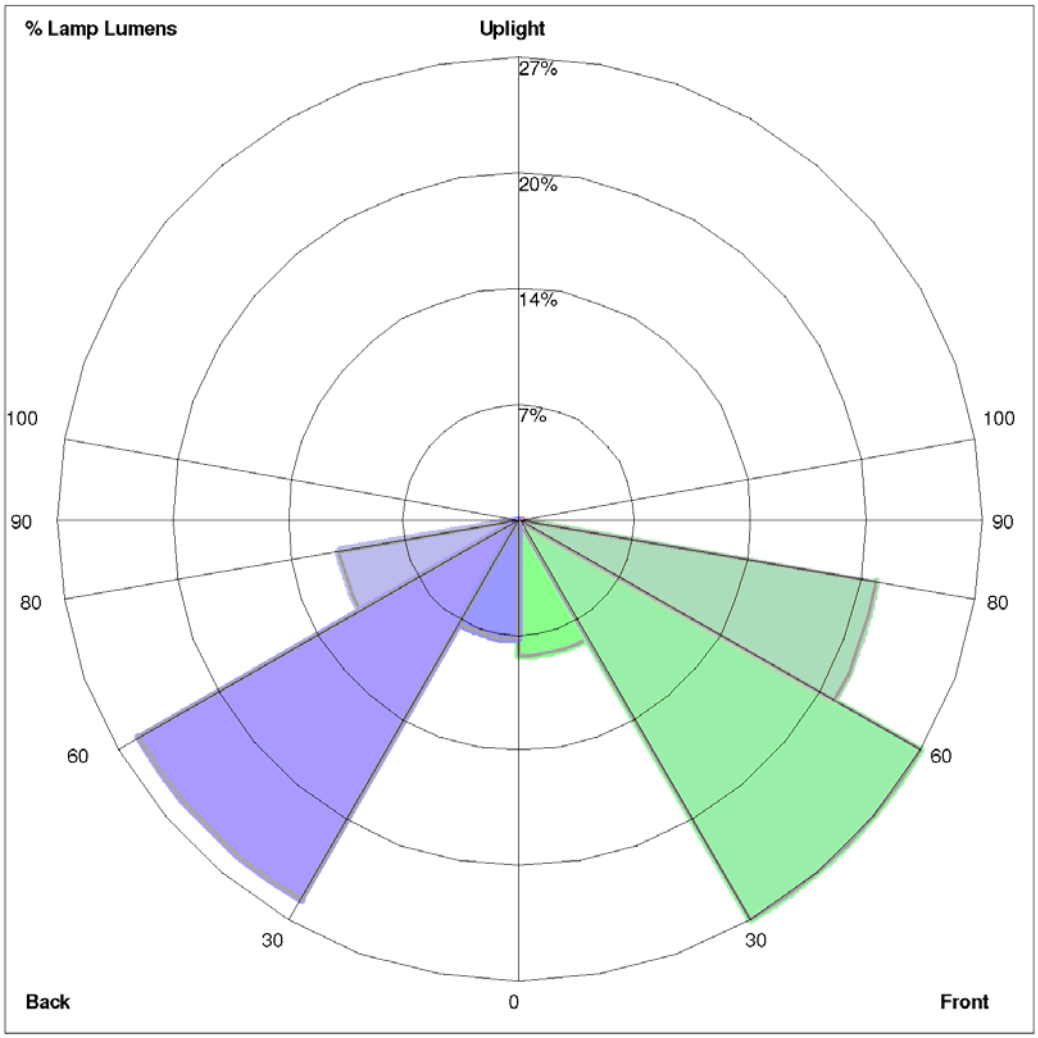
IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

LUMINAIRE CLASSIFICATION SYSTEM (LCS) GRAPH



Percent Lamp Lumens:
Front: Low=8.0%, Medium=27.0%, High=21.2%, Very High=0.3%
Back: Low=7.0%, Medium=25.6%, High=10.7%, Very High=0.2%
Uplight: Low=0.0%, High=0.0%

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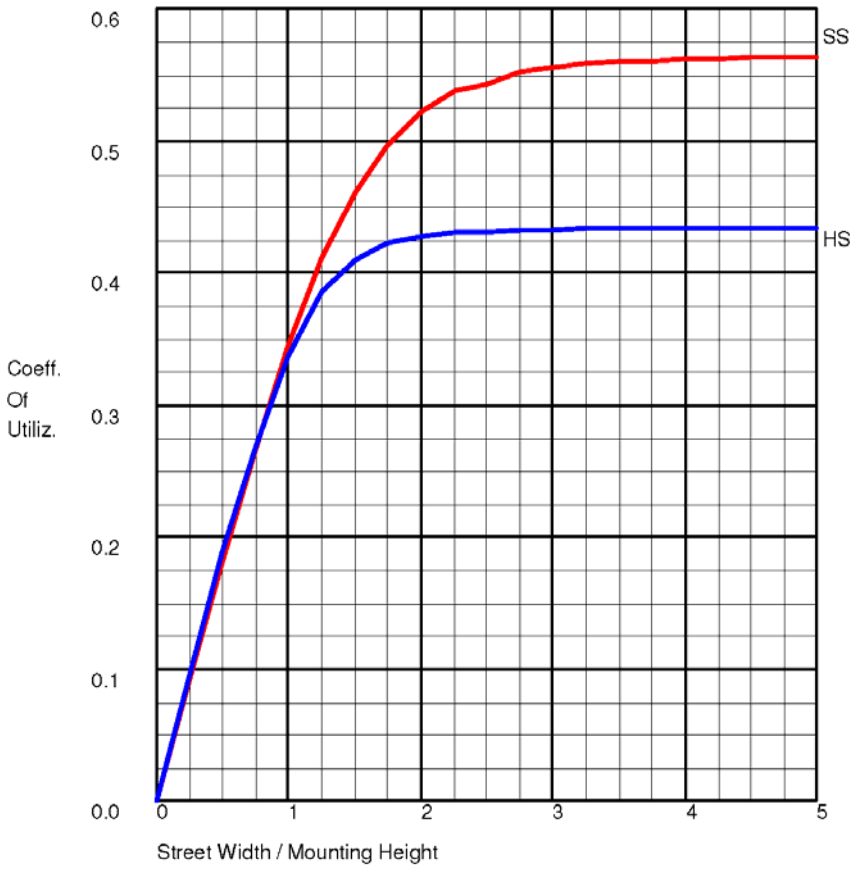
IES ROAD REPORT
PHOTOMETRIC FILENAME : BLD-STR-T3-__-025-LED-B-525.IES

COEFFICIENTS OF UTILIZATION



FLUX DISTRIBUTION

	Lumens	Percent Of Lamp
Downward Street Side	1928.1	56.5
Downward House Side	1485.4	43.5
Downward Total	3413.5	100.0
Upward Street Side	0.0	0.0
Upward House Side	0.0	0.0
Upward Total	0.0	0.0
Total Flux	3413.5	100.0

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Results derived from content of manufacturers photometric file.

Vendor C Photometric Report (supplied by vendor)

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

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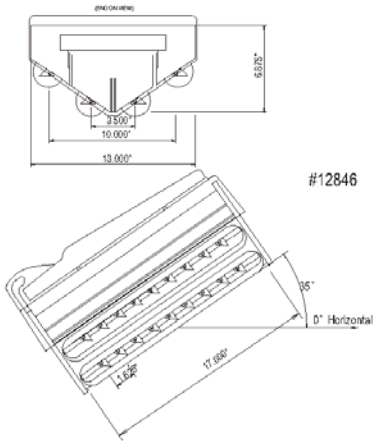
LTL NUMBER: 12846 DATE: 03-17-2008
PREPARED FOR: RELUME TECHNOLOGIES
CATALOG NUMBER: R7200 COBRA 796-4202
LUMINAIRE: EXTRUDED ALUMINUM HOUSING WITH MOLDED ACRYLIC END AND TOP CAPS, FORMED BLACK ENAMEL AND SPECULAR ALUMINUM REFLECTORS, CLEAR ACRYLIC ENCLOSURES.
LAMP: 48 WHITE LEDS
LED DRIVER: TWO ADVANCE LEDINTA0024V41FO
ELECTRICAL VALUES: 120.0VAC, 0.9581A, 114.19W
LUMINAIRE EFFICACY: 43.5 LUMENS/WATT
NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*



IES CLASSIFICATION: **TYPE III**
LONGITUDINAL CLASSIFICATION: **SHORT**
CUTOFF CLASSIFICATION: **CUTOFF****

**CUTOFF DESIGNATION IS NOT DEFINED FOR ABSOLUTE PHOTOMETRIC TESTS. THIS CUTOFF RATING IS BASED ON THE MAXIMUM CANDELA READING PER LUMINAIRE RATED AT 1000 LUMENS.

FLUX DISTRIBUTION

LUMENS	DOWNWARD	UPWARD	TOTALS
HOUSE SIDE	1119.50	0.00	1119.50
STREET SIDE	3846.49	4.49	3850.98
TOTALS	4965.99	4.49	4970.48

*DATA WAS ACQUIRED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY. A UDT MODEL #211 PHOTODETECTOR AND UDT MODEL #S370 OPTOMETER COMBINATION WERE USED AS A STANDARD. A SPECTRAL MISMATCH CORRECTION FACTOR WAS EMPLOYED BASED ON THE SPECTRAL RESPONSIVITY OF THE PHOTODETECTOR AND THE SPECTRAL POWER DISTRIBUTION OF THE TEST SUBJECT.

Approved By: MG

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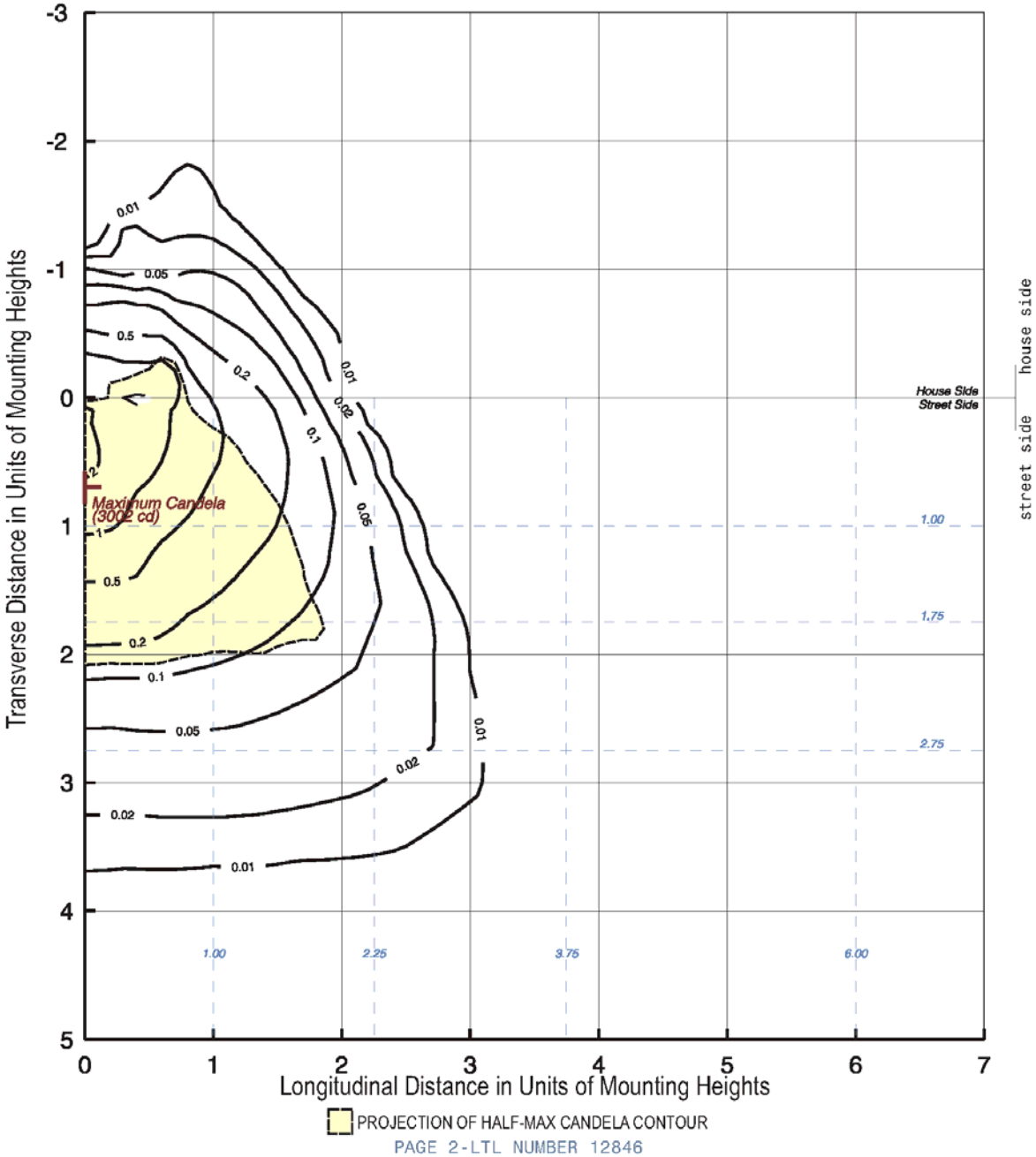
ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION
VALUES BASED ON 30.00 FOOT MOUNTING HEIGHT



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CANDELA DISTRIBUTION

	0	5	15	25	35	45	55	65	75	85	90
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	12	12	12	11	5	5	8	12	12	0	0
90	17	15	17	18	17	8	6	9	6	3	0
87.5	23	23	21	26	27	21	12	12	11	9	3
85	35	33	39	50	54	35	24	18	15	12	12
82.5	60	59	81	83	81	59	29	26	15	14	12
80	124	125	140	136	199	215	41	27	26	20	15
77.5	238	229	261	343	631	704	130	33	27	23	21
75	481	470	563	779	1074	1168	431	51	29	32	29
72.5	744	753	895	1100	1250	1360	896	155	39	41	47
70	890	896	1044	1220	1350	1473	1243	438	72	48	66
67.5	1037	1035	1202	1371	1516	1535	1416	862	221	65	59
65	1361	1339	1496	1543	1613	1576	1473	1202	554	152	96
62.5	1864	1867	2044	1686	1650	1570	1531	1372	922	395	232
60	2080	2112	2502	1823	1695	1586	1594	1433	1187	725	503
57.5	2239	2257	2563	1865	1755	1656	1607	1488	1315	969	779
55	2398	2425	2511	1895	1797	1705	1610	1531	1369	1101	920
52.5	2537	2570	2546	1922	1805	1726	1589	1570	1431	1159	1008
50	2640	2659	2609	1936	1847	1749	1610	1607	1490	1222	1076
47.5	2770	2784	2682	1987	1885	1784	1669	1610	1532	1285	1119
45	2853	2846	2701	2008	1898	1809	1726	1597	1568	1345	1196
40	2963	2959	2695	2032	1937	1855	1739	1668	1546	1488	1398
35	3002	2975	2667	2070	1963	1883	1790	1683	1623	1585	1758
30	2941	2917	2528	2073	1995	1901	1815	1693	1588	1544	1570
25	2804	2792	2392	1993	1907	1874	1799	1677	1564	1496	1460
20	2553	2532	2195	1918	1823	1778	1714	1636	1586	1516	1454
15	2257	2192	2008	1844	1708	1647	1613	1635	1659	1582	1532
10	2032	2004	1904	1824	1769	1704	1671	1633	1613	1544	1514
5	1953	1972	1969	1873	1793	1716	1612	1562	1510	1454	1416
0	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309

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CANDELA DISTRIBUTION

	95	105	115	125	135	145	155	165	175	180
180	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0
90	0	0	0	2	0	2	0	0	0	0
87.5	3	2	2	3	2	3	0	0	0	0
85	9	8	8	5	5	6	0	0	0	0
82.5	11	9	8	8	6	6	0	0	0	0
80	14	9	11	6	8	6	3	0	0	0
77.5	21	12	11	9	6	6	5	0	0	0
75	20	20	11	11	5	5	3	0	0	0
72.5	44	26	24	20	18	23	5	8	3	0
70	62	42	29	21	21	21	24	5	8	0
67.5	80	53	30	18	20	42	41	2	6	3
65	99	84	47	36	39	51	72	8	11	18
62.5	154	124	80	63	62	69	124	18	15	27
60	337	196	140	114	101	92	107	26	11	18
57.5	572	353	244	200	149	107	87	60	14	12
55	735	475	330	292	206	119	68	95	18	9
52.5	809	559	389	318	230	154	90	108	20	15
50	892	588	416	325	241	146	124	72	39	21
47.5	940	645	455	357	265	172	145	65	65	57
45	1014	713	526	405	301	277	155	95	125	136
40	1241	997	854	684	618	449	343	300	234	229
35	2049	1943	1644	1169	759	589	512	395	356	356
30	1785	1790	1451	1195	961	707	550	524	544	563
25	1568	1702	1500	1226	1023	925	860	786	788	777
20	1467	1627	1561	1326	1165	1110	1049	1024	1046	1055
15	1514	1564	1626	1490	1342	1235	1172	1165	1180	1178
10	1481	1442	1428	1401	1344	1308	1258	1258	1231	1256
5	1384	1312	1234	1169	1103	1049	1050	1049	1049	1085
0	1309	1309	1309	1309	1309	1309	1309	1309	1309	1309

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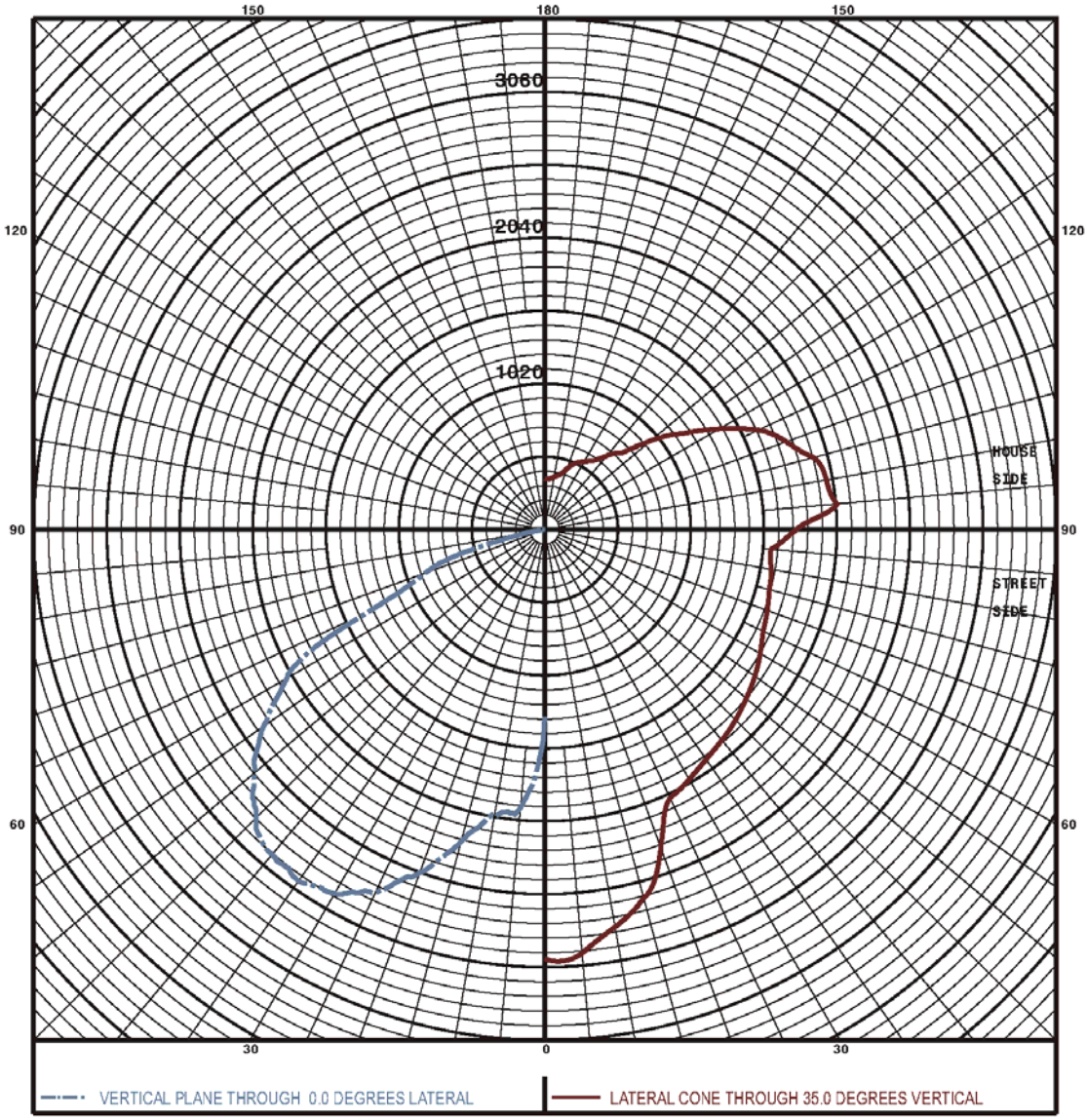
MAXIMUM PLANE AND CONE PLOTS OF CANDELA



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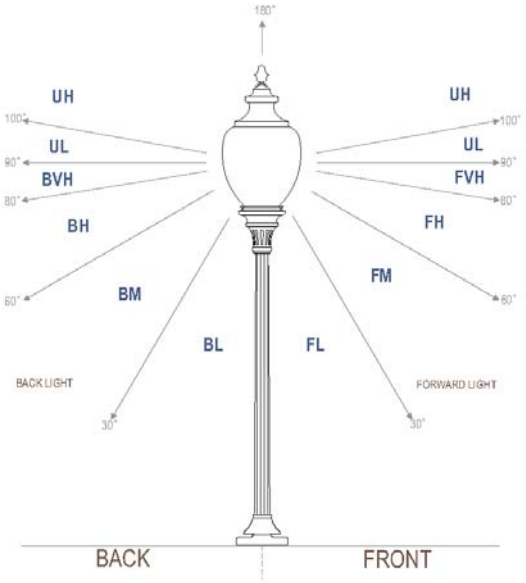
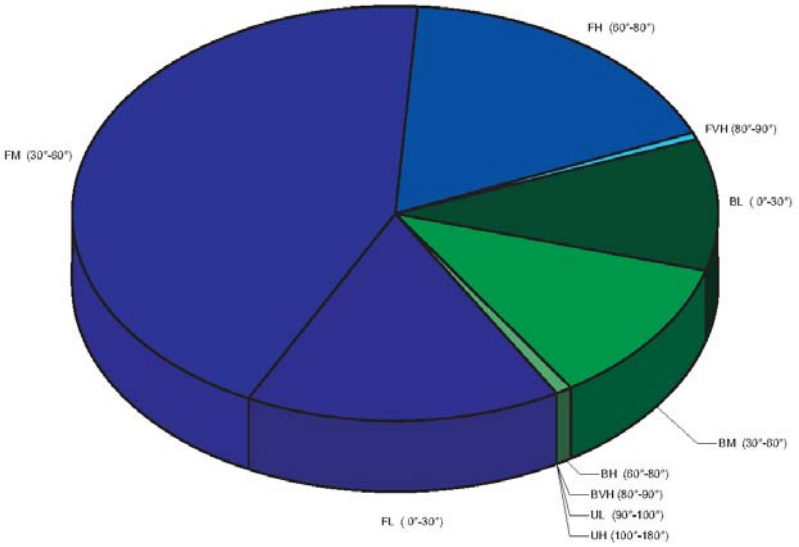
FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



ZONE	FLUX LUMINAIRE LUMENS	FLUX % OF LUMINAIRE LUMENS
FORWARD LIGHT	3846	77.4
FL (0°-30°)	783	15.8
FM (30°-60°)	2174	43.7
FH (60°-80°)	869	17.5
FVH (80°-90°)	20	0.4
BACK LIGHT	1120	22.5
BL (0°-30°)	514	10.3
BM (30°-60°)	569	11.4
BH (60°-80°)	35	0.7
BVH (80°-90°)	2	0
UPLIGHT	4	0.1
UL (90°-100°)	4	0.1
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



PAGE 6-LTL NUMBER 12846

Vendor D Photometric Report (from ALADAN, with vendor supplied photometrics). Luminaire is Type III semi-cutoff HPS scaled to 22000 lumens.

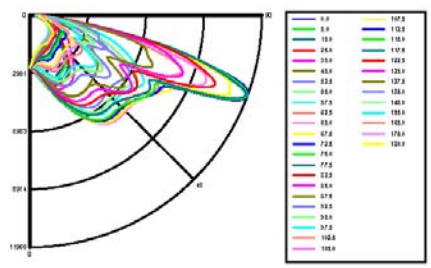
GE C&I LIGHTING SYSTEMS - EAST FLAT ROCK NC USA M2RR25S***GMS3 GE177260.ies

M-250R2

Luminaire Properties

Number of Lamps:	1
Lumens Per Lamp:	22000
Input Watts:	305
Distribution:	Direct
Symmetry:	Bilateral 0-180
Photometric Type:	Type C
Luminous Shape:	Rectangle
Units:	Feet
Luminous Dimensions:	
0-180 Axis:	1.10
90-270 Axis:	0.90
Height:	0.30
Spacing Criteria (0):	1.59
Spacing Criteria (90):	2.38
Spacing Criteria (Four Luminaires):	1.79

Candela Plot



Zonal Lumen Summary

Zone	Lumens	% Lamp	% Fixture
0-30	2623	12	16
0-40	4770	22	30
0-60	10005	45	62
0-90	16159	73	100
90-120	0	0	0
90-150	0	0	0
90-180	0	0	0
0-180	16159	73	100

Coefficients of Utilization

pfc=	0.20																	
pcc->		0.80				0.70				0.50			0.30			0.10		0.00
pw->	0.70	0.50	0.30	0.10	0.70	0.50	0.30	0.10	0.50	0.30	0.10	0.50	0.30	0.10	0.00	0.00	0.00	0.00
RCR																		
0	88	88	88	88	86	86	86	86	82	82	82	78	78	78	75	75	75	74
1	78	73	69	65	75	71	67	64	68	65	62	65	62	60	57	57	57	56
2	69	61	55	50	67	60	54	49	57	52	48	54	50	47	44	44	44	44
3	62	52	45	39	60	51	44	39	49	43	38	46	41	37	35	35	35	35
4	56	45	38	32	54	44	37	32	42	36	31	40	35	31	28	28	28	28
5	51	40	32	26	49	39	32	26	37	31	26	36	30	26	24	24	24	23
6	46	35	28	22	45	35	27	22	33	27	22	32	26	22	20	20	20	20
7	43	32	24	19	41	31	24	19	30	24	19	29	23	19	17	17	17	17
8	40	29	22	17	38	28	21	17	27	21	17	26	21	16	15	15	15	15
9	37	26	19	15	36	26	19	15	25	19	15	24	18	15	13	13	13	13
10	34	24	17	13	33	23	17	13	23	17	13	22	17	13	12	12	12	12

General Information

HSNG: CAST HOUSING CAST DOOR/COVER
REFL: SEMI-SPEC HYDROFRM ALUM
ENCL: PRISMATIC MOLDED GLASS
ACSY:
SOCKET POSITION: 1DH
COMMENT:

Calculated light levels are based on specific information that has been supplied to GE Lighting Systems.
Any differences in luminaire installation, lighted area geometry and obstructions in the lighted area may produce different results from the predicted values.
Normal tolerances of voltage, lamp output, and ballast and luminaire manufacturer will affect results.

Candela Distribution

	0.00	5.00	15.00	25.00	35.00	45.00	52.50	55.00	57.50	62.50	65.00	67.50	72.50
0.00	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688
5.00	2963	2968	2977	2977	2959	2900	2875	2867	2864	2860	2858	2840	2807
15.00	3584	3597	3623	3733	3861	3989	3995	3997	3993	3984	3980	3947	3885
25.00	3368	3461	3648	3835	4125	4627	4996	5119	5225	5438	5544	5522	5482
35.00	3067	3172	3384	3546	3912	4838	5764	6072	6266	6653	6846	6774	6629
45.00	2325	2380	2493	2636	3113	4591	5606	5944	6206	6728	6989	6904	6728
55.00	1318	1395	1549	1879	2475	4268	5786	6292	6547	7058	7313	7306	7295
60.00	1324	1364	1448	1716	2257	3826	5911	6358	6802	7627	7773	7918	7704
62.50	1329	1351	1395	1637	2149	3604	5570	6004	6437	7458	7858	8257	7927
65.00	1331	1335	1344	1555	2042	3384	4847	5408	5986	7627	8197	8776	9473
67.50	1184	1188	1192	1366	1795	2950	4015	4796	5579	8061	9429	10800	11464
70.00	1038	1038	1038	1177	1549	2517	3392	4250	5111	8378	9673	10969	11966
72.50	891	889	884	988	1302	2083	2891	3716	4541	7746	9170	10595	11319
75.00	744	739	730	799	1054	1650	2356	3104	3861	6345	7381	8419	9141
77.50	647	656	675	752	1003	1456	1929	2539	3146	4855	5584	6310	6965
80.00	550	574	620	704	953	1263	1540	1918	2297	3291	3692	4090	4354
82.50	453	493	565	658	902	1069	1157	1327	1496	1914	2079	2244	2475
85.00	359	409	510	612	851	876	843	902	970	1173	1250	1327	1428
87.50	330	374	458	546	739	761	629	647	664	724	770	816	911
90.00	304	337	405	480	629	647	493	484	475	510	546	579	664

Calculated light levels are based on specific information that has been supplied to GE Lighting Systems.
Any differences in luminaire installation, lighted area geometry and obstructions in the lighted area may produce different results from the predicted values.
Normal tolerances of voltage, lamp output, and ballast and luminaire manufacturer will affect results.

Candela Distribution

	77.50	82.50	85.00	87.50	92.50	95.00	97.50	102.50	105.00	107.50	112.50	115.00	117.50	122.50	125.00
0.00	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688	2688
5.00	2772	2739	2721	2704	2671	2653	2631	2589	2567	2543	2490	2466	2451	2422	2407
15.00	3784	3648	3579	3472	3254	3146	3016	2757	2627	2543	2380	2297	2235	2112	2050
25.00	5293	4954	4787	4525	4004	3742	3555	3181	2994	2834	2508	2347	2233	2002	1888
35.00	6204	5504	5152	4805	4114	3766	3513	3007	2754	2594	2270	2110	2022	1848	1760
45.00	6332	5711	5401	5042	4321	3962	3648	3018	2704	2530	2180	2006	1907	1707	1608
55.00	7071	6631	6413	5942	5003	4532	4107	3256	2831	2596	2123	1888	1791	1602	1505
60.00	7161	6250	5507	4763	3674	3335	2994	2781	2649	2517	2169	1982	1795	1481	1355
62.50	7203	6241	5460	4677	3342	2948	2552	2193	2112	2033	2033	1932	1828	1522	1373
65.00	9253	8173	7143	6123	4081	3469	2867	2229	2024	1828	1650	1641	1641	1549	1412
67.50	11141	9720	8283	6846	4294	3568	2840	2024	1786	1549	1327	1280	1232	1225	1203
70.00	11889	10188	8382	6574	3819	3122	2424	1683	1461	1241	994	931	867	825	840
72.50	10791	9372	7850	6327	3733	3023	2312	1591	1340	1089	843	783	724	647	642
75.00	9176	8309	7152	6004	3597	2908	2237	1496	1250	1012	783	706	647	570	543
77.50	7058	6532	5680	4831	3078	2543	2006	1360	1157	953	730	664	596	510	484
80.00	4380	4048	3656	3265	2407	2059	1709	1258	1067	876	680	603	528	442	429
82.50	2567	2457	2297	2134	1683	1478	1276	953	829	706	579	524	469	392	374
85.00	1505	1454	1377	1309	1107	986	867	680	603	537	442	409	392	341	323
87.50	986	970	906	843	730	664	596	469	440	409	356	343	332	306	301
90.00	730	689	638	587	493	453	416	356	339	323	288	288	288	273	273

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Candela Distribution

	135.00	145.00	155.00	165.00	175.00
0.00	2688	2688	2688	2688	2688
5.00	2297	2253	2202	2193	2178
15.00	1888	1802	1751	1736	1736
25.00	1683	1555	1564	1624	1659
35.00	1522	1463	1472	1555	1641
45.00	1428	1344	1353	1428	1514
55.00	1250	1173	1250	1386	1445
60.00	1096	1076	1113	1170	1203
62.50	1021	1027	1047	1060	1082
65.00	944	979	979	953	961
67.50	854	924	937	906	902
70.00	766	867	893	858	843
72.50	678	812	849	812	783
75.00	587	757	807	766	724
77.50	526	675	761	755	682
80.00	464	594	713	744	638
82.50	403	515	667	735	594
85.00	341	433	620	724	552
87.50	308	392	537	620	532
90.00	277	352	453	515	510

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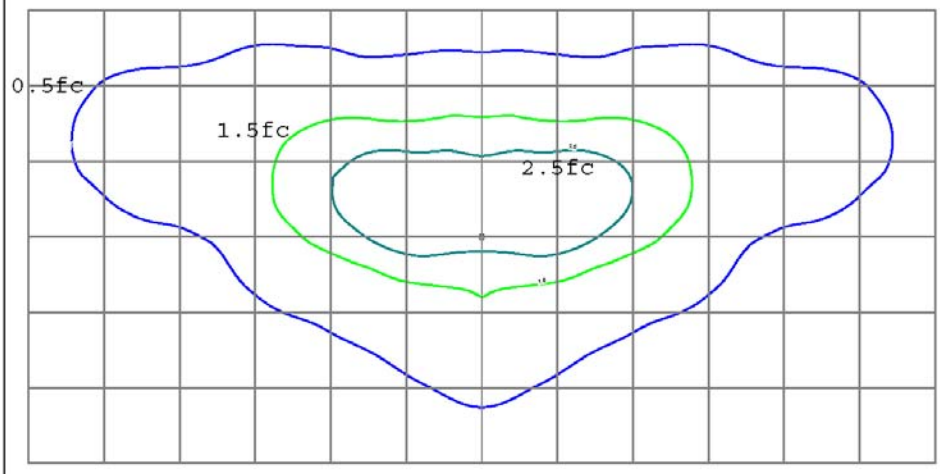
GE C&I LIGHTING SYSTEMS - EAST FLAT ROCK NC USA M2RR25S***GMS3 GE177260.ies

M-250R2

Luminaire Properties

Mounting Height:	30.00 ft.	Input Watts:	305
Number of Lamps:	1	Distribution:	Direct
Lumens Per Lamp:	22000		

Iso-Template



Grid Spacing: 0.5 Mounting Height:
Units: fc

Calculated light levels are based on specific information that has been supplied to GE Lighting Systems.
Any differences in luminaire installation, lighted area geometry and obstructions in the lighted area may produce different results from the predicted values.
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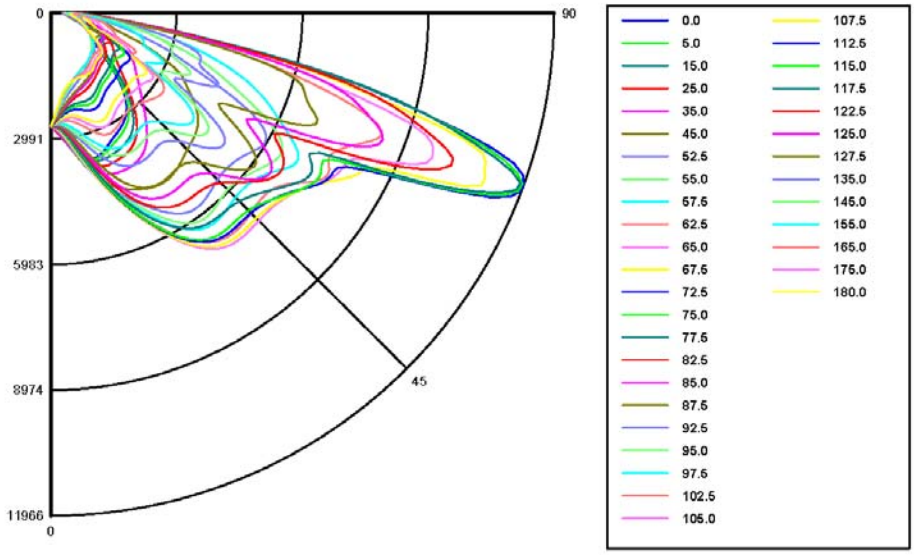
GE C&I LIGHTING SYSTEMS - EAST FLAT ROCK NC USA M2RR25S***GMS3 GE177260.ies

M-250R2

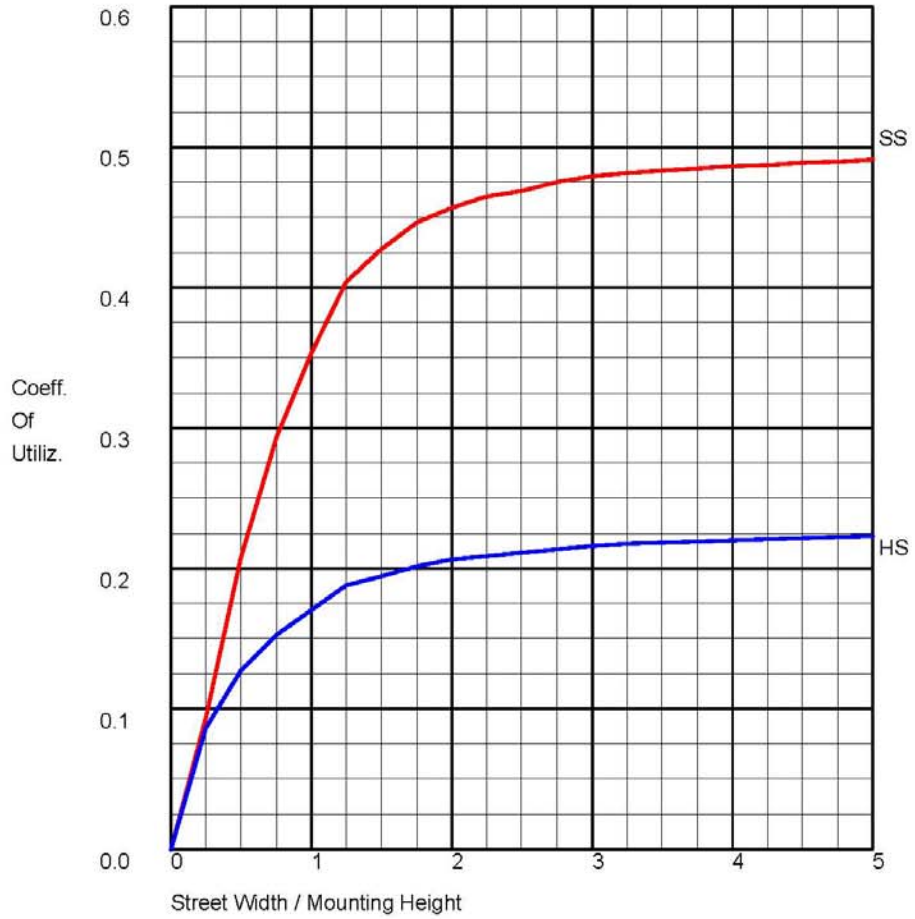
Candela Plot



Calculated light levels are based on specific information that has been supplied to GE Lighting Systems.
Any differences in luminaire installation, lighted area geometry and obstructions in the lighted area may produce different results from the predicted values.
Normal tolerances of voltage, lamp output, and ballast and luminaire manufacturer will affect results.

IES ROAD REPORT
PHOTOMETRIC FILENAME : VENDORD3.IES

COEFFICIENTS OF UTILIZATION



FLUX DISTRIBUTION

	Lumens	Percent Of Lamp
Downward Street Side	14070.7	50.3
Downward House Side	6481.1	23.1
Downward Total	20551.8	73.4
Upward Street Side	0.0	0.0
Upward House Side	0.0	0.0
Upward Total	0.0	0.0
Total Flux	20551.8	73.4

Photometric Toolbox Professional Edition (c) copyright 1995-2008 by Lighting Analysts, Inc.
Calculations based on published IES Methods and recommendations, values rounded for display purposes.
Results derived from content of manufacturers photometric file.

dix F: Phase One

es below summarize the preliminary results from the first phase on this project.

1: Phase One

	30 Minute Run-time at 75°F ambient							
r	**Model #**	**Stated Wattage**	**Amperage**	**VA**	**Power Factor**	**Wattage @ 30min**	**Temperature on Heatsink (°F)**	**Temperatu on Face**
	EB-1010-FX-AC100	100	1.51	177	0.63	112	125	95
	SL-200W1S3-FX	100	0.77	92	0.98	90	124	90
	BLD-SL-T3-AA-085-LED/B-UL-SV-R	128	0.99	118	0.99	117	122	127
	LTW-R4800	86	0.61	73	0.97	71	124	95
	RG2-07-C00	140	1.78	211	0.68	145	122	104
	ESL-C01H150W-02A	150	1.31	156	0.98	154	97	97
	SL-200W1S3-IMS	130	1.1	130	0.95	125	129	98

ts:

icon Lighting Distribution information was not available
ds wiring per NEC
cal Fan for EOI and Global Green wil be a maintenance issue
MA Twistlock Receptacle for EOI, Global Green, Relume, Fox Semicon
ue for Fox Semicon
hot spot on edges not in center
commended angle for BetaLED unit due to adjustable arm.

2: Phase One (2)

180 Minute Run-time at 75°F ambient								
cturer	**Model #**	**Stated Wattage**	**Amperage**	**VA**	**Power Factor**	**Wattage @ 180min**	**Temperature on Heatsink (°F)**	**Temperature on Face**
reen	EB-1010-FX-AC100	100	1.52	180	0.62	112	162	100
	SL-200W1S3-FX	100	0.77	91	0.98	90	131	96
	BLD-SL-T3-AA-085-LED/B-UL-SV-R	128	0.99	118	0.99	117	134	137
	LTW-R4800	86	0.66	73	0.97	71	145	104
con	RG2-07-C00	140	1.92	226	0.67	151	135	113
	ESL-C01H150W-02A	150	1.33	155	0.98	153	105	104
	SL-200W1S3-IMS	130	1.11	131	0.95	124	133	98

nts:
Green - heat melting silicone/dielectric inside unit.
ransition from #8AWG to terminal strip connection/forks (all units)

Appendix G: Phase Two Lab Results

The tables below summarize the results from the second phase on this project.

Table G1: Phase Two

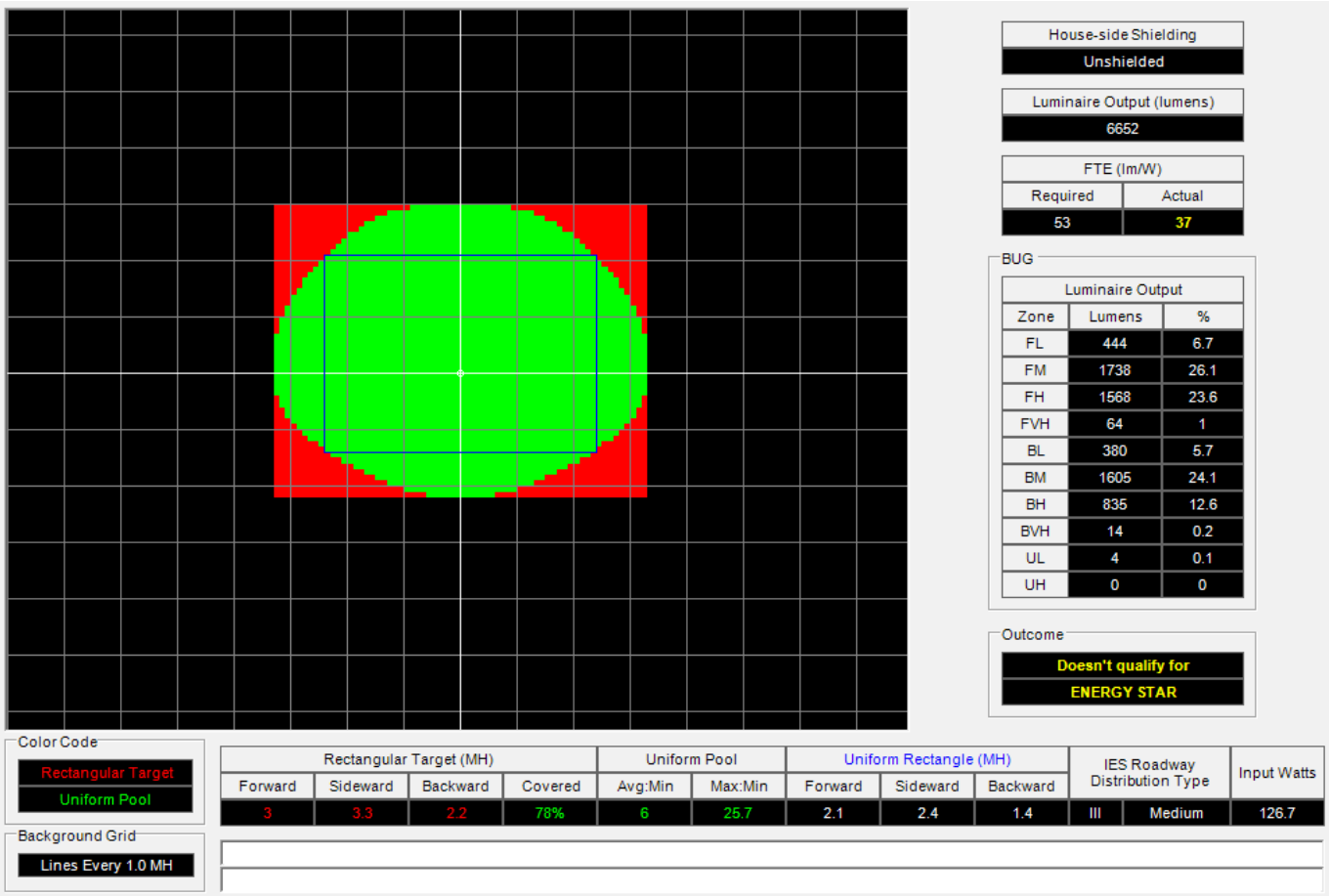
180 Minute Run-time @ 38 degrees F ambient						
Manufacturer	***Amperage***	***VA***	***Power Factor***	***Wattage @ 30min***	***Temperature on Heatsink (°F)***	***Temperature on Face (°F)***
Vendor A	0.61	237.2	0.81	119	90.5	59.5
Vendor B	0.50	236	0.85	101	88	84.5
Vendor C	0.51	239.2	0.87	105	116	67.5
Vendor D HPS	1.17	232.7	0.98	269	145	170.0

Table G2: Phase Two

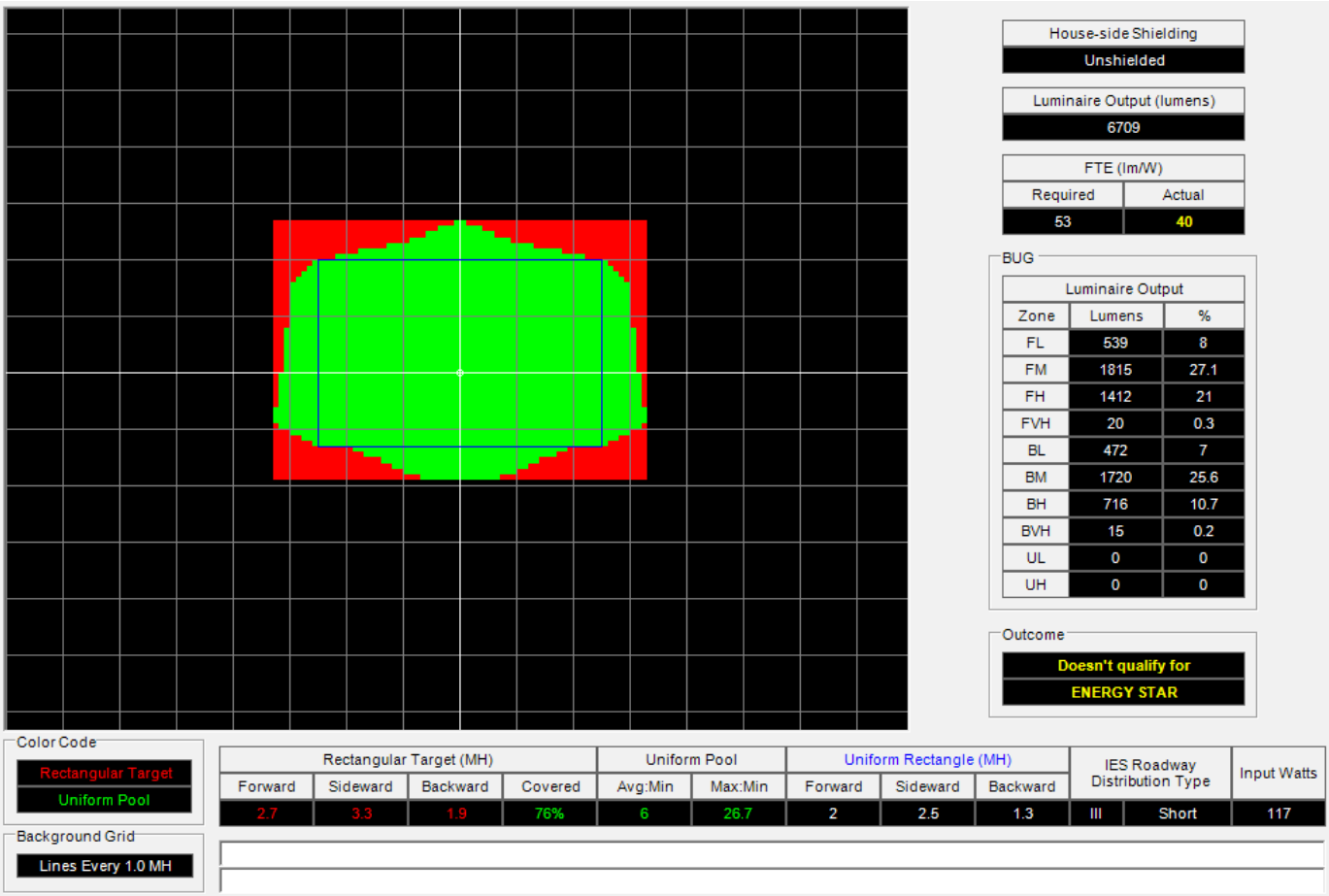
180 Minute Run-time @ 75 degrees F ambient						
Manufacturer	***Amperage***	***VA***	***Power Factor***	***Wattage @ 30min***	***Temperature on Heatsink (°F)***	***Temperature on Face (°F)***
Vendor A	0.60	105.0		63.0	112	106
Vendor B	0.48	209.1		100.4	97	118
Vendor C	0.50	105.6		52.8	122	84
Vendor D HPS	1.80	NA	NA	NA	NA	N/A

Appendix H: Fitted Target Efficacy Results

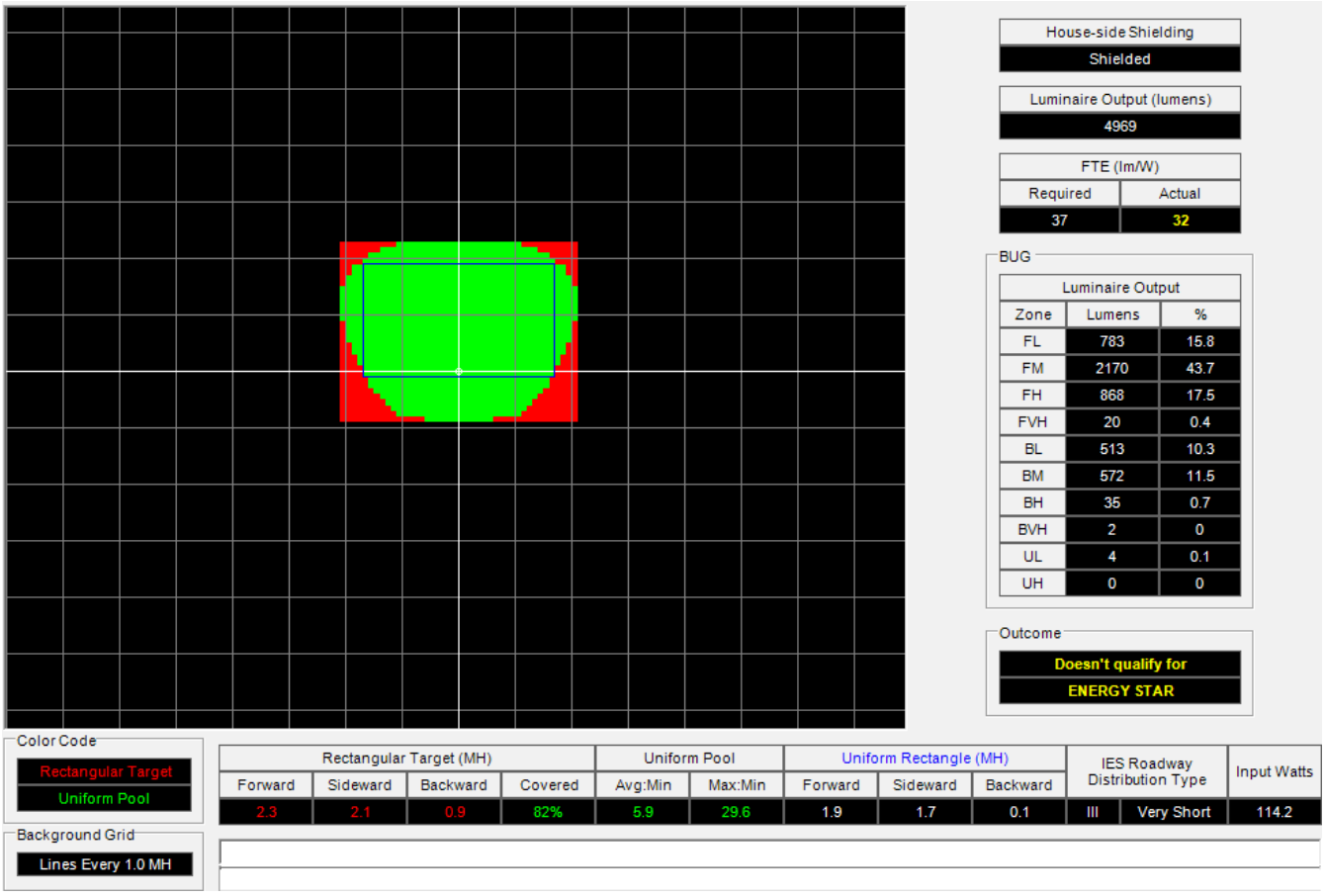
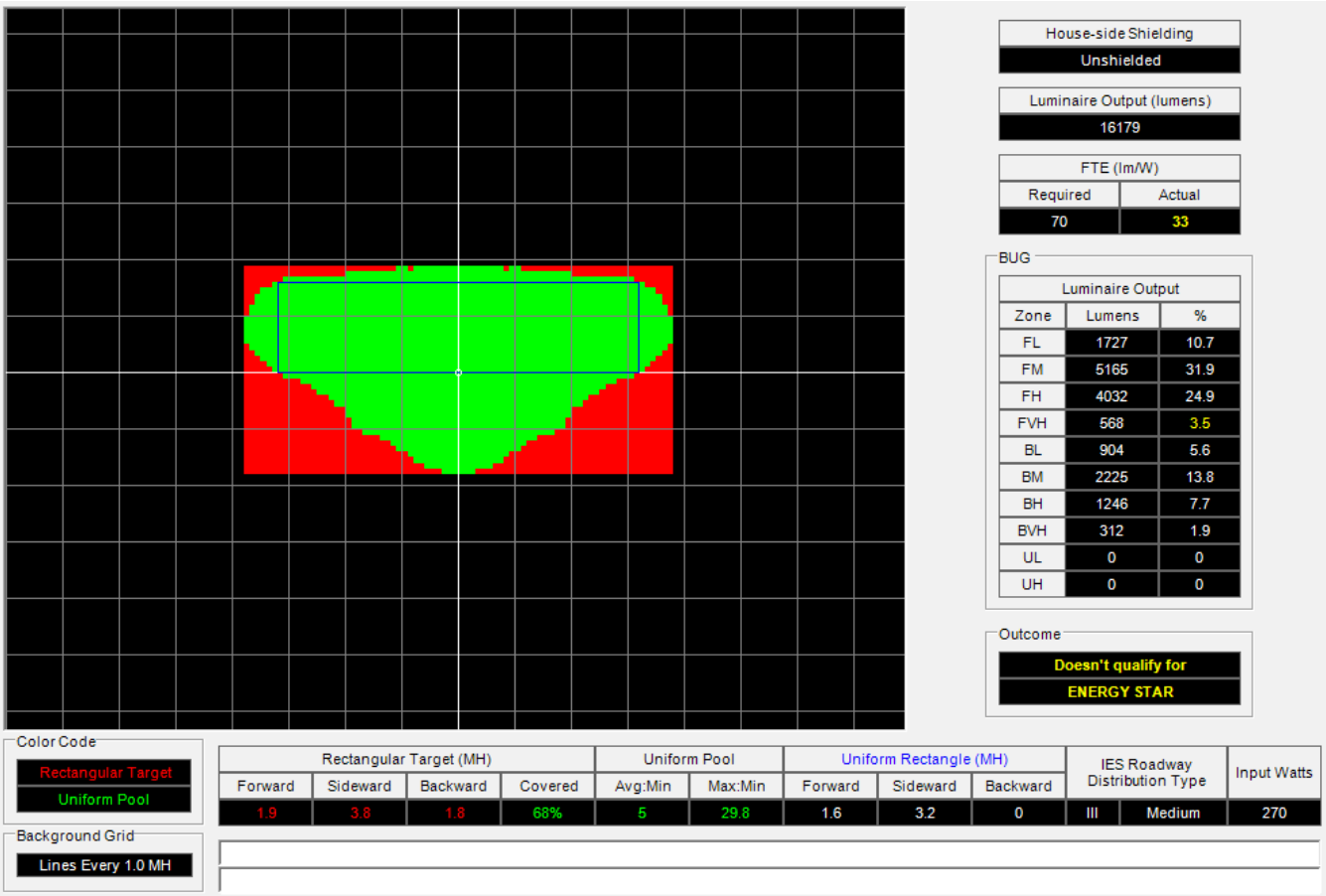
PNNL FTE Tool Version Beta B.1.1
Vendor A Fitted Target Efficacy



Vendor B Fitted Target Efficacy



Vendor C Fitted Target Efficacy



Vendor D Fitted Target Efficacy