GATEWAY DEMONSTRATIONS

LED Street Lighting

Host Site: City of San Francisco, California

Final Report prepared in support of the
U.S. DOE Solid-State Lighting
Technology Demonstration Gateway Program
and PG&E Emerging Technologies Program

Study Participants:
U.S. Department of Energy
Pacific Gas & Electric
City of San Francisco, California
Energy Solutions

December 2008

Prepared for the U.S. Department of Energy and
Pacific Gas & Electric by Energy Solutions

Pacific Gas and Electric Company®

Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report #0727

LED Street Lighting
San Francisco, CA

Issued:	December 2008
Project Manager:	Mary Matteson Bryan, P.E. Pacific Gas and Electric Company
Prepared By:	Tyson Cook, Project Manager Jordan Shackelford, Project Manager Terrance Pang, Director Energy Solutions 1610 Harrison St. Oakland, CA 94612 (510) 482-4420

Table of Contents

List of Tables

List of Figures

Preface

Energy Solutions provided monitoring, data collection, and data analysis services for an LED Street Lighting Assessment project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company. The project was done in collaboration with Pacific Northwest National Laboratory (representing the Department of Energy) as part of the GATEWAY demonstration program. The project replaced high pressure sodium luminaires on four avenues in a San Francisco, CA neighborhood with new LED luminaires from four companies, Beta LED, Cyclone, Leotek, and Relume, referred to hereinafter as A, B, C, and D, respectively.

Acknowledgements

This project was funded by the Emerging Technologies Program of Pacific Gas and Electric Company. Energy Solutions would like to gratefully acknowledge the direction and assistance of Pacific Gas and Electric Company, the City of San Francisco, Pacific Northwest National Laboratory, Beta LED, Cyclone, Leotek and Relume for their participation and support of this project.

Executive Summary

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

Demonstration areas were chosen on 38th, 41st, 42nd, and 44th Avenue, between Taraval and Santiago Streets in the residential Sunset District of San Francisco. Each avenue has a total of five street lights from the beginning to end of the block. The three central street lights on each avenue, at spacings of 150' and 200', comprised the Test Area. The two additional street lights, one on either side of the Test Area, served as buffers. On each avenue, all five original HPS Type II dropped-lens luminaires were first replaced with 100 watt nominal HPS Type II full cutoff luminaires, and then with a like number of LED luminaires from four different companies (one company on each street). Mounting heights for the luminaires ranged from 24' to 34' above the road surface, and the street lights were located on alternating sides of the streets within the Test Areas.

This report is intended to independently demonstrate the performance of a number of currently available products in one specific application. It is not intended to compare manufacturers of LED products against each other. The best product for any given application will depend heavily on the particular characteristics and relevant criteria for that application. This report cannot be used for commercial purposes.

Energy Performance

While lighting performance varied among the LED luminaires assessed in this study, energy savings potential was high in each case, with energy reductions ranging from 50% to 70% over the current HPS system. A summary of measured electric power results from the study are tabulated in Table I below for the base case HPS luminaires and for luminaires from each LED manufacturer. Annual savings for electrical energy and cost are estimated based on an assumed 4,100 annual hours of operation.[1]

[1] From PG&E LS-2 Rate Schedule, Appendix E.

Table I: Average Luminaire Power and Estimated Savings

Luminaire Type	**Power** (W)	**Power Savings** (W)	**Estimated Annual Energy Savings** (4100 hr/yr, kWh)	**Energy Cost Savings**
HPS Type II cut-off	138.32	-	-	--
LED A	58.66	79.66 (57.6%)	321	$30.20
LED B	62.22	76.10 (55.0%)	342	$28.45
LED C	41.25	97.07 (70.2%)	398	$38.77
LED D	69.21	69.11 (50.0%)	283	$25.01

This study estimates that if the nationwide stock of installed HPS roadway luminaires were replaced with LED luminaires such as those that were found to perform well in the field, 8.1 TWh of total annual energy savings could be achieved, with a corresponding 5.7 million metric tons of CO_2 emissions abated (See Potential Energy Savings Section).

Lighting Performance[2]

Illuminance measurements to evaluate HPS and LED performance were taken over a grid covering the roadway surface under each Test Area and illuminance metrics were calculated identically for each luminaire type over both luminaire spacings (150' and 200') and over the sum of the two spacings. Comparative metrics included maximum, minimum and average illuminance, uniformity values (Coefficient of Variation, Average-to-Minimum Uniformity Ratio, and Maximum-to-Minimum Uniformity Ratio), and the percentage of total Test Area grid points that were measurably illuminated (.05 footcandles or greater).

In order to compare illuminance levels from the HPS and LED sources, both photopic and scotopic illuminance levels were measured. Though standards for roadway lighting levels are currently written only for photopic levels, illuminance levels under nighttime roadway conditions typically fall under the mesopic range of visual perception, where both photopic and scotopic illuminance are important. For more information on mesopic illuminance, which is presently receiving more attention in the outdoor lighting design community, see Appendix B: Mesopic Illuminance.

When comparing lighting performance for LED outdoor retrofits, it is important to recognize that equivalent lumen output may not be necessary. This is because improvements in color rendering, lighting distribution, and enhanced nighttime lighting conditions (scotopic or mesopic vision advantages) may allow for a reduction in total lumen output from LED light sources relative to HPS.

---

[2] Though the four Test Areas chosen were largely similar in terms of street light locations, spacing, and layout, variation in conditions including baseline lighting levels is such that direct comparisons should not be drawn between the different manufacturer's LED luminaires from measured results. Accordingly, measured lighting performance for each LED luminaire is compared only to base case HPS luminaire performance in that Test Area. However, computer modeling of a hypothetical Test Area of the same general dimensions as the field Test Areas was also carried out in order to allow for better comparison of lighting performance between LED luminaires. Summary results are provided in the Executive Summary; a more in depth discussion can be found in the Lighting Performance Section of this report.

Two of the LED options, luminaire types A and C, delivered lighting performance that was equivalent or better than the baseline HPS by most metrics, showing promise for broader installation in similar applications. Some increase in lumen output may be desired to improve average photopic illuminance levels, though lower average levels do not necessarily indicate worse lighting performance. In comparing lighting quality, it was observed that the lighting distribution of HPS luminaires was such that they typically over-lit the area directly beneath the luminaires, creating 'hotspots,' or areas of relatively high illuminance and contrast, that may have inflated the average illuminance calculations. LED options B and D showed limited applicability for the site dimensions assessed in this study, though they may be appropriate for other types of installations.

Table II: Comparison of Measured Photopic Performance for LED Luminaire A, Entire Test Area

Luminaire	Grid Points Illuminated[3]	Average Illuminance (All Measured Points, footcandles)	Coefficient Of Variation	Average-to-Minimum Uniformity (Illuminated Points Only)[4]
HPS	85%	0.5	0.98	5.3 : 1
LED A	95%	0.3	0.82	3.4 : 1

LED luminaire A provided measurable illumination over most of the Test Area and was by most metrics more uniform than the base case HPS luminaires. While LED A provided slightly reduced average photopic values, average scotopic illuminance values were increased.

Table III: Comparison of Measured Photopic Performance for LED Luminaire B, Entire Test Area

Luminaire	Grid Points Illuminated	Average Illuminance (All Measured Points, footcandles)	Coefficient Of Variation	Average-to-Minimum Uniformity (Illuminated Points Only)
HPS	86%	0.5	0.84	5.5 : 1
LED B	56%	0.2	1.42	3.7 : 1

As compared to the base case HPS luminaires, LED luminaire B provided a smaller area of measurable illumination, mixed uniformity results, and lower average photopic illuminance, though average scotopic illuminance remained the same or slightly increased, depending on spacing.

Table IV: Comparison of Measured Photopic Performance for LED Luminaire C, Entire Test Area

Luminaire	Grid Points Illuminated	Average Illuminance (All Measured Points, footcandles)	Coefficient Of Variation	Average-to-Minimum Uniformity (Illuminated Points Only)
HPS	79%	0.6	1.08	7.5 : 1
LED C	83%	0.2	0.90	2.5 : 1

[3] 'Grid Points Illuminated' is the percentage of grid points that were measurably illuminated (.05 footcandles or greater).

[4] Average-to-Minimum Uniformity was calculated as the average of illuminance values for grid points that were measurably illuminated (.05 footcandles or greater), divided by minimum measured illuminance value.

Like LED A, LED C provided measurable illumination over most of the Test Area at uniformity greater than the base case HPS luminaires although both average photopic and scotopic values were reduced.

Table V: Comparison of Measured Photopic Performance for LED Luminaire D, Entire Test Area

Luminaire	Grid Points Illuminated	Average Illuminance (All Measured Points, footcandles)	Coefficient Of Variation	Average-to-Minimum Uniformity (Illuminated Points Only)
HPS	99%	0.5	0.96	5.0 : 1
LED D	66%	0.3	1.34	5.2 : 1

LED luminaire D, similar to luminaire B, provided a smaller area of measurable illumination, mixed uniformity results, and lower average photopic illuminance than the HPS luminaires, though scotopic averages increased slightly.

Due to variations between the Test Areas, direct comparisons should not be drawn on lighting performance between the different manufacturer's LED luminaires based on the measured results. As a result, computer simulations were used to model photopic illuminance performance on a hypothetical street, thereby eliminating field variables associated with each specific installation site. The same metrics used for the measured results were calculated for these simulated results.

Table VI: Summary of Computer Modeled Photopic Lighting Performance Results at 150' Spacing

Luminaire	Grid Points Illuminated	Average Illumination (All Modeled Points, footcandles)	Coefficient Of Variation	Average-to-Minimum Uniformity (All Modeled Points)
HPS	100%	0.63	0.87	9 : 1
LED A	99%	0.30	0.71	6 : 1
LED B	72%	0.34	1.31	165 : 1
LED C	100%	0.15	0.62	2 : 1
LED D	79%	0.35	1.07	22 : 1

Economic Performance

As an emerging technology, LED street lights have yet to experience major market penetration, but cost reductions and performance improvements are continuing to increase LED street lighting viability. Lighting, energy, and economic performance will all be important factors in LED street lighting developments. High initial cost of LED street lights has been a challenge for the economic case, as demonstrated by previous studies,[5] but energy savings and projected maintenance cost savings through the luminaire lifetime both improve LED street light economics. The level of savings will of course depend on energy and maintenance costs for any given location.

[5] See,Cook, et al. "PG&E Emerging Technologies Program Application Assessment Report #0714: LED Street Lighting; Oakland, CA." January 2008. Available online through the Emerging Technologies Coordinating Council at http://www.etcc-ca.com

In this evaluation, simple payback and net present value were calculated for each LED luminaire type, considering both retrofit and new construction cases and based on estimated energy savings from field measurements and estimated host site maintenance costs. Retrofit economics consider the entire LED luminaire cost as well as cost of installation, while new construction only includes the incremental cost of the LED luminaire above an HPS luminaire.

Economic estimates are sensitive to site-specific variables such as maintenance and energy costs, and to LED luminaire cost. Of particular note, estimates are also dependant upon assumptions for LED luminaire lifetime, which is a function of the life of all parts of the luminaire (LEDs, driver, housing, coating, etc.). Manufacturers' claims for luminaire lifetimes are highly variable. For more details see the Economic Performance section. Readers are advised to use their own cost estimates and assumptions when possible.

Table VII: LED Luminaire Economic Performance (relative to HPS base case)

	New Construction		Retrofit	
Luminaire	**Simple Payback (Years)**	**15-Year NPV**	**Simple Payback (Years)**	**15-Year NPV**
LED A	6.3	$306.72	10.8	$99.72
LED B	13.3	-$16.09	18.1	-$223.09
LED C	3.7	$512.34	7.4	$305.34
LED D	15.3	-$96.43	20.4	-$303.43

The products evaluated here that generally performed better in terms of lighting performance also proved to be more economically attractive. Results show longer paybacks for retrofit scenarios but more reasonable paybacks for new street light installations, especially for LEDs A and C. Net present value, a more robust metric for evaluating energy efficiency investments, is positive for LEDs A and C in both the retrofit and new construction scenario.

Overall results from this assessment show that energy savings potential from current LED street lighting is significant. This savings potential is likely to further increase in the future as the energy and lighting performance of LED street lights continues to improve. However, not all products currently available are ready for mass deployment; limitations continue to exist in the lighting performance of some. Additionally, economic viability, though subject to location details, will remain a key factor that must be weighed in concert with lighting performance. Incentive program development may further encourage LED street light adoption. This study recommends that any such incentive programs include performance standards that consider warranty, efficacy, light distribution, and other important criteria.

Project Background

Project Overview

This LED street lighting assessment project studied the applicability of light emitting diode (LED) luminaires as replacements for existing street lights. One hundred watt nominal high pressure sodium (HPS) luminaires were replaced with new LED luminaires from four manufacturers on four streets located in the residential Sunset District of San Francisco, CA. The LED technologies were evaluated for lighting performance, energy and power usage, economic factors (such as simple payback and net present value), and qualitative satisfaction. The assessment was conducted as part of the Emerging Technologies Program of Pacific Gas and Electric Company (PG&E). The Emerging Technologies program "is an information-only program that seeks to accelerate the introduction of innovative energy efficient technologies, applications and analytical tools that are not widely adopted in California…. [The] information includes verified energy savings and demand reductions, market potential and market barriers, incremental cost, and the technology's life expectancy."[6]

Technology and Market Overview

The most prevalent roadway lighting technology today is high intensity discharge (HID), at over 90% of all roadway lights. These are commonly high pressure sodium lights, and less frequently mercury vapor, metal halide and low pressure sodium.[7] HPS lights are used primarily because of their long rated life and high efficiency relative to other options. However, HPS technology is not without drawbacks, such as low color rendition (typical CRI of 22) due to narrow spectral distribution.[8]

Though the market penetration of LED street lighting at the time of this assessment is low, the technology is making inroads due to potential savings in energy and maintenance costs compared to traditional HID sources. Also, due to the inherent directionality of LEDs, they offer the potential for lighting performance improvements such as more efficient lighting distribution and increased uniformity. The US Department of Energy (DOE) is currently evaluating outdoor applications of LEDs through field demonstration and lab testing programs (such as CALiPER

[6] Pacific Gas and Electric Company (2006). Program Descriptions, Market Integrated Demand Side Management, Emerging Technologies. PGE 2011.

[7] Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I." Table 5-17.

[8] High-Intensity Discharge Lamps Analysis of Potential Energy Savings Docket #: EE-DET-03-001 USDOE Technical Support Document: Energy Efficiency Program For Commercial and Industrial Equipment. December 2004.

and GATEWAY),[9] and acknowledges that "LED technology is rapidly becoming competitive with [HID] light sources for outdoor area lighting."[10]

One of the major market barriers to LED roadway luminaire adoption currently is the initial cost of LEDs, which tend to be much higher than HID sources. However, LED technology has been experiencing steady rates of improvement not only in efficiency (approximately 35% annually) but also in cost (approximately 20% annually) according to a DOE study.[11] Another recent publication, referencing an industry source, projects advancements in LED chip manufacturing will allow for LED cost reductions in 2009 of up to 50% over current costs, with total costs of roughly a penny per lumen.[12] Finally, PG&E recently completed a follow-up assessment of LED street lighting in Oakland, California that demonstrated a luminaire cost reduction of 36% in less than 12 months.[13]

A new DOE report entitled 'Energy Savings Estimates of LEDs in Niche Lighting Applications' estimates that street and area lighting (including floodlights, parking garages, highway, billboard, pathway, and more) represents over 178.3 TWh of national energy usage annually, or 40.7 GW of electric power demand (assuming 4,380 hours of annual operation).[14] The report concludes that at 100% replacement of all street and area lighting sources with high efficacy LED luminaries, matching previous light sources lumen for lumen, the nation could save an impressive 44.7 TWh of electrical energy annually.[15]

However, a lumen for lumen replacement scenario for LED outdoor retrofits does not account for improvements in color rendering, lighting distribution, and enhanced night time lighting conditions (scotopic or mesopic vision advantages) that might allow for a reduction in total output from LED light sources relative to HPS. Recognizing the increasing interest in nighttime performance of LEDs, the DOE study notes that more energy savings would be possible if these factors were

---

[9] DOE's Commercially Available LED Product Evaluation and Reporting (CALiPER) program supports testing of a wide array of SSL products available for general illumination. DOE allows its test results to be distributed in the public interest for noncommercial, educational purposes only. See http://www.netl.doe.gov/ssl/comm_testing.htm.

DOE's GATEWAY Demonstration Programs support demonstrations of high-performance LED products to develop field data and experience for applications that save energy, are cost effective, and maintain or improve light levels. See http://www.netl.doe.gov/ssl/techdemos.htm.

[10] LED Application Series: Outdoor Area Lighting. USDOE Building Technologies Program. PNNL-SA-60645.June 2008. http://www.netl.doe.gov/ssl/PDFs/OutdoorAreaLighting.pdf

[11] Navigant Consulting, Inc. (2006). "Solid State Lighting Research and Development Portfolio. Multi-Year Development Plan. FY'07-FY'12."

[12] Kanellos, Michael. *Greentech Innovations: LED Lights to Drop by 50% or More Next Year?* November 3, 2008. http://www.greentechmedia.com/

[13] Cook, et al. "PG&E Emerging Technologies Program Application Assessment Report #0726: LED Street Lighting, Phase III Continuation; Oakland, CA." November 2008. Available online through the Emerging Technologies Coordinating Council at http://www.etcc-ca.com

[14] Navigant Consulting, Inc. (2008) Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications. Building Technologies Program, Office of Energy Efficiency and Renewable Energy, US DOE.

[15] Ibid, page 61

taken into account.[16] Because this is increasingly a part of the lighting design and energy planning discussion, evaluation of photopic and scotopic illuminance to characterize nighttime lighting performance of LED street lights is included in this assessment.

Demonstration Technology Information

Four LED manufacturers were asked to provide an LED street light product appropriate for replacement of 100 Watt HPS cobrahead fixtures with Type II optics. The LED manufacturers were provided with relevant demonstration Test Area dimensions, including mounting height, pole spacing and curb to curb street width. Manufacturers were also asked to provide model numbers, cut sheets, independent lab test reports if available, and unit pricing information.

While only one luminaire type was tested from each manufacturer in this demonstration, other products available from these manufacturers will have differing performance characteristics. Additionally, performance may improve in future generations of these products, some of which are now available. Results from this demonstration are only meant to characterize performance of the specific luminaire models evaluated under this study's test conditions.

For the four LED products assessed in this demonstration, Pacific Northwest National Laboratory provided test results on luminaire photometrics, power, and efficacy from independent testing laboratories. Lab results for luminaires power consumption ranged from 36.7 watts to 73.3 watts, with efficacies ranging from 18.7 lumens/watt to 71.2 lumens/watt. Correlated color temperatures (CCT) were calculated to be from a low of 5,210 K to a high of 14,628 K, with Color Rendition Indices (CRI) from 68 to 75.

Table VIII: Laboratory Reported LED Lighting and Energy Performance

Luminaire	Power	Lumens / watt	CCT (K)	CRI
LED A	58.6	54.7	6,227	75
LED B	54.4	18.7	14,628	74
LED C	36.7	71.2	5,210	68
LED D	73.3	46.9	6,052	72

Each manufacturer also provided information regarding LED rated lifetimes and product warranties. Warranties range from two to seven years, while LED lifetimes of 50,000 to over 100,000 hours were reported. While it is likely that well designed luminaires with quality components can last beyond the minimum reported LED life of 50,000 hours, industry standard methods to verify these lifetimes are still in development. Additionally, as a luminaire consists of multiple components (LEDs, driver, housing, coating, etc.), the expected useful life of the luminaire may not be the same as that of the LEDs. Instead, the lifetime should be considered to be limited by the first of all the components comprising the luminaire to fail.

[16] The DOE report leaves the energy savings analysis at equivalent lumen output because lighting standards bodies such as the Illuminating Engineering Society of North America (IESNA) and the International Commission on Lighting [Commission Internationale de l'Eclairage] (CIE) do not yet include these factors in standards development, though the research on and consideration of these factors continues.

Table IX: Manufacturer Information

Luminaire	Warranty (years)	Rated LED Life (hours)[17]
LED A	5	117,000
LED B	2	50,000
LED C	5	50,000
LED D	7	70,000

Brief descriptions of each demonstration LED product are provided below; full lab test reports are also included in Appendix F.[18]

LED A: Type II, full cutoff luminaire; 30 LEDs with individual clear optics below each, arranged in three, 10 LED light bars, in an aluminum housing with no enclosure.

Figure 1: Side and Bottom Perspectives of LED A

[17] Refers to rated LED life (rather than whole luminaire life) as provided by manufacturers in product specification sheets.

[18] Product photographs used here are from laboratory reports in Appendix F.

LED B: Type II, full cutoff luminaire; 14 white LEDs in a specular aluminum housing with clear plastic cover.

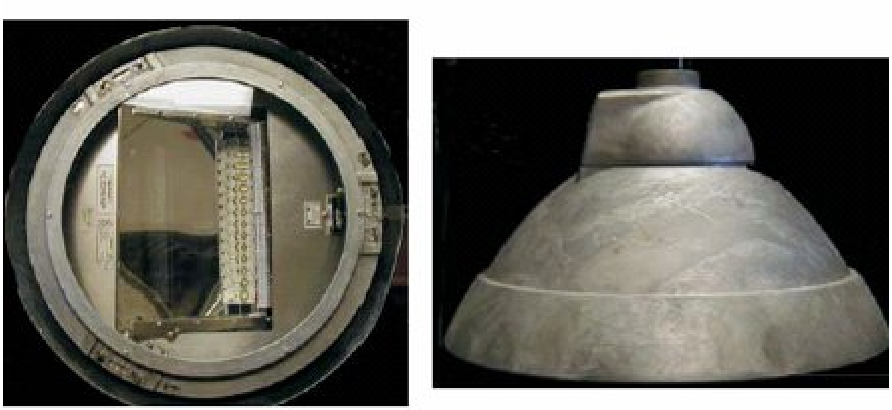


Figure 2: Side and Bottom Perspectives of LED B

LED C: Type III, cutoff luminaire; 36 LEDs in a cast aluminum housing, with a specular metal lens frame, molded gray reflector and clear plastic enclosure.

Figure 3: Bottom Perspective of LED C

LED D: Type III, cutoff luminaire; 24 LEDs in 4 rows, tilted 35 degrees from vertical with individual hemispherical integral lenses and formed reflectors, housed in extruded aluminum with a specular interior.

Figure 4: Front Perspective of LED D

Project Objectives

The objectives of this study were to examine energy, lighting, and economic performance of LED luminaires from four manufacturers as compared to cobra-head style HPS Type II full cutoff luminaires. The potential electrical demand and energy savings were measured in terms of average wattage and estimated annual kWh usage. Lighting performance was measured in terms of illuminance (photopic and scotopic), uniformity, correlated color temperature (in Kelvin), and by the satisfaction and concerns of interested parties. Finally, economic performance was evaluated through simple payback and net present value analyses for substitution of HPS street lights with LED luminaires, in new installation and retrofit scenarios.

Methodology

Host site information

A total of twenty LED luminaires from four different manufacturers were installed on four avenues in a residential neighborhood in San Francisco, CA. Five luminaires were installed on each avenue on 38th, 41st, 42nd, and 44th Avenues between Santiago and Taraval Streets to replace all of the street lights in the Test Areas. To establish a consistent baseline, new HPS Type II full cutoff luminaires were installed along each demonstration avenue before replacement with the LED luminaires. Each Test Area consisted of three luminaires from a single manufacturer, bracketed on both sides by identical luminaires to serve as buffers. Spacing of monitored luminaires was 150' and 200' (on alternating sides of the street) in each location, and spacing from monitored luminaires to buffer luminaires ranged from 60' to 200'. Luminaire mounting heights ranged from 24' to 34' above the road surface.

Streets used for demonstration purposes were chosen based on comparable street light spacing and layout, consistent lamp wattage, and minimal obstructions for photometric measurements. Close proximity of all demonstration sites was intended to facilitate demonstration activities and consistent street lighting layouts were also intended to allow for comparisons between the demonstration sites, though in practice none of the sites were equivalent enough for direct comparison.

Monitoring Plan

The Monitoring Plan consisted primarily of illuminance measurements and time series power measurements. The measurements taken included: photopic illuminance, scotopic illuminance, correlated color temperature, RMS watts, amps, volts, and power factor. Estimated annual energy usage from the lighting systems was also calculated based on PG&E rate schedules and the estimated load (in watts) from each luminaire.

Both photopic and scotopic illuminance measurements were taken at a height of 18" above ground, after civil twilight, and when ambient light from the moon was at a minimum. 280 measurement points were laid out on a 5' x 12.5' grid in each monitoring area, totaling 350' x 45.' This monitoring grid followed as closely as possible Illuminating Engineering Society of North America (IESNA) guidance for photometric measurements of street lighting systems.[19] The avenues in the demonstration area were 40' in width with one parking lane and one traffic lane in either direction. An additional line of measurement points was included on the sidewalks on either side of the avenues; inset 2.5' from the curb. Note that photometric measurements only took place at points within parking lanes where parked vehicles were not present and on sidewalks where there were no obstructions from shadows.

Measurements in each Test Area were repeated twice: once with new HPS luminaires and once with new LED luminaires. In Appendix C: Monitoring Layout, Figure 51 details the monitoring grid layout out and Figure 52 represents the cells where measurements were recorded. Measurement points were located in the following arrangement:

[19] See LM – 50 – 99; IESNA Guide for Photometric Measurement of Roadway Lighting Installations. Recommendations call for three luminaire cycles; the monitored cycle and one complete cycle on either side. Due to street block and lighting configuration in the demonstration neighborhood, only two luminaire cycles are included at each site; the monitored cycle and ½ a cycle on either side.

- 10 points transverse to the street lanes (east-west) at 5’ spacing, with two points per lane beginning ½ point spacing (2.5’) in from street curb (onto the sidewalk on either sides of the road).
- Each line of transverse points was laid out with 12.5’ longitudinal (north-south) spacing between them, beginning ½ point spacing (6.25’) in from the first luminaire in each monitored cycle, and ending ½ point spacing in the last luminaire in each monitored cycle.

Correlated color temperature measurements were taken directly under test fixtures for both HPS and LED luminaires in each Avenue. If instrument limitations did not allow direct correlated color temperature measurements, chromaticity coordinates were measured and later converted to correlated color temperature based on published equations.[20] The method for obtaining correlated color temperature values was identical for both HPS and LED luminaires.

Power measurements were 15 minute averaged recordings logged over several days, using a Dent ElitePro Datalogger. Measurements included RMS Watts, Amps, Volts, and Power Factor and were taken on one luminaire per Test Area.

Completion of illuminance measurements necessitated several visits to the sites. Monitoring equipment for power measurements on the luminaires was installed during HPS fixture and lamp change out, and was removed after power monitoring on the LED luminaires was complete.

A description of each of the field visits follow:

FIELD VISIT 1

The following occurred during this visit:

1) Evaluate, select and photograph appropriate demonstration avenues.
2) Measure and mark the illuminance measurement grids in preparation for subsequent field visits.

FIELD VISIT 2

The second visit took place during the last week of July. Prior to this visit, the existing dropped-lens HPS fixtures were replaced with new HPS Type II full cutoff fixtures, and new lamps were installed. The timing of this visit allowed adequate lamp burn-in time (100+ hours). During this visit, photometric measurements were taken for the HPS luminaires. Information collected included photopic and scotopic illuminance levels, and chromaticity coordinates. Photographs were taken to provide qualitative indication of lighting performance. All light measurements were taken after civil twilight. Specific objectives of Field Visit II included:

1) Collect HPS illuminance and CCT measurements on the Data Collection Form (photopic illuminance (fc), scotopic illuminance (fc), chromaticity coordinates / CCT).
2) Take HPS on-site photographs

[20] McCamy, Calvin S. (April 1992). "Correlated color temperature as an explicit function of chromaticity coordinates". Color Research & Application 17 (2): 142–144.

Field Visit 3

The third visit took place in the last week of August. During this visit, photometric measurements of LED luminaires were taken. Information was collected on photopic and scotopic illuminance levels. Illuminance measurements were taken at the same locations where they were taken for the HPS luminaires and were taken after civil twilight. In addition, photographs were taken from the same locations and with the same camera settings as in Field Visit II. Between the second and third visits, new LED luminaires were installed to replace the HPS luminaires in the designated areas; again allowing for 100+ hours of burn-in time.

Specific objectives of Field Visit III included:

1) Collect LED illuminance and CCT measurements on the Data Collection Form (photopic illuminance (fc), scotopic illuminance (fc), chromaticity coordinates / CCT).
2) Take LED on-site photographs

Overhead Photography Visits

For broader perspective qualitative representations of lighting distribution and quality, overhead photos were taken from a vantage roughly 40' above road surface for each demonstration avenue during two additional site visits. Photos were taken for HPS Type II full cutoff luminaires in August and for LED luminaires in September.

Monitoring equipment used in the execution of the Monitoring Plan was either owned by Energy Solutions, or obtained from the Pacific Energy Center Tool Lending Library or Sacramento Municipal Utility District's Energy and Technology Center. The equipment used is detailed below:

Illuminance Meter

Solar Light SnP Meters with Photopic and Scotopic Detectors

PMA 220

PMA 2100 [21]

Correlated Color Temperature Meter

Konica Minolta Chroma Meter

Power Meter

Dent ElitePro Datalogger

Digital Camera

Nikon D80

[21] The Solar Light PMA 2100 was cross calibrated to the PMA 220 by a series of tandem field measurements.

Project Results and Discussion

Electrical Demand and Energy Savings

Data on the power characteristics of the base case HPS luminaires and the LED luminaires were recorded over several nights for one of each fixture type using a DENT ElitePro Datalogger. The measurements were taken for between 10 and 15 days. Because the meter was installed at a height that was not within reach from the ground, the monitoring team relied upon PG&E and their street lighting maintenance crew to install and remove the meters. The number of days metered for each luminaire is a product of when the data meter could be installed and removed. No significant variations in power consumption occurred during the measured period.[22] Spot readings were also taken on an HPS dropped-lens luminaire as these luminaires are common in the study area.

The base case HPS luminaire consumed an average of 138 watts per luminaire over the monitored period. As a result the estimated annual power consumption for the luminaire, assuming 4100 hours of operation annually, is 567 kWh. The dropped-lens HPS consumed an average of 144 watts per luminaire over the monitored period, or an estimated annual power consumption of 583 kWh.

The energy consumption for the LED luminaires ranged from a low of roughly 41 watts for luminaire type C to a high of roughly 69 watts for luminaire type D. This represents savings of 50% to 70% versus the base case HPS luminaire, or 280 to 400 kWh per year.

Complete measured power data and calculated power and energy savings from the base case for each fixture are given in the following tables.

Table X: Measured Power Data

Luminaire Type	**Voltage** (V)	**Current** (A)	**Power** (W)
HPS Type II full cutoff (base case)	122.21	1.13	138.32
HPS dropped-lens[23]	122.20	1.20	144.10
LED A	123.23	0.48	58.66
LED B	120.50	0.52	62.22
LED C	122.29	0.34	41.25
LED D	121.60	0.57	69.21

[22] See Appendix A.

[23] Significant digits vary as a result of different meter used for spot-measurement of HPS dropped-lens type luminaire.

Table XI: Potential Demand and Energy Savings

Luminaire Type	Power (W)	Power Savings (W)	Estimated Annual Usage (4100 hr/yr, kWh)	Estimated Annual Savings (4100 hr/yr, kWh)
HPS Type II full cutoff (base case)	138.32	-	567	-
HPS dropped-lens[24]	144.10	-5.78 (-4.0%)	583	-15
LED A	58.66	79.66 (57.6%)	246	321
LED B	62.22	76.10 (55.0%)	255	342
LED C	41.25	97.07 (70.2%)	169	398
LED D	69.21	69.11 (50.0%)	284	283

Lighting Performance

ILLUMINANCE

Due to variations between the Test Areas, it is not possible to draw direct comparisons on lighting performance between the different manufacturer's LED luminaires. As a result, each manufacturer's LED luminaires are initially compared only to the performance of the base case HPS luminaires that were previously installed on the same street. Thereafter, computer modeling results are used to provide a comparison of lighting performance on a hypothetical street.

MEASUREMENT POINTS

Photopic and scotopic illuminance measurements were taken over a 350' x 45' area containing 3 luminaires at spacings of 150', and 200' as described in the Monitoring Plan section. However, the nature of these test sites was such that the monitoring was significantly obstructed in some cases for the parking lanes and on the sidewalks: points at 0', 5', 40', and 45' transverse to the street. Due to the extent of obstructed monitoring points, illuminance calculations are based only on measurements from the 'traffic lanes': those ranging from 10' – 35' transverse to the street.

As can be expected in any field test, there was slight variation within the Test Areas such as the orientation of the luminaire arms, and the installation parameters of the luminaires. While this results in measurements not in the exact preferred locations relative to each luminaire, any deviation can be assumed to be identical for both the base case and new luminaires, thereby negating its effect when those are compared.

METRICS

Illuminance metrics were calculated identically for each luminaire type, over both luminaire spacings (150' and 200'), and over the entire Test Area. All metrics were calculated for photopic and scotopic illuminance measurements.

---

[24] Significant digits vary as a result of different meter used for spot-measurement of HPS dropped-lens type luminaire.

For some pole spacings, the HPS and LED luminaires were not sufficient to illuminate all parts of the Test Areas to a level detectable by the photometer (0.05 fc minimum detection). The numbers of the points with light levels above that threshold, as a percentage of the total numbers of measurement points, are shown below as 'Grid Points Illuminated.' This, combined with the average illumination, indicates the amount of light provided by the luminaires.

Average illuminance levels were calculated based on all measured points in the traffic lanes, as described above, and rounded to the nearest tenth of a footcandle. While these levels provide some indication of the total amount of light output by each luminaire, they may not be wholly indicative of lighting output.[25]

The uniformity of the light provided by the luminaires was measured by three metrics: Coefficient of Variation (CV), Average-to-Minimum Uniformity ratio (AMU), and Maximum-to-Minimum Uniformity ratio (MMU).

CV, also known as relative standard deviation, is a measure of the disparity between the actual values of all measured points and the average of those values. It is calculated as the standard deviation of the distribution, divided by the average illuminance. It is useful because it provides an indication of the uniformity of all points across the test entire area. A lower CV is indicative of a more uniform distribution.

AMU provides an indication of how low the minimum measured level is, compared to the average of all measured values. It is calculated by dividing the average of all measured values by the single lowest value measured.

MMU provides indication of the largest disparity in illuminance level between any two points in the area of interest – the minimum measured value compared to the maximum measured value. It is calculated by dividing the single highest of all measured values by the single lowest level measured.

When there is incomplete illuminance of an area, neither AMU of MMU can be calculated because it would require dividing by zero. As a result, these values have been calculated for the illuminated areas only: the average or maximum of measurable values divided by the lowest measurable value. This signifies the disparity between the minimum and average values, and the greatest disparity between two points, where measurable amounts of light were provided. This suggests what that the disparities would be in a situation where the luminaire spacing was just sufficient to provide 100% illumination.

COMPANY A LED LUMINAIRE

The LED luminaires from Company A were installed on 41st Ave. Both photopically and scotopically, they provided measurable illumination over all of the 150' spacing, and over roughly 90% of the 200' spacing. This is the same as the HPS luminaires in the 150' spacing, and an improvement in the 200' spacing. The resulting 95% of points with measurable illumination over the entire area under the LED luminaire was also an increase over the base case HPS.

The average photopic illuminance provided by the LED luminaires was decreased in both spacings as well as over the entire area, although the average scotopic illuminance was conversely increased. As mentioned above, these values may not be wholly indicative of lighting output.

The CV was lower with the LED luminaires versus the HPS luminaires across all spacings, and in both types of illuminance. This indicates that, considering all measured points, the LED luminaires tended to provide a more uniform lighting distribution than the HPS luminaires in all cases.

[25] See 'Discussion' section.

Photopically, the LEDs provided better uniformity in illuminated areas when measured by AMU and MMU across the entire area and in the 200' spacing, but slightly worse in the 150' spacing. Scotopically, the LEDs performed worse in these metrics in all cases.

Consolidated illuminance values for the LED luminaires from Company A are shown below, followed by surface plots generated to provide further qualitative understanding.

Table XII: LED A Photopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	100%	0.5	0.79	2.5 : 1	10.5 : 1
LED A (150')	100%	0.3	0.61	3.6 : 1	12.0 : 1
HPS (200')	73%	0.4	1.15	5.6 : 1	21.0 : 1
LED A (200')	92%	0.3	0.91	3.2 : 1	10.0 : 1
HPS (Entire Area)	85%	0.5	0.98	5.3 : 1	21.0 : 1
LED A (Entire Area)	95%	0.3	0.82	3.4 : 1	12.0 : 1

Table XIII: LED A Scotopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	100%	0.4	0.80	3.9 : 1	16.0 : 1
LED A (150')	100%	0.7	0.67	7.6 : 1	28.0 : 1
HPS (200')	67%	0.3	1.20	4.5 : 1	16.0 : 1
LED A (200')	91%	0.5	1.07	6.5 : 1	23.0 : 1
HPS (Entire Area)	81%	0.3	1.01	4.2 : 1	16.0: 1
LED A (Entire Area)	95%	0.6	0.93	7.0 : 1	28.0 : 1

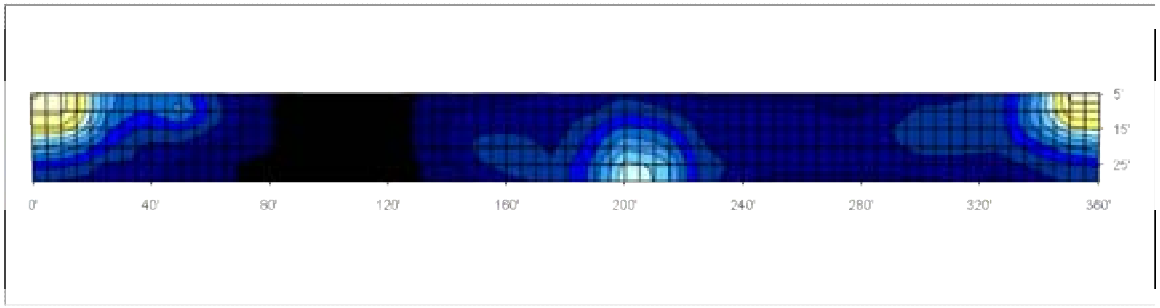


Figure 5: HPS Photopic Surface Plot, 41st Ave

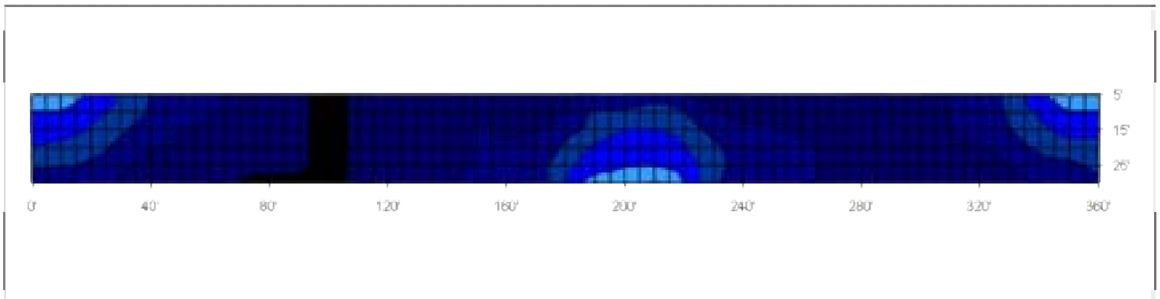


Figure 6: LED A Photopic Surface Plot, 41st Ave

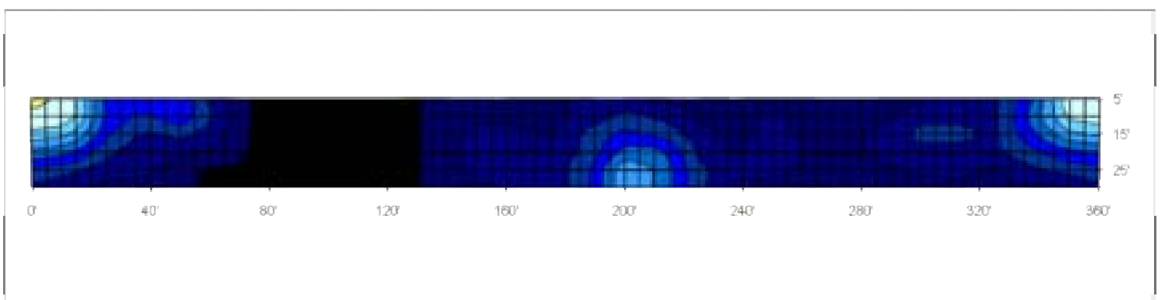


Figure 7: HPS Scotopic Surface Plot, 41st Ave

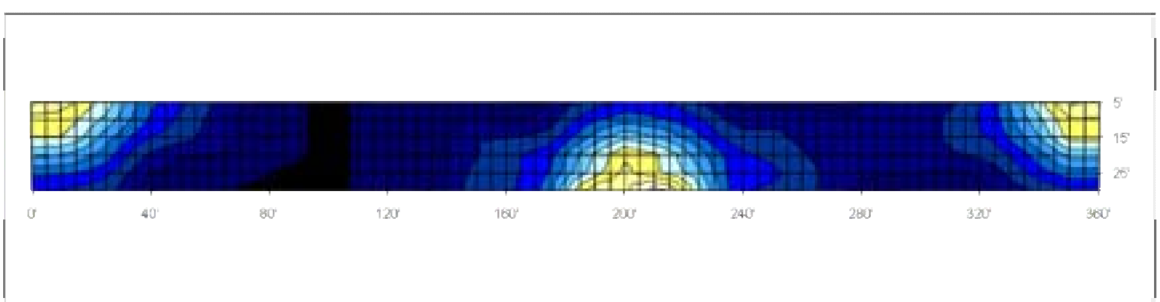


Figure 8: LED A Scotopic Surface Plot, 41st Ave

0.1-0.3 0.3-0.5 0.5-0.7 0.7-0.9 0.9-1.1 1.1-1.3 1.3-1.5 1.5-1.7 1.7-1.9 1.9-2.1 2.1-2.3 2.3-2.5

Company B LED Luminaire

The LED luminaires from Company B were installed on 38th Ave. The LED luminaires did not provide 100% illumination over either spacing, while the base case HPS luminaires were sufficient to illuminate all points in the 150' spacing but not the 200' spacing. This was true both photopically and scotopically, with corresponding decreases in the percentage of points with measurable illumination across the entire area under the LED luminaires.

The average photopic and scotopic illuminance provided by the LED luminaires was also decreased in both spacings as well as over the entire area although, as mentioned above, these values may not be wholly indicative of lighting output.

As measured by CV, the uniformity was decreased in all cases (higher CV) for the LED luminaires as compared to the HPS luminaires, although photopic uniformity ratios were decreased. This decrease in uniformity ratios however, is likely an artifact of generally reduced photopic light output by the LED luminaires as compared the HPS luminaires.

Consolidated illuminance values for the LED luminaires from Company B are shown below, followed by surface plots generated to provide further qualitative understanding.

Table XIV: LED B Photopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	100%	0.6	0.66	5.7 : 1	17.0 : 1
LED B (150')	63%	0.2	1.18	4.7 : 1	12.0 : 1
HPS (200')	76%	0.4	0.99	5.3 : 1	18.0 : 1
LED B (200')	51%	0.2	1.51	3.4 : 1	12.0 : 1
HPS (Entire Area)	86%	0.5	0.84	5.5 : 1	18.0 : 1
LED B (Entire Area)	56%	0.2	1.42	3.7 : 1	12.0 : 1

Table XV: LED B Scotopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	100%	0.4	0.70	4.4 : 1	14.0 : 1
LED B (150')	71%	0.5	1.30	8.7 : 1	35.0 : 1
HPS (200')	72%	0.3	1.05	4.0 : 1	13.0 : 1
LED B (200')	51%	0.4	1.59	8.5 : 1	32.0 : 1
HPS (Entire Area)	84%	0.4	0.88	4.2 : 1	14.0 : 1
LED B (Entire Area)	60%	0.4	1.53	8.9 : 1	35.0 : 1

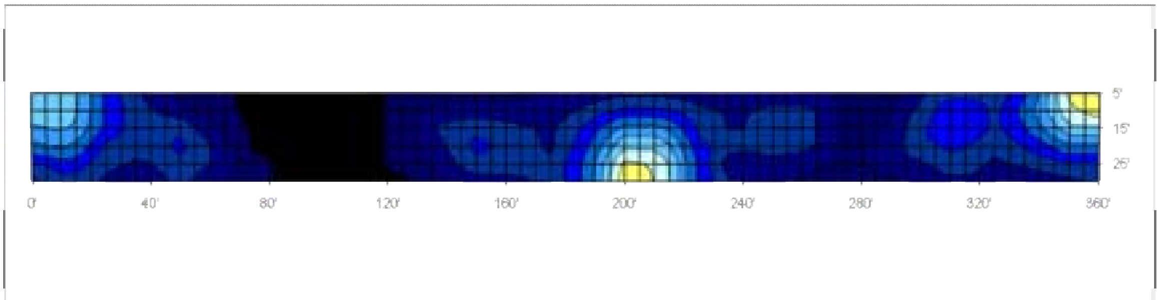


Figure 9: HPS Photopic Surface Plot, 38th Ave

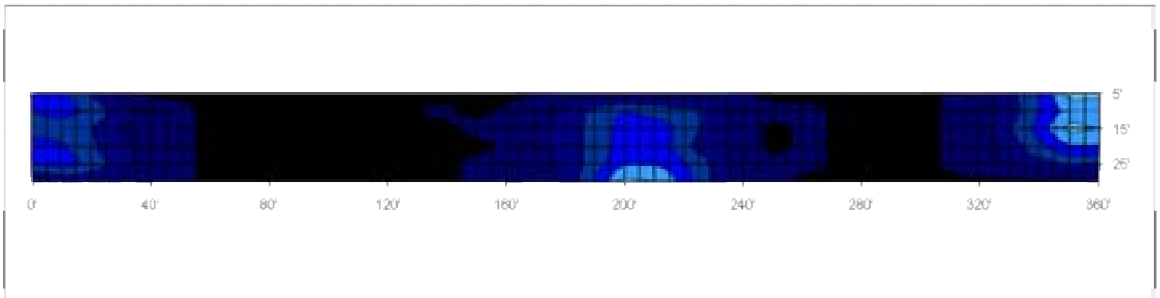


Figure 10: LED B Photopic Surface Plot, 38th Ave

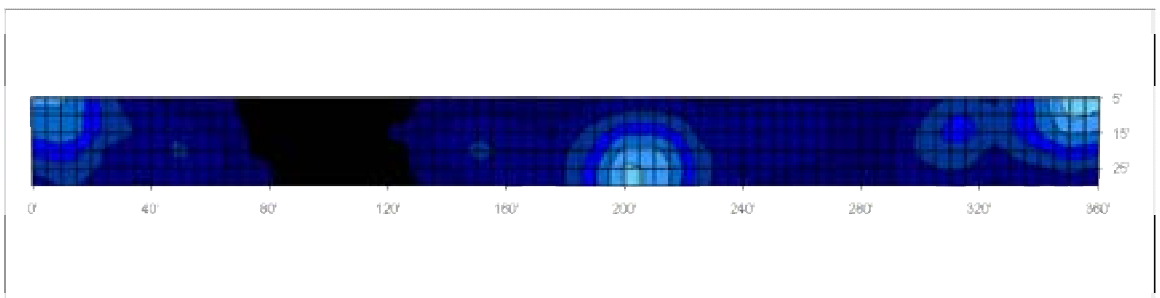


Figure 11: HPS Scotopic Surface Plot, 38th Ave

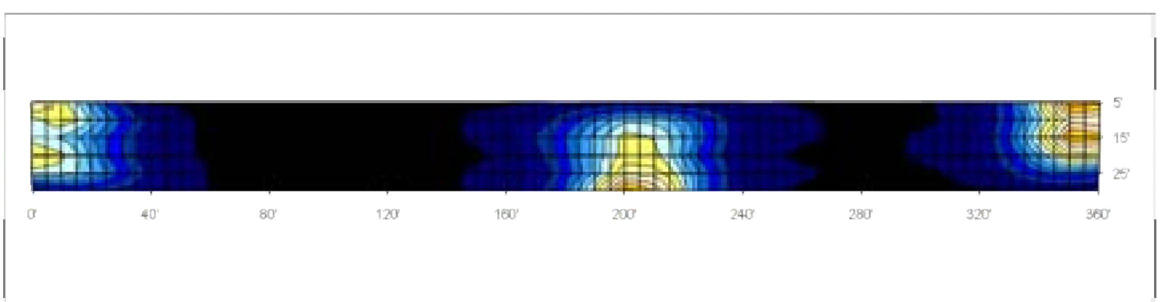


Figure 12: LED B Scotopic Surface Plot, 38th Ave

0.1-0.3 0.3-0.5 0.5-0.7 0.7-0.9 0.9-1.1 1.1-1.3 1.3-1.5 1.5-1.7 1.7-1.9 1.9-2.1 2.1-2.3 2.3-2.5

Company C LED Luminaire

The LED luminaires from Company C were installed on 42nd Ave. Both photopically and scotopically, they provided measurable illumination over nearly all of the 150' spacing, and over roughly 70% of the 200' spacing. This is an improvement over the HPS luminaires scotopically in the 150' spacing, and both photopically and scotopically in the 200' spacing. As a result, the approximately 85% of points with measurable illumination over the entire area under the LED luminaires was also an increase.

The average photopic and scotopic illuminance provided by the LED luminaires was decreased in both spacings as well as over the entire area, although these values may not be wholly indicative of lighting output.

CV was lower with the LED luminaires versus the HPS luminaires across all spacings, and in both types of illuminance. This indicates that, considering all measured points, the LED luminaires tended to provide a more uniform lighting distribution than the HPS luminaires in all cases.

The LEDs also provided better uniformity in illuminated areas when measured by AMU and MMU in all cases, both photopically and scotopically.

Consolidated illuminance values for the LED luminaires from Company C are shown below, followed by surface plots generated to provide further qualitative understanding.

Table XVI: LED C Photopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	100%	0.7	0.84	7.1 : 1	28.0 : 1
LED C (150')	99%	0.2	0.62	2.4 : 1	7.0 : 1
HPS (200')	63%	0.5	1.32	8.0 : 1	28.0 : 1
LED C (200')	72%	0.2	1.03	2.7 : 1	8.0 : 1
HPS (Entire Area)	79%	0.6	1.08	7.5 : 1	28.0 : 1
LED C (Entire Area)	83%	0.2	0.90	2.5 : 1	8.0 : 1

Table XVII: LED C Scotopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (All Measured Points, footcandles)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	94%	0.5	0.86	5.6 : 1	20.0 : 1
LED C (150')	100%	0.3	0.61	4.0 : 1	13.0 : 1
HPS (200')	57%	0.4	1.38	6.7 : 1	26.0 : 1
LED C (200')	73%	0.3	1.08	4.4 : 1	13.0 : 1
HPS (Entire Area)	73%	0.4	1.12	6.1 : 1	26.0 : 1
LED C (Entire Area)	85%	0.3	0.93	4.2 : 1	13.0 : 1

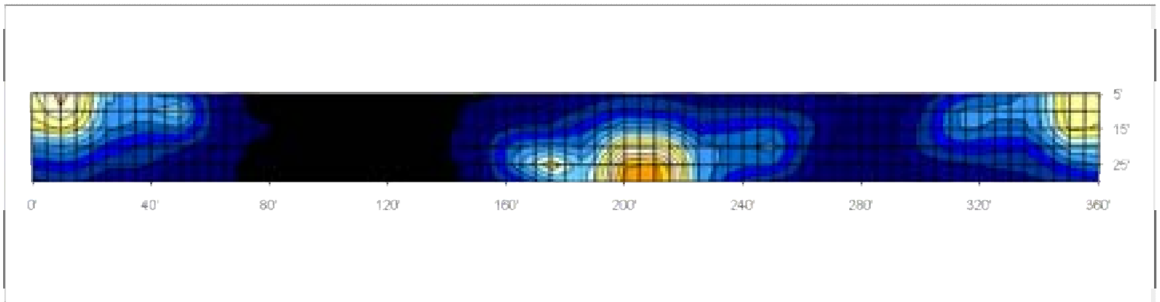


Figure 13: HPS Photopic Surface Plot, 42nd Ave

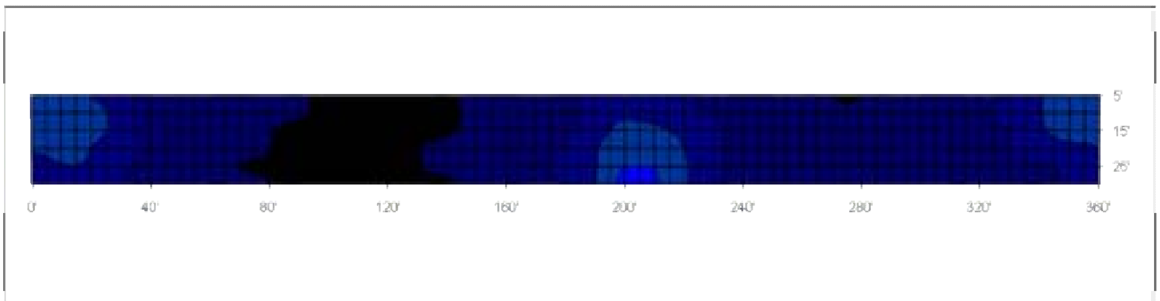


Figure 14: LED C Photopic Surface Plot, 42nd Ave

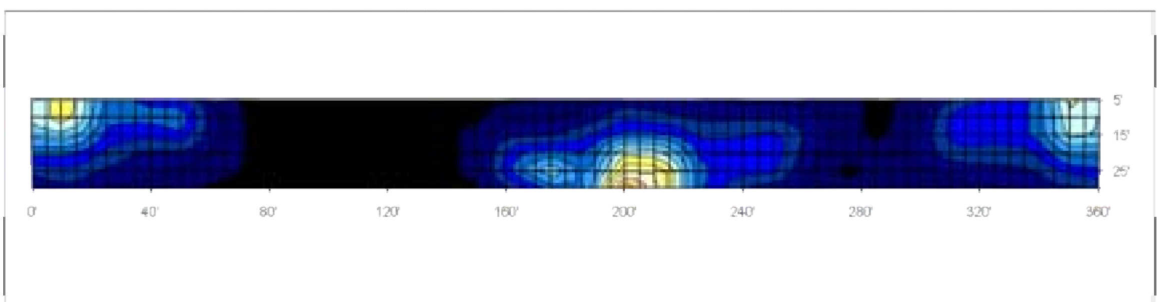


Figure 15: HPS Scotopic Surface Plot, 42nd Ave

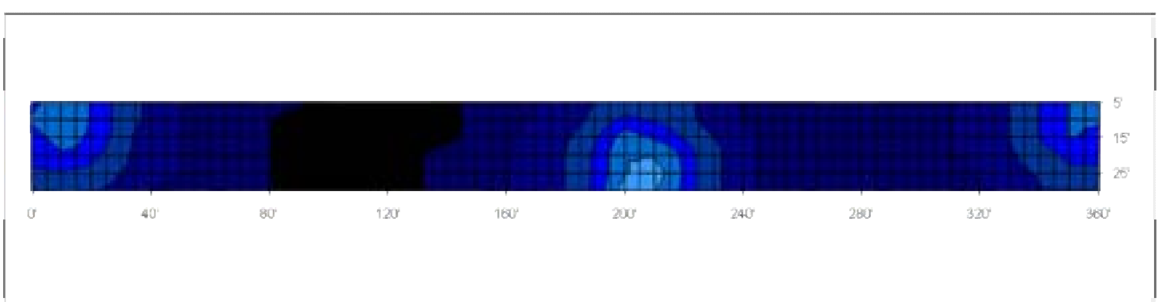


Figure 16: LED C Scotopic Surface Plot, 42 Ave

0.1-0.3 0.3-0.5 0.5-0.7 0.7-0.9 0.9-1.1 1.1-1.3 1.3-1.5 1.5-1.7 1.7-1.9 1.9-2.1 2.1-2.3 2.3-2.5

Company D LED Luminaire

The LED luminaires from Company D were installed on 44th Ave. Both photopically and scotopically, the LED luminaires provided measurable illumination over roughly 85% of grid points in the 150' spacing, and roughly half of grid points in the 200' spacing. As a result, roughly two-thirds of grid points were illuminated across the entire area. This is compared to the HPS luminaire, which illuminated 99% of all grid points photopically, and 93% scotopically.

The average photopic and scotopic illuminance provided by the LED luminaires was also uniformly decreased photopically, although it conversely increased scotopically. As mentioned above, these values may not be wholly indicative of lighting output.

As measured by CV, the uniformity was decreased in all cases (higher CV) for the LED luminaires as compared to the HPS luminaires, although photopic MMU values were decreased, and photopic AMU was decreased in 150' spacing.

Consolidated illuminance values for the LED luminaires from Company D are shown below, followed by surface plots generated to provide further qualitative understanding.

Table XVIII: LED D Photopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (footcandles, All Measured Points)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	97%	0.6	0.87	5.9 : 1	21.0 : 1
LED D (150')	83%	0.4	0.95	5.2 : 1	18.0 : 1
HPS (200')	100%	0.4	1.03	4.4 : 1	23.0 : 1
LED D (200')	53%	0.3	1.53	5.1 : 1	18.0 : 1
HPS (Entire Area)	99%	0.5	0.96	5.0 : 1	23.0 : 1
LED D (Entire Area)	66%	0.3	1.34	5.2 : 1	18.0 : 1

Table XIX: LED D Scotopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Average Illuminance** (footcandles, All Measured Points)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (Illuminated Points Only)	**Maximum-to-Minimum Uniformity** (Illuminated Points Only)
HPS (150')	90%	0.4	0.88	4.7 : 1	15.0 : 1
LED D (150')	83%	0.7	1.01	10.1 : 1	38.0 : 1
HPS (200')	95%	0.3	1.02	3.4 : 1	17.0 : 1
LED D (200')	51%	0.5	1.58	10.6 : 1	35.0 : 1
HPS (Entire Area)	93%	0.4	0.96	4.0 : 1	17.0 : 1
LED D (Entire Area)	65%	0.6	1.41	10.3 : 1	38.0 : 1

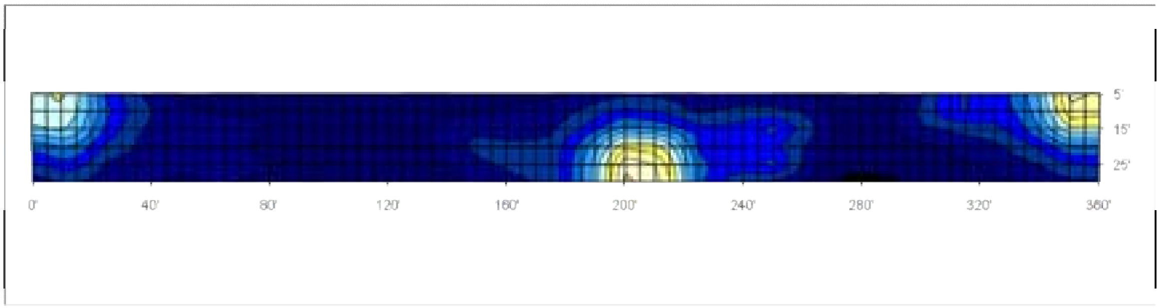


Figure 17: HPS Photopic Surface Plot, 44th Ave

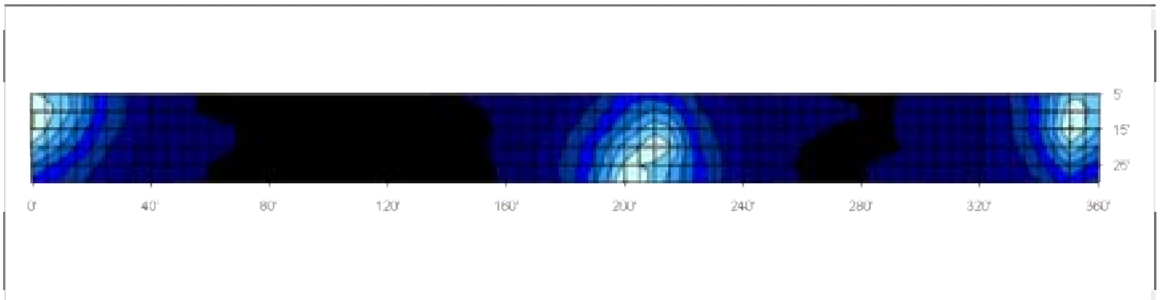


Figure 18: LED D Photopic Surface Plot, 44th Ave

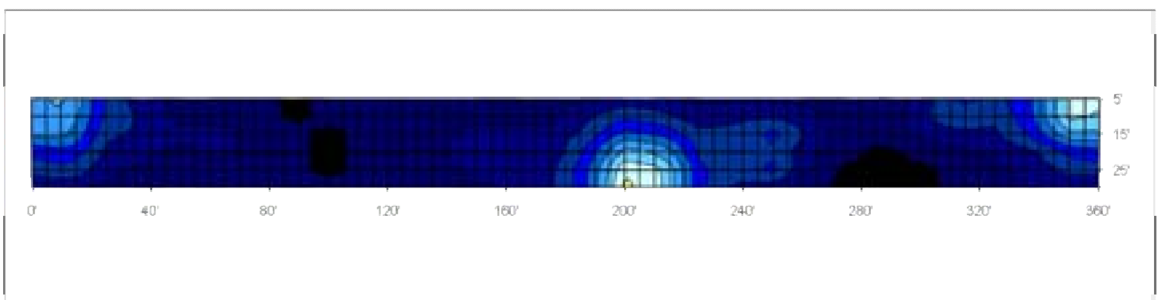


Figure 19: HPS Scotopic Surface Plot, 44th Ave

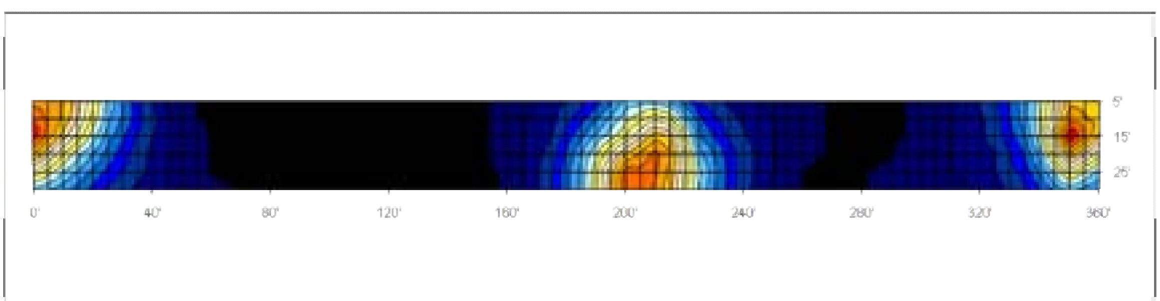


Figure 20: LED D Scotopic Surface Plot, 44th Ave

0.1-0.3 0.3-0.5 0.5-0.7 0.7-0.9 0.9-1.1 1.1-1.3 1.3-1.5 1.5-1.7 1.7-1.9 1.9-2.1 2.1-2.3 2.3-2.5

LUMINAIRE COMPARISON

In addition to field measurements, computer simulations were run to model photopic illuminance performance of all luminaires for a hypothetical street. This modeling provides useful data for comparison that eliminates field variables associated with each specific installation site. Additionally, greater precision for hypothetical data can be achieved using computer simulations than is possible for data gathered in the field.

Modeling was done using manufacturer .IES files for a hypothetical 450 foot street with luminaire spacings of 100', 150', and 200' (luminaires at 0', 100', 250', and 450'). The width of the modeled street was 40', and the modeling resolution was 5'.

To verify accuracy of computer modeling, computer models of Test Areas were also compared to, and found to be in agreement with, field data.

Metrics for the modeled data were calculated identically to those for the measured data,[26] with the exception of the uniformity ratios. Since the modeled illuminance values were not subject to the same minimum illuminance limitations as the measured data, the uniformity ratios in the modeled results were calculated using all grid points. This resulted in very high uniformity ratios in some cases, where the luminaires provide very little illuminance. While uniformity ratios this high are unrealistic in the real world due to ambient lighting, these values are informative as a metric for comparing luminaires.[27]

In the 100' spacing, all luminaires other than LED B provided illuminance over all modeled points. Average illuminance among the LED luminaires ranged from a low of 0.22 footcandles for LED C to a high of 0.51 footcandles for both LED B and D. This is compared to an average of 0.93 footcandles for the HPS luminaires. CV was reduced by the LED luminaires A and C versus the HPS luminaires, indicating that those LED luminaires tended to provide more uniform lighting when considering the full distribution. Uniformity ratios were also decreased by LED luminaires A, C, and D, again indicating increased uniformity.

In the 150' spacing, complete or near-complete illuminance over all modeled points was provided by the HPS luminaires, as well as LED luminaires A and C. Average illuminance among the LED luminaires ranged from a low of 0.15 footcandles for LED C to a high of 0.35 footcandles for LED D, while the HPS luminaires provided an average of 0.63 footcandles. Uniformity improvements were again shown by CV and uniformity ratios by LED luminaires A and C versus the HPS luminaires. However, uniformity was decreased by these metrics under LED luminaires B and D.

Finally, in the 200' spacing, no luminaire was able to provide complete illuminance over all modeled points. LED A performed the best at 84%, followed by the HPS luminaires and then LED C. Average illuminance among the LED luminaires ranged from 0.11 footcandles to 0.26 footcandles, again with LED luminaires C the lowest and LED luminaires B and D the highest. As in the 150' spacing, uniformity was increased by all metrics by LED luminaires A and C versus the HPS luminaires, and decreased by LED luminaires B and D.

Consolidated illuminance values for all luminaires are shown below, followed by surface plots generated to provide further qualitative understanding.

---

26 This includes 'Grid Points Illuminated,' which was calculated as the percentage of all grid points with a modeled illuminance level greater than or equal to 0.05 footcandles.

27 The very high uniformity ratios indicated for some luminaires resulted from minimum illuminance values near zero. In the real world, ambient light would raise these minimum values disproportionately to the average and maximum values, thereby decreasing the uniformity ratios.

Table XX: Modeled Photopic Illuminance Values for All Luminaires

Luminaire (Spacing)	**Grid Points Illuminated**[28]	**Average Illuminance** (footcandles, All Modeled Points)	**Coefficient Of Variation**	**Average-to-Minimum Uniformity** (All Modeled Points)	**Maximum-to-Minimum Uniformity** (All Modeled Points)
HPS (100')	100%	0.93	0.63	7 : 1	17 : 1
LED A (100')	100%	0.44	0.45	3 : 1	6 : 1
LED B (100')	80%	0.51	0.96	215 : 1	868 : 1
LED C (100')	100%	0.22	0.36	2 : 1	3 : 1
LED D (100')	100%	0.51	0.70	4 : 1	11 : 1
HPS (150')	100%	0.63	0.87	9 : 1	36 : 1
LED A (150')	99%	0.30	0.71	6 : 1	21 : 1
LED B (150')	72%	0.34	1.31	165 : 1	981 : 1
LED C (150')	100%	0.15	0.62	2 : 1	6 : 1
LED D (150')	79%	0.35	1.07	22 : 1	98 : 1
HPS (200')	79%	0.48	1.14	39 : 1	198 : 1
LED A (200')	84%	0.23	0.96	11 : 1	47 : 1
LED B (200')	49%	0.26	1.61	168 : 1	1,318 : 1
LED C (200')	65%	0.11	0.86	5 : 1	19 : 1
LED D (200')	60%	0.26	1.36	1,228 : 1	7,176 : 1

[28] While all grid points had some level of modeled illuminance and taken into account for these metrics, 'Grid Points Illuminated' was calculated to be consistent with that used with the measured date (the percentage of grid points with an illumination greater than or equal to 0.05 footcandles).

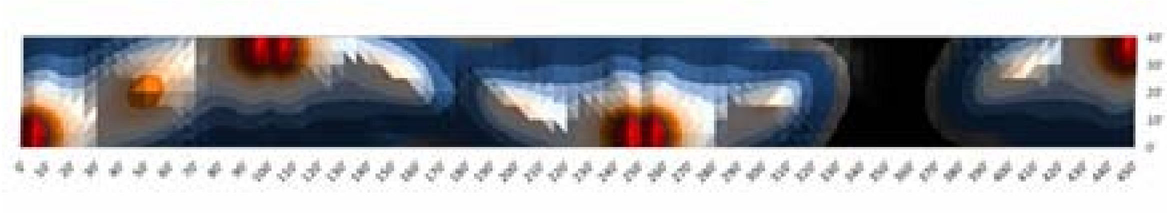


Figure 21: HPS Photopic Surface Plot, Computer Model

Figure 22: LED A Photopic Surface Plot, Computer Model

Figure 23: LED B Photopic Surface Plot, Computer Model

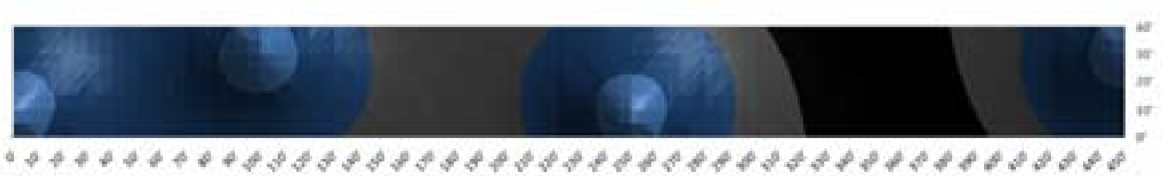


Figure 24: LED C Photopic Surface Plot, Computer Model

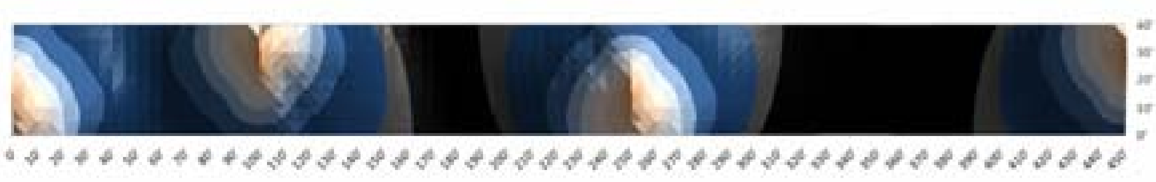


Figure 25: LED D Photopic Surface Plot, Computer Model

COLOR TEMPERATURE

Color temperature measurements were measured using a Konica Minolta Chromameter under three HPS Type II full cutoff luminaires on each avenue and under three of each type of LED luminaire. Correlated Color Temperature was calculated from measured tristimulus coordinates. The average CCTs for each HPS luminaire and LED luminaire are provided below; all recorded values are given in Appendix A: Monitoring Data.

Table XXI: Average Measured Correlated Color Temperature

Luminaire	CCT (K)
HPS*	2,077
LED A	6,573
LED B	12,710
LED C	4,582
LED D	5,781

*HPS CCT displayed is average over four streets, HPS CCT for each street is reported in Appendix A: Monitoring Data

PHOTOGRAPHIC COMPARISONS

To provide further qualitative indication of lighting performance, various ground level and overhead photographs were taken of each fixture type. These photographs were taken with a Nikon D80 digital camera, with identical settings under HPS and LED luminaires.

First, various ground level photographs were taken to show the lighting underneath each fixture type as it would be observed by a driver or pedestrian. These photographs were taken at a height of 5 feet, with the camera settings indicated below. It should be noted that, in order to provide better indication of differences in lighting color, the white balance of the camera was manually set to 4000K for these photographs and held constant under all luminaires. One HPS and one LED ground level photograph for each demonstration area is shown below.

Ground Level Camera Settings
Flash: No
Focal Length: 18 mm
F-Number: F/8
Exposure Time: 4 sec.
White Balance: 4000K

Figure 26: Base Case Ground Level Photograph for LED A (41st Ave under HPS)

Figure 27: Ground Level Photograph under LED A (41st Ave)

Figure 28: Base Case Ground Level Photograph for LED B (38th Ave under HPS)

Figure 29: Ground Level Photograph under LED B (38th Ave)

Figure 30: Base Case Ground Level Photograph for LED C (42nd Ave under HPS)

Figure 31: Ground Level Photograph under LED C (42nd Ave)

Figure 32: Base Case Ground Level Photograph for LED D (44th Ave under HPS)

Figure 33: Ground Level Photograph under LED D (44th Ave)

To provide better indication of lighting distribution, photographs were also taken from an overhead vantage point. These photographs were taken with automatic white balance adjustment, and other camera settings as indicated below. One HPS and one LED overhead photo for each demonstration area are shown.

Overhead Camera Settings
Flash: No
Focal Length: 18 – 20 mm
F-Number: F/5
Exposure Time: 2 sec.
White Balance: Automatic

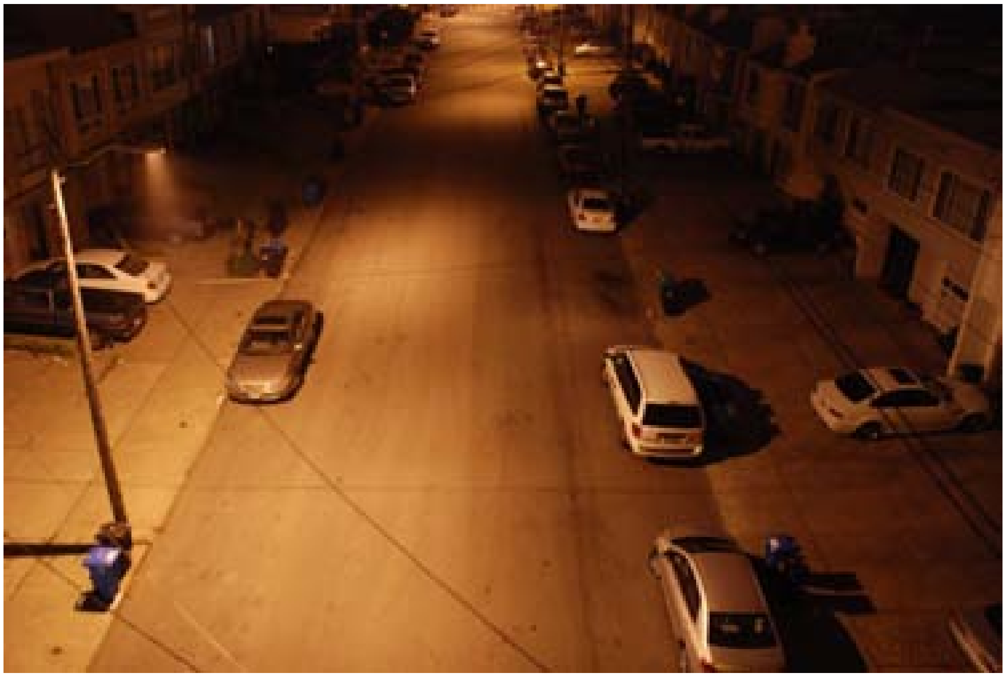


Figure 34: Base Case Overheard Photograph for LED A (41st Ave under HPS)

Figure 35: Overhead Photograph under LED A (41st Ave)

Figure 36: Base Case Overheard Photograph for LED B (38th Ave under HPS)

Figure 37: Overhead Photograph under LED B (38th Ave)

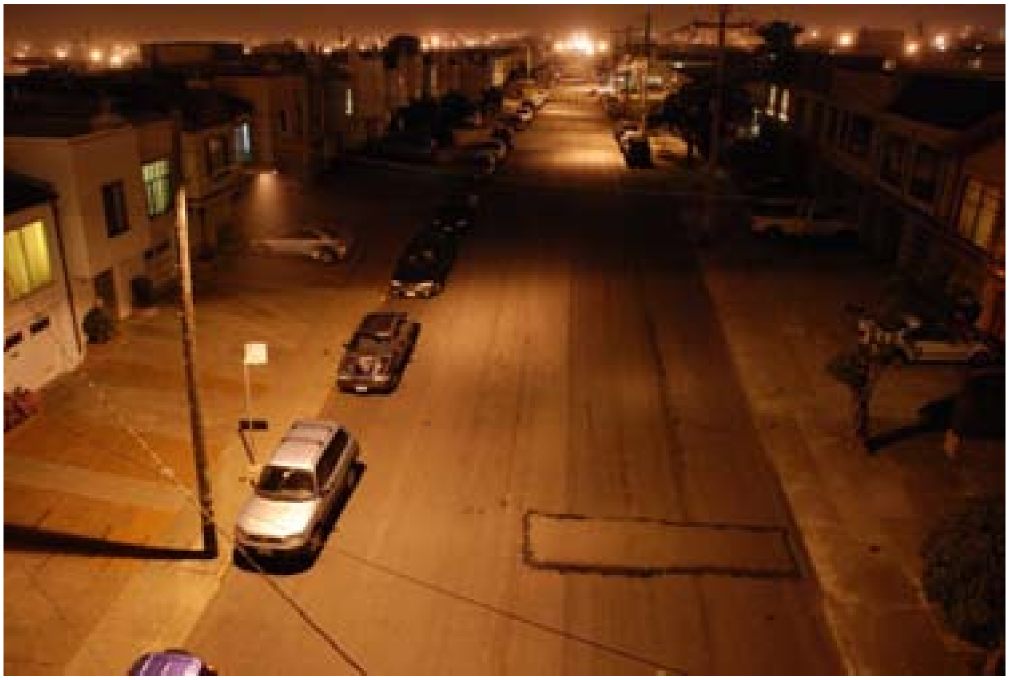


Figure 38: Base Case Overheard Photograph for LED C (42nd Ave under HPS)

Figure 39: Overhead Photograph under LED C (42nd Ave)

Figure 40: Base Case Overheard Photograph for LED D (44th Ave under HPS)

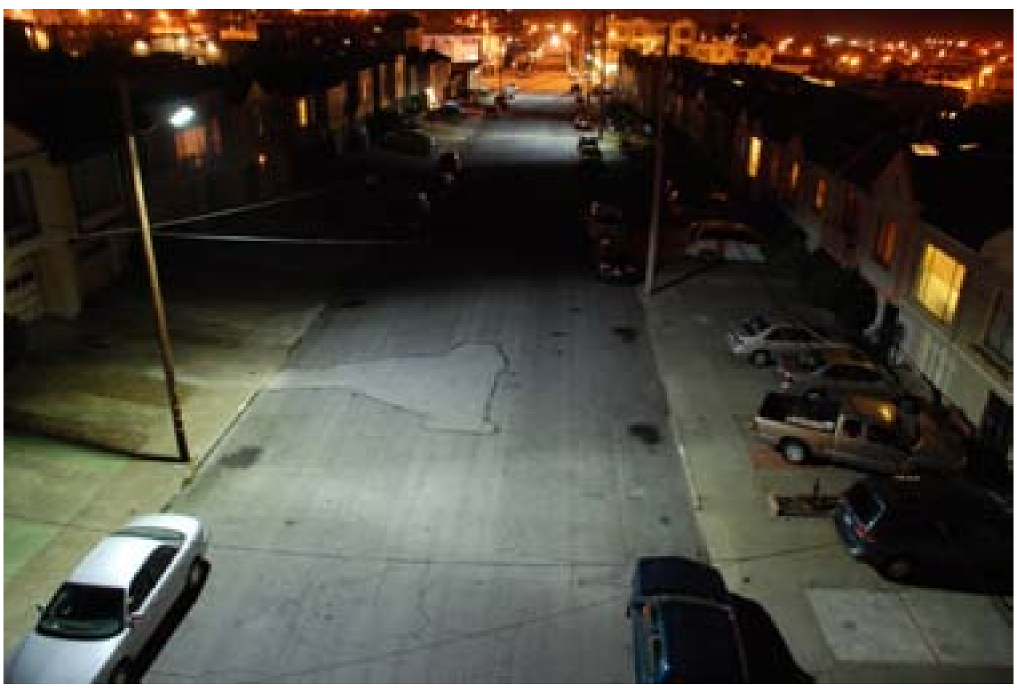


Figure 41: Overhead Photograph under LED D (44th Ave)

CUSTOMER ACCEPTANCE

The Pacific Northwest National Laboratory managed the customer opinion survey for this assessment. A public opinion research firm, Fairbank, Maslin, Maullin & Associates, was engaged to contact residents of the neighborhood by telephone and obtain their feedback on the new lights. A total of 46 were reached, 31 of which (67%) had noticed the new street lights.

Of those that noticed the new street lights, the number providing opinions on each street ranged from 9 to 15. As a result, the margin of sampling error was relatively high for each LED product, precluding statistical extrapolation to a larger population. While there was also no statistically significant preference for or against the LED luminaires compared to the base case HPS luminaires in general, there was indication that customer opinion regarding LED luminaires in this study varied by both manufacturer and by the specific aspect of lighting performance being considered. In some cases, responses indicated increased perception of lighting performance from the LED luminaires. This was especially true for areas in which the LED luminaires showed good quantitative performance. In other cases respondents indicated perceived reduction in lighting performance for the LED luminaires, suggesting that those particular luminaires may not have been well matched to the particular installation area.

Economic Performance

Cost and savings estimates were used to evaluate economic performance of each LED luminaire versus the base case HPS luminaires through simple payback and net present value (NPV) analyses.[29]

Economic estimates are sensitive to site-specific variables such as maintenance and energy costs and LED luminaire cost. Of particular note, estimates are also dependant upon assumptions for LED luminaire lifetime, which is a function of the life of all parts of the luminaire (LEDs, driver, housing, coating, etc.). Manufacturers' claims for luminaire lifetimes are highly variable. Readers are advised to use their own cost estimates and assumptions when possible.

ESTIMATED ENERGY COSTS

To estimate energy costs for each luminaire, a 2008 PG&E LS-2 rate schedule for customer-owned street lights, was used.[30] Under this rate schedule, street lights are billed a monthly set rate based on the type of lamp and an assumed 4100 hours of annual operation. One hundred-twenty volt, nominal 100 watt HPS luminaires are billed at a rate of $4.9220 per luminaire per month. While PG&E is planning to generate rates for LED street lights, currently there is no published rate schedule. As a result, an estimate of $0.12004 per kWh based on the LS-2 rate schedule was used. The energy costs for the LED luminaires were then calculated assuming this charge and based on the energy performance of each LED luminaire as measured in the field. Annual energy savings ranged from $25 to $39 per luminaire for the LEDs.[31]

ESTIMATED HPS MAINTENANCE COSTS

Street light maintenance can be divided into two broad categories: scheduled group lamp replacements, and burn-out replacements due to lamp or other component failure. Often, a combination of both maintenance categories is utilized, as burn-outs occur even in a group replacement scheme. In this demonstration, PG&E's total maintenance costs for HPS luminaires were estimated based on reported labor and material spending for PG&E's street light maintenance system, from January through September of 2008, for both group and burn out replacement scenarios. General data on monthly system wide street light replacements via group and burn out maintenance were provided for the same time period. A system wide annual maintenance cost per luminaire was then calculated based on the fraction of PG&E's total HPS street light fleet (estimated at 197,000 units[32]) maintained through group replacement and burn out scenarios every year and the total annual costs for each scenario.

---

[29] NPV calculations were based on a project analysis term of 15 years, an escalation rate for all costs of 3% annually, and a real discount rate of 5%. Readers are advised to use their own rates if applicable. See the Simple Payback and Net Present Value Calculations Tables in Appendix D: Economic Data and Calculations.

[30] See Appendix E: PG&E LS-2 Rate Schedule.

[31] See Appendix A.

[32] Based on communications with PG&E's Distribution Maintenance division.

Because mercury is present in HPS lamps, removed lamps are treated as hazardous waste. They therefore incur addition disposal charges, which were also included in maintenance costs on an annualized per-lamp basis.

Resulting costs used in this analysis are estimates based on available data; due to uncertainties on reported costs and maintenance totals, these estimates should not be considered absolute. Readers are advised to use their own estimates if possible. Assumptions and calculations can be found in Appendix D: Economic Data and Calculations.

Monthly budget estimates from PG&E did not include administrative overhead and management costs for the street lighting division. If these costs were included in the analysis, the annual maintenance costs per fixture would be higher. The maintenance cost savings here are therefore conservative. A large-scale change over to lower maintenance luminaires would likely reduce administrative and management costs, though some of these costs would not vary with respect to the maintenance performance characteristics due to a required base level of administrative and management time, regardless of maintenance activity.

ESTIMATED LED MAINTENANCE COSTS

The manufacturers of the LED luminaires assessed in this study supplied predicted lives for the LEDs used in the luminaires ranging from 50,000 to over 100,000 hours (roughly 12 to 29 years at 4100 hours per year). These lifetimes are significantly longer than an HPS rated lamp life of 30,000 hours, or roughly 7 years. Though LED lamps are expected to outlast HPS lamps, it was assumed that LED luminaires would still require some level of maintenance costs for occasional catastrophic failure and periodic routine visits for cleaning, inspection, photocell repair, and so forth.

Since LED sources tend toward rare catastrophic failure, the commonly accepted metric for determining rated life is the amount of time the LED source takes to depreciate to 70% of its initial lumen output (known as L70). However, the most relevant currently established industry-standard testing procedure, IESNA LM-80, does not specifically provide a method for measuring depreciation at the whole luminaire level. It is instead a component (package, module or array) level test, which then must be correlated to overall performance based on the thermal and electrical properties of the luminaire. Additionally, there is not currently an accepted standard for extrapolating from the depreciation measured during LM-80 testing (6,000 hours) to depreciation over the useful life of a luminaire. The IESNA is currently working on development of a standardized method (TM-21) for extrapolation of LM-80 data, but this has not been finalized. As a result, there is no unprejudiced methodology to properly verify manufacturers' claims for lumen maintenance Additionally, as a luminaire consists of multiple components (LEDs, driver, housing, coating, etc.), the expected useful life of the luminaire may not be the same as that of the LEDs. Instead, the lifetime should be considered to be limited by the first of all the components comprising the luminaire to fail.

In order to maintain a consistent comparison between the HPS luminaires and the four LED products in light of the current difficulties with determining LED luminaire useful lives, a 16 year (65,600 hrs) luminaire life was assumed. This is the lifetime given by the Database for Energy Efficient Resources for HPS fixtures.[33] It should be understood that this assumption will likely overstate the life of some LED luminaires, while understating the life of others.

[33] The Database for Energy Efficient Resources (DEER) is a California Energy Commission and California Public Utilities Commission (CPUC) sponsored database; available at http://www.energy.ca.gov/deer

Since the assumed life of the luminaires is greater than the longest time period considered (15 years), end-of-life replacement costs were not included in this analysis. However, it was assumed that a small percent (10%) of LED luminaires will fail before the end of this assumed luminaire life. Luminaire replacement frequency was then based on an annualized probability of failure.[34] Annual maintenance costs were calculated based on the probability of luminaire failure during and after the warranty period for each manufacturer, because it was assumed that the cost of replacement for LED luminaire failure under warranty would be only labor, while cost of replacement after warranty included labor and luminaire replacement.[35]

LED luminaire costs were based on bulk purchase rate estimates (1000+ units) for each LED manufacturer. Given the downward trend in LED luminaire costs today, future replacement costs can reasonably be expected to be lower per unit, but due to a lack of information on expected cost reductions, LED luminaire replacement costs were held constant. Note that individual or small number luminaire purchases would likely carry higher luminaire costs than those used in this analysis and thereby lengthen the simple payback period and decrease the net present value.

For the HPS luminaires, maintenance accounted for roughly 29% of the total annual cost (energy + maintenance). Estimated maintenance costs for the LED luminaires varied depending on expected luminaire costs and manufacturer warranty periods and ranged between 21% and 28% of total annual cost, but 59% to 68% less than the HPS base case.[36]

Table XXII: Estimated Annual Costs and Savings per Luminaire

Luminaire Type	Maintenance Cost	Maintenance Savings	Energy Cost	Energy Savings	Total Cost	Total Savings
HPS	$24.44	--	$59.06	--	$83.50	--
LED A	$8.17	$16.27	$28.86	$30.20	$37.03	$46.47
LED B	$10.13	$14.31	$30.61	$28.45	$40.74	$42.77
LED C	$7.78	$16.66	$20.30	$38.77	$28.07	$55.43
LED D	$9.04	$15.40	$34.05	$25.01	$43.09	$40.41

For comparison between LED and base case HPS options, two economic scenarios were considered: a 'new construction' scenario in which LED luminaires are installed instead of the standard 100 watt HPS luminaires, and a 'retrofit' scenario in which LED luminaires are installed in place of existing and fully functional 100 watt HPS luminaires. The details of these scenarios are presented in the Simple Payback and Net Present Value Calculations tables of Appendix D: Economic Data and Calculations.

NEW CONSTRUCTION ECONOMICS

In the new construction scenario, the cost of installation is assumed to be the same for both luminaire types. As a result, the incremental cost of installation for LED luminaires is only the difference in material costs between the LED luminaires and the HPS luminaires. For the new

[34] Lacking information, on probability distributions of failure over time, a uniform distribution was used to estimate annual failure rates.

[35] See LED Luminaire Maintenance Cost Estimates table in Appendix D for calculations and assumptions.

[36] For further details, see Appendix D.

construction scenario, simple paybacks for the LED luminaires ranged from 3.7 years to 15.3 years, with 15-year net present values from -$96 to $512.

Table XXIII: New Construction Economics

Luminaire Type	Initial Investment	Incremental Cost	Annual Savings	Simple Payback (Years)	15-Year NPV
HPS	$107.00	--	--	--	--
LED A	$400.00	$293.00	$46.47	6.3	$306.72
LED B	$675.00	$568.00	$42.77	13.3	-$16.09
LED C	$310.00	$203.00	$55.43	3.7	$512.34
LED D	$725.00	$618.00	$40.41	15.3	-$96.43

Retrofit Economics

In the retrofit scenario, there is no assumed initial investment in the HPS luminaires. As a result, the incremental cost of LED installation is the full estimated cost of the LED luminaire plus estimated installation costs, driving payback higher and net present value lower. For the retrofit scenario, simple paybacks for the LED luminaires ranged from 7.4 years to 20.4 years, with 15-year net present values from -$303 to $305.

Table XXIV: Retrofit Economics

Luminaire Type	Initial Investment	Incremental Cost (Includes Labor)	Annual Savings	Simple Payback (Years)	15-Year NPV
HPS	--	--	--	--	--
LED A	$400.00	$500.00	$46.47	10.8	$99.72
LED B	$675.00	$775.00	$42.77	18.1	-$223.09
LED C	$310.00	$410.00	$55.43	7.4	$305.34
LED D	$725.00	$825.00	$40.41	20.4	-$303.43

Calculated simple payback periods and net present values for each LED option are sensitive to estimated maintenance savings, which will vary for a given street lighting customer depending on cost of labor and materials, size of street light system, maintenance practices, and other variables. Because of wide differences in maintenance costs, simple payback and net present value ranges were calculated for new construction and retrofit scenarios for a range of maintenance savings estimates. Readers are advised to use their own estimates if applicable. Also, due to many unknowns regarding field maintenance requirements for the LED luminaires, simple payback and net present values were calculated for two conditions: assuming the LED maintenance costs estimated above and assuming an LED luminaire maintenance cost of zero. Figures Figure 42 through Figure 45 below plot simple payback and net present value curves for each LED luminaire at a maintenance savings range of $0 to $100 for new construction and retrofit scenarios.

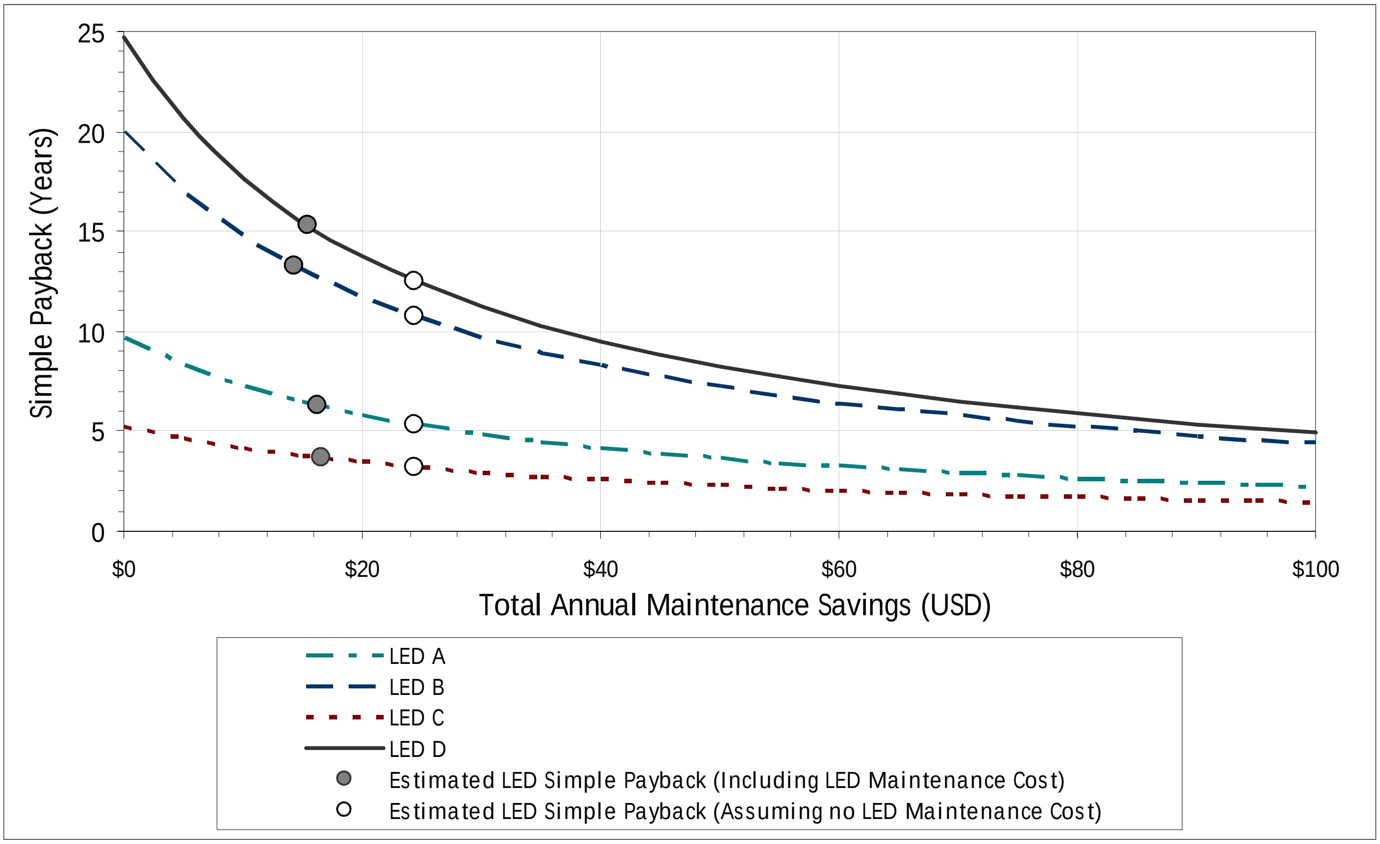


Figure 42: Estimated LED Luminaire Simple Payback for New Construction Scenario

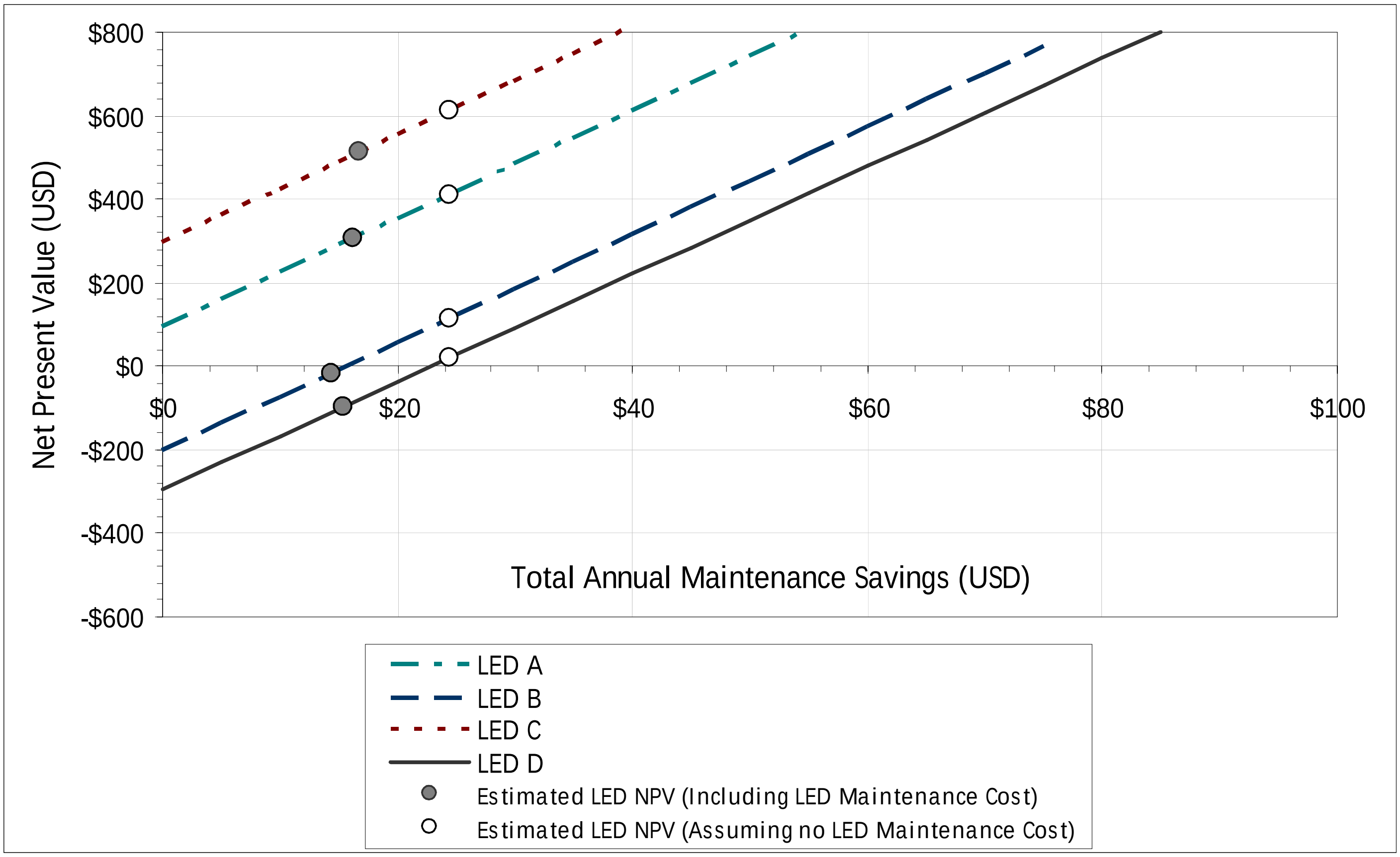


Figure 43: Estimated LED Luminaire 15-Year Net Present Value for New Construction Scenario

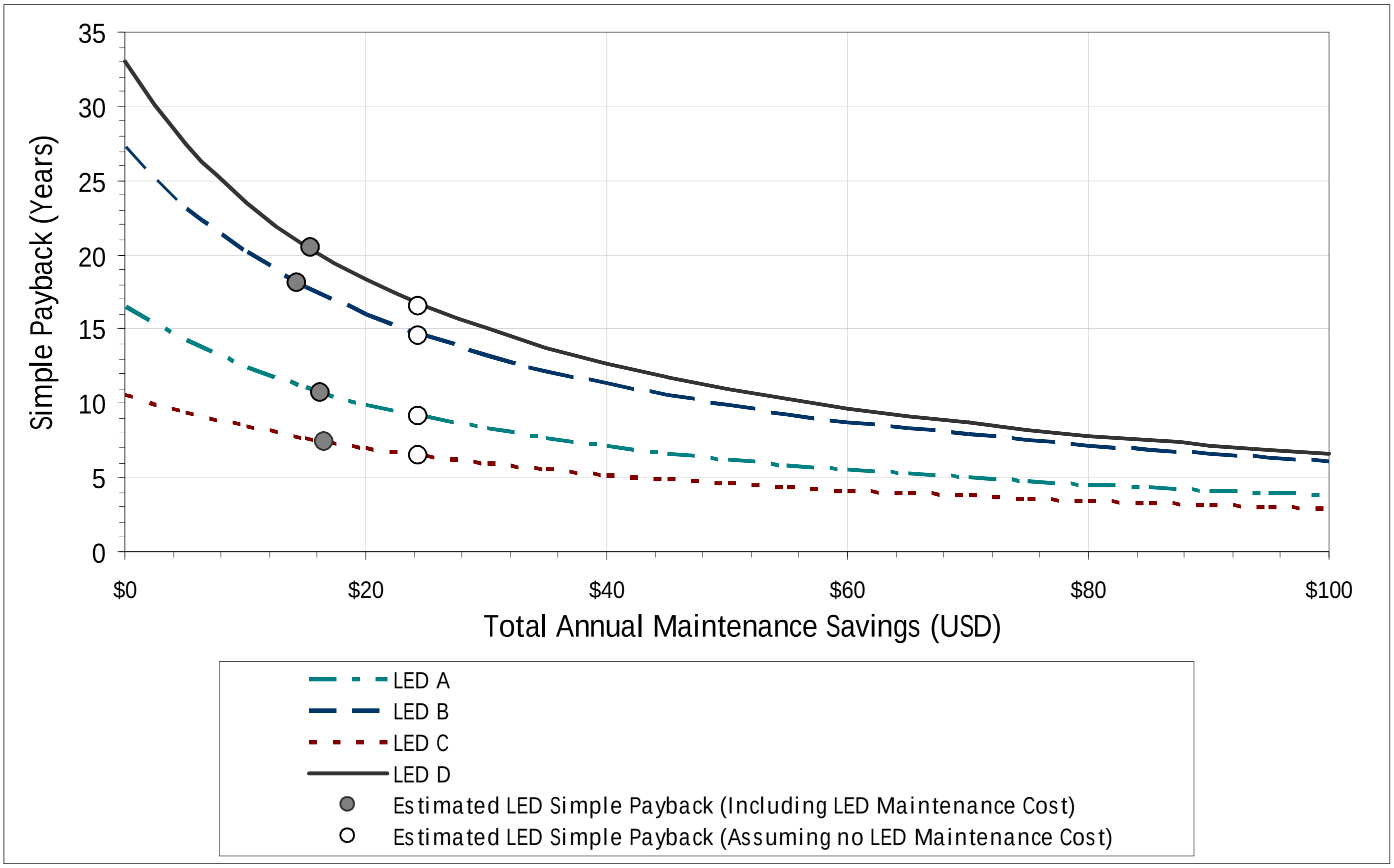


Figure 44: Estimated LED Luminaire Simple Payback for Retrofit Scenario

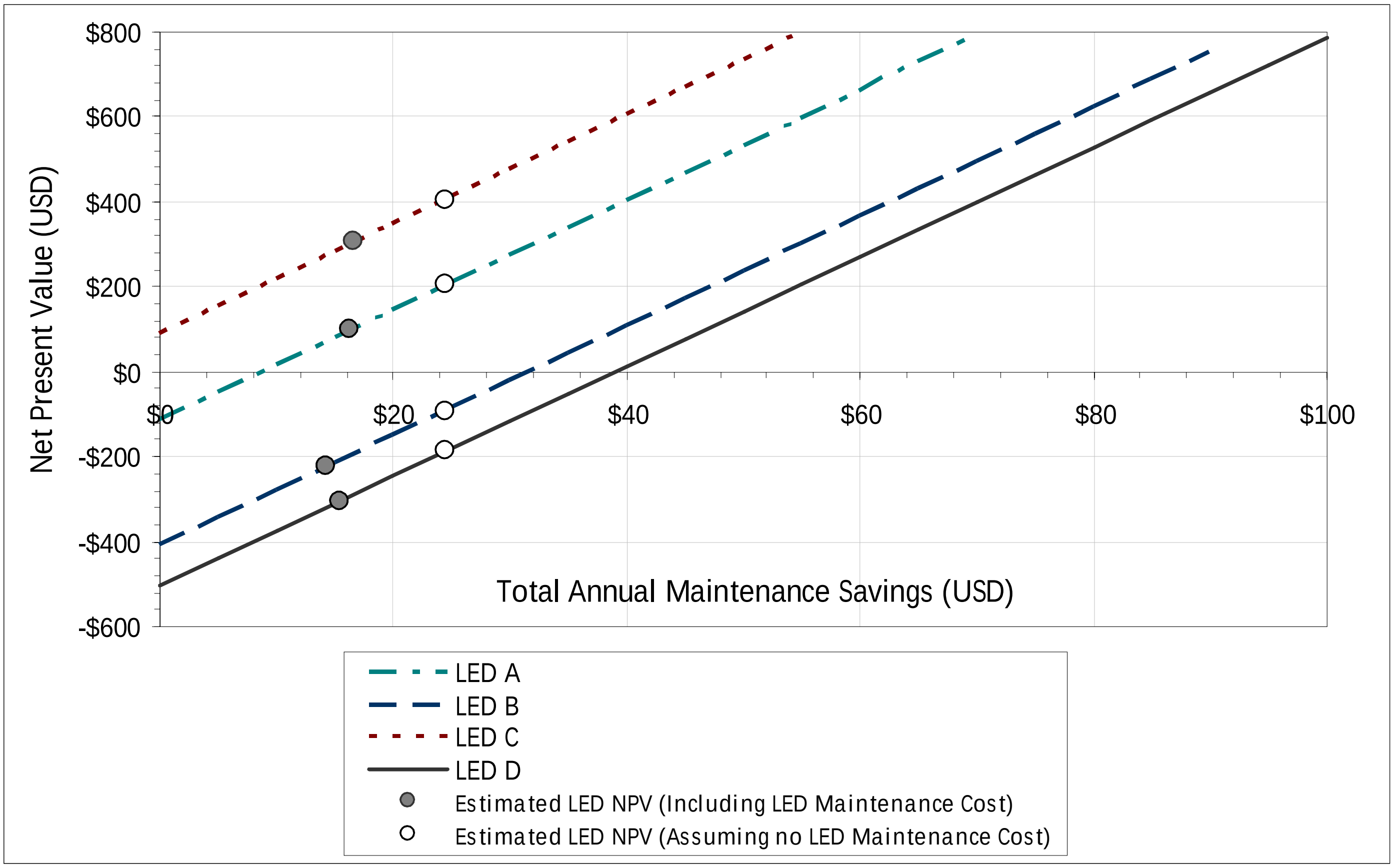


Figure 45: Estimated LED Luminaire 15-Year Net Present Value for Retrofit Scenario

Discussion

At the current state of the technology, white LED luminaires can be a viable, cost effective replacement for HPS street lights and have the potential for significant energy savings. However, as this study demonstrates, the viability and cost-effectiveness depends highly on the specific product and specific application considered. In this particular application, two of the four LED luminaires tested were shown to be both technically and economically feasible.

Technical Feasibility

For an LED luminaire to be a technically feasible replacement for an existing luminaire there are a number of factors that must be considered. The first main category of factors is the purely mechanical considerations. Examples of these considerations are whether the luminaire can be properly installed in the same location as the luminaire to be replaced, whether the luminaire is durable enough to operate in the installation environment, and whether the luminaire is interoperable with required accessories such as photocells. The other main category of technical feasibility is that of performance considerations – whether the luminaire provides the necessary amount of lighting, whether the lighting distribution is sufficient, etc. Included in this category are also considerations such as the efficacy of the luminaires and the correlated color temperature of light produced.

MECHANICAL CONSIDERATIONS

While some LED luminaires may not meet the mechanical requirements for replacement, the preconditions for inclusion in this study were such that all luminaires studied met these criteria. Specifically, all of the LED luminaires studied were required to be able to operate on a 120-volt circuit, work with photocells, and to be installed on the existing mounting arms for the base case HPS luminaires.

Beyond the preconditions for inclusion, there was variation in both the ease of installation and perceived durability of the luminaires. LED luminaire B was perceived as the easiest to install and adjust, especially for one installer, although installation time wasn't significantly reduced from two of the other luminaires (A and C). LED luminaire C was considered the next easiest to install, although the perceived durability was less than the other luminaires. LED luminaire A required some verification that installation was done correctly due to multiple possible electrical connections, resulting in a slightly more difficult installation than the other two luminaires. LED luminaire D was the most difficult to install, requiring some modification to the bracket on the pole for completion. While purely anecdotal, this information was deemed appropriate for inclusion in this report as it represents the opinions of experienced street light technicians. In general, all LED luminaires took more time to install than the base case HPS luminaires, although this may be partially explained by familiarity with those luminaires.

PERFORMANCE CONSIDERATIONS

The primary determinant of whether the LED luminaires performed sufficiently to be feasible replacements for the base case luminaires was whether they provided adequate lighting. Commonly accepted guidelines for street lighting are laid out in IESNA's Standard Practice for Roadway

Lighting, RP-8-00 (Table 2: Recommended Values).[37] For this particular demonstration area (local roads with low pedestrian conflict), the applicable guidelines call for a minimum average photopic illuminance of 0.4 footcandles and a maximum AMU of 6.0:1. It should be noted however, that these guidelines assume certain lighting characteristics that may not be directly applicable to white LED illumination; average illuminance values in and of themselves do not necessarily denote superior light performance. This is because the lighting distributions may be such that hotspots (areas of high illuminance and contrast) exist in areas directly below luminaires, increasing averages but not necessarily adding useful light.

As a result of the potential problems with average illuminance, this study places more weight on percentages of area with illuminance above 0.05 footcandles as a metric for providing adequate lighting.[38] This is a gauge of whether luminaires maintain a minimum lighting level across the entire area of interest. When combined with uniformity measurements and average illuminance levels, this metric provides a good indication of the overall lighting performance.

While good lighting design for new installations will meet certain criteria (such as 100% of area of interest illuminated, minimum uniformity levels, or average illuminance levels), these criteria may or may not be met by existing installations. As a result, these criteria should not necessarily be used to determine whether a new luminaire is a sufficient replacement for an existing luminaire. For example, the base case HPS luminaires in this study only met the RP-8 guidelines in 2 of 12 luminaire spacings evaluated in the Test Areas.

Additionally, while light levels have traditionally only been measured by photopic illuminance, visual perception follows scotopic illuminance during very low light conditions. The relative importance of scotopic illuminance and photopic illuminance at modestly low light levels are still uncertain. It is reasonable to assume though, that better lighting performance will result if minimum lighting levels are maintained while scotopic illuminance is increased. In recent years interest has also grown in scotopic light due to the potential to perceive objects more clearly from sources with enhanced scotopic quality, particularly at night. As a result, both photopic and scotopic illuminance values were measured and reported in this study.

It should also be noted that proper lighting design takes into account the mean lumen output of light sources/luminaires. This provides indication of the average lighting performance over the useful life of those luminaires. Unfortunately, accepted industry standards do not currently exist to determine the depreciation of LED luminaire performance over time. As discussed previously in the Economic Performance section, the most relevant currently established testing procedures do not apply at the whole luminaire level. Instead, correlations must be made with other measurements to predict changes in performance over time. Since there is not currently an accepted standard for making this correlation, only initial outputs are considered here.

As mentioned in the 'Project Results' section, variations existed between the Test Areas used for each LED luminaire type. Among others, these variations included differences in luminaire mounting heights, differences in precise luminaire locations, differences in street geometry, and differences in installation parameters such as luminaire aiming. As a result, direct comparisons should not be made of lighting performance between the different manufacturer's LED luminaires based on the field testing. However, LED luminaires tested in this studied did vary substantially in

[37] American National Standard Practice for Roadway Lighting. ANSI / IESNA RP-8-00, Approved 6/27/2000 Reaffirmed 2005. Page 8

[38] 0.05 footcandles was primarily chosen as minimum illuminance level because it was the lowest level detectable by the meters used in this demonstration. This level is slightly lower than the minimum level acceptable by RP-8-00 standards in this application, as determined by minimum average illuminance and maximum AMU (0.4 fc / 6 = 0.0667 fc).

their ability to provide equivalent lighting compared to the base case HPS luminaires in each Test Area.

Readers are advised that the LED manufacturers assessed here also offer other LED street light products that may vary in terms of energy and lighting performance. The results discussed here are only meant to characterize performance of the specific luminaire models evaluated under this study's test conditions.

LED Luminaire A Photometric Performance

LED luminaire A generally provided measurable illumination over a larger area, and which was more uniform, than the base case HPS luminaires. This is evidenced by the increased percentage of grid points illuminated both photopically and scotopically as compared to the HPS luminaires over the larger spacing and over the entire area, and the decreased coefficients of variation in all cases. The LED luminaires also provided increased average scotopic illuminance values, although the average photopic values were reduced. This does not necessarily denote inferior light performance however, because the lighting distribution of HPS luminaires is such that they must over-light the area directly below (creating 'hotspots') in order to maintain minimum levels further away.

HPS luminaires provide most of their light in wavelengths where photopic vision is more sensitive than scotopic vision. As a result, the photopic MMU values should be considered when evaluating the prevalence of hotspots in their distribution. Indeed, high MMU values over the entire testing area indicate that the increased average illuminance values may be the result of hotspots. Qualitative evidence of this is provided by observing the photopic surface plot. The much lower MMU value in the 150' than the 200' spacing is the result of overlapping light from the two bounding luminaires slightly raising the minimum illuminance level which, at very low light levels, can have a significant impact. While MMU was increased scotopically by the LED luminaires, reduced CV values in all cases indicates that, when considering all points, the LED luminaires still provided more uniform light than the base case HPS luminaires.

LED Luminaire B Photometric Performance

As compared to the base case HPS luminaires, LED luminaire B provided a smaller area of measurable illumination and reduced uniformity. This is evidenced by a decreased percentage of grid points illuminated, and the increased coefficients of variation in all cases. While photopic AMU and MMU values were improved by the LEDs, this is likely the result of generally decreased photopic light output as opposed to increased uniformity. Qualitative evidence of this is provided by observing the photopic surface plot.

The LED luminaires also provided decreased average photopic illuminance values, although the average scotopic values were increased. This increase in average scotopic illuminance is likely the result of hotspots directly beneath the luminaires, similar to those occurring photopically under the base case HPS luminaires. Again, qualitative evidence of this is provided by observing the surface plots in the 'Project Results' section.

LED Luminaire C Photometric Performance

Like LED luminaire A, LED luminaire C generally provided measurable illumination over a larger area, and which was more uniform, than the base case HPS luminaires. This is evidenced by the maintained or increased percentage of grid points illuminated both photopically and scotopically as compared to the HPS luminaires in all cases, and the decreased coefficients of variation in all cases. The LED luminaires also provided decreased AMU and MMU values in all cases, further indicating better uniformity than the base case HPS luminaires.

The LED luminaires did, however, have decreased average illuminance values compared to the base case HPS luminaires in all cases. This does not necessarily denote inferior light performance however, because the lighting distribution of HPS luminaires is such that they must over-light the area directly below (creating 'hotspots') in order to maintain minimum levels further away.

As previously mentioned, the photopic MMU values should be considered when evaluating the prevalence of hotspots in the HPS distribution. High MMU values for the HPS luminaire in all cases, combined with high CV values, indicate that at least a portion of their increased average illuminance values may be the result of hotspots. Again, qualitative evidence of this is provided by observing the photopic surface plot.

It should be mentioned that LED luminaire C used the least amount of energy of any luminaire tested, and was also the lowest output luminaire available from the manufacturer. It is reasonable to assume that a moderate increase in light output could be achieved with a similarly uniform lighting distribution, and slight increase in energy consumption.

LED Luminaire D Photometric Performance

LED luminaire D, similar to luminaire B, provided a smaller area of measurable illumination and reduced uniformity compared to the base case HPS luminaires. The LED luminaires provided a decreased percentage of grid points illuminated, and the increased coefficients of variation in all cases. Photopic AMU and MMU values were improved by the LEDs, however scotopic AMU and MMU values were worsened.

The LED luminaires also provided decreased average photopic illuminance values, although the average scotopic values were increased. As with LED luminaire B, this increase in average scotopic illuminance is likely the result of hotspots directly beneath the luminaires, similar to those occurring photopically under the base case HPS luminaires. Qualitative evidence of this is provided by observing the surface plots in the 'Project Results' section.

Comparison of LED Luminaire Photometric Performance

The different luminaires in this study varied greatly in their ability to provide satisfactory light output over different spacings. While, as previously mentioned, direct comparisons could not be made between measurements taken in the field, computer simulations provide a means for such comparison.

In modeled results LED luminaires A, C, and D, as well as the HPS luminaire, each provided significant illumination across all points in the 100' spacing. LED luminaires A and C and the HPS luminaire each also provided significant illumination across all points in the 150' spacing. While no luminaire considered was sufficient to provide illumination across all of the 200' spacing, the percent of illuminated points was increased by LED luminaire A versus the base case HPS luminaire.

Modeled average photopic illuminance values were decreased by all LED luminaires versus the base case HPS luminaires. High average photopic illuminance values for HPS luminaires may be partially compensated for by the higher color temperature of the LED luminaires though, which would increase scotopic levels. Among the LED luminaires, luminaires B and D generally provided the highest calculated average illuminance values, followed by LED A, and finally LED C. In addition, it is reasonable to assume that a moderate increase in light output could be achieved for the LED luminaires while maintaining very similar lighting distributions, and with an increase in energy consumption that would still be significantly less than the HPS luminaires. This is particularly true of LED luminaire C, which had the lowest average illuminance values, but also used the least amount of energy of any luminaire tested, and was the lowest output luminaire available from the manufacturer.

As has been indicated, the HPS average illuminance values do not necessarily denote superior light performance due to the possibility that the averages are increased by hotspots. As a result, it is very important to also consider the uniformity of lighting distributions. LED luminaire B had the highest coefficient of variation of all considered luminaires in all cases, indicating the worst uniformity when judged based on all calculated points. LED luminaire D had the second highest CV in all cases, followed by the base case HPS luminaire. Both LED luminaire A and LED luminaire C demonstrated reduced CVs versus the other luminaires in all cases, with LED C slightly better than LED A. The uniformity performance of the LED luminaires was similar when measured by uniformity ratios. The exception was LED luminaire D, which demonstrated increased uniformity versus the HPS luminaire in the 100' spacing, but decreased uniformity versus all the other luminaires in the 200' spacing.

All considered, the LED luminaires varied in their viability to replace the base case HPS luminaire. When based on percentage of points illuminated and uniformity from computer simulations, LED luminaire A provided maintained or increased performance versus the base case HPS luminaire in all cases. LED luminaire B, on the other hand, provided decreased performance in all cases. LED C provided increased or maintained performance in the 100' and 150' spacings, but not in the 200' spacing, and LED D provided increased or maintained performance in the 100' spacing alone. As a result, LEDs may be a viable replacement for HPS fixtures if the LED luminaire is well chosen.

Other Performance Considerations

In addition to variation in photometric performance, the LED luminaires tested in this demonstration varied greatly in other metrics such as Color Rendition Index, Correlated Color Temperature, power usage, and efficacy. The metric which showed the least variation was that of CRI; all of the LED luminaires showed increased CRI over the base case HPS luminaires. The LED luminaires had CRIs determined by independent laboratory testing of approximately 75, 74, 68, and 72, for types A, B, C, and D respectively. The HPS lamps used in the base case luminaires had a manufacturer reported CRI of 22.

The Correlated Color Temperatures calculated based on the lighting measured underneath LED luminaire types A, C, and D ranged from roughly 4500 to 6500K, with LED C the lowest and LED A the highest. These values are similar to some mid-wattage mercury vapor lamps (~5700K), indicating that they are appropriate for street lighting applications. They are compared to the calculated HPS color temperatures of roughly 2000K, and in keeping with the independent laboratory testing of the LED luminaires, which showed CCTs from 5210 to 6227K. LED type B however, had a calculated CCT of nearly 13000K and a laboratory tested CCT of 14628K. This is likely to be too high to be acceptable to most customers.

The power usage of the LED luminaires ranged from a roughly 40 to 70 watts, depending on the manufacturer. This is compared to the roughly 130 watts used by the base case HPS luminaires. The variation in efficacy between the LED luminaires was more significant, however. The most efficacious luminaire, LED C, emitted approximately 71 photopic lumens per watt. This was nearly four times as much as the least efficacious luminaire, LED B, which produced approximately 19 lumens per watt. The other luminaires, LED A and LED D, produced approximately 55 and 47 lumens per watt respectively.[39] The base case HPS luminaires tested emitted roughly 45 lumens per

[39] Based on independent test laboratory results.

watt;[40] lower than all but the worst performing LED luminaire. This indicates that, if necessary, any of LED types A, C, or D could be used to generate an equivalent amount of photopic light output to the HPS luminaires while using less energy.

Customer Acceptance

General opinions expressed regarding the LED luminaires in this study suggest that there is some amount of variance in customer acceptance, by both manufacturer and by the specific aspect of lighting performance being considered. In some cases, especially for LED luminaires in areas that showed good quantitative lighting performance, there was indication of positive customer perception of lighting performance. In other cases, responses indicating perceived reduction in lighting performance suggest that those particular luminaires may not have been well matched to the particular installation area. However, individual sample sizes were not great enough to extract statistically valid conclusions regarding specific luminaires, i.e., one vs. another. Similarly, overarching trends did not show statistically significant preference for or against the LED luminaires in general.

This lack of strong statistical preference is in some cases partially a result of the percentage of respondents indicating no opinion, or others reporting that they had not even noticed the new streetlights installed in their neighborhood. In this case, no news can be good news; it is reasonable to take some number of the “no opinion/ do not know” responses, in addition to those who explicitly noted “no change,” as qualitative indication that the LED luminaires are at least sufficient replacements for the base case luminaires.

Ultimately, if a new energy-saving technology can be substituted for the old and no one notices or is otherwise displeased, then the technology has surpassed what can be a significant market hurdle. In contrast, technologies that engender significant negative qualitative response will continue to face market resistance no matter how much energy they save.

Economic Feasibility

Market adoption of LED street lighting on a larger scale will hinge not only on lighting and energy performance, but also on economic competitiveness for new lighting installations and retrofit projects. The relatively high initial cost of LED street lights is certainly a barrier to wider use, though costs continue to decrease, as has been noted previously. Energy savings also help to buy down the incremental cost of LEDs relative to HID options, but the influence of this factor will depend on the degree of savings and energy costs for a given product and location. Expected maintenance cost savings for LED street lights, based on reduced need for burn-out or group replacement visits annually, should further the economic case for LEDs. However, there are still many unknowns regarding LED luminaire lifetimes; the diodes themselves are expected to last quite long (50,000 + burn hours) but there is less certainty regarding component and overall luminaire lifetimes (see Economic Performance section). Product warranties in this study ranged from 2 to 7 years.

Decision makers may look at the simple payback of LED investments compared with HPS when planning retrofits or new street light projects. Including estimated energy and maintenance savings, it was found that a purchaser could expect 3.7 to 6.3 year paybacks for the more affordable and higher performing options in a new installation scenario, and 7.4 to 10.8 for a retrofit scenario. For

[40] Based on manufacturer provided photometric files and measured power usage.

the lowest cost luminaire to meet a payback threshold of 5 years or less in the retrofit scenario, the LED luminaire cost would need to drop by over $130 per luminaire or the savings (energy + maintenance) improve by $25 - $30 per year per luminaire over current estimates.

However, since simple payback is not a very robust metric for economic decision making, this assessment also included net present value calculations for investments in LED street lights. These calculations are highly sensitive to the specifics of a given project, such as energy and maintenance costs, a customer's discount rate, escalation rates, and the time horizon for investment decisions. General assumptions were used here to calculate net present value for retrofits and new street light projects; for the more affordable and higher performing luminaires, 15-year NPV was in the $300 to $500 range for new construction and $100 to $300 for retrofit. This is the equivalent of an internal rate of return of 18% to 30% for new construction and 9% to 15% for retrofit. In many cases these would be considered acceptable returns for street lighting investment decisions.

To reiterate, wide differences from location to location in maintenance and energy costs mean that simple payback and net present value ranges may vary for LED street lighting projects. Readers are advised to use their own estimates for economic variables if available.

Incentive programs could also help bring LED street light prices down to a more attractive level. PG&E uses Emerging Technologies assessments to support development of potential incentives for viable emerging energy efficient solutions. Because the performance and quality of LED luminaires are critical to the long-term delivery of energy savings, it is important that incentive programs include quality control mechanisms. Incentive programs should include performance standards for qualifying products that include minimum criteria for warranty, efficacy, light distribution, and other important criteria.

Potential Savings

The LED luminaires assessed in this study showed significant energy savings potential, achieving from 50% to 70% energy savings compared to the base case HPS luminaires. Of course, lighting performance must be taken into account along with any energy performance characteristics when evaluating LED street lighting options. This study found that some of the LEDs delivered both significant energy savings and equivalent or improved lighting performance relative to the HPS luminaires. For these luminaires, potential energy savings through large scale adoption could be significant.

A 2002 DOE report estimated annual energy usage of 31 TWh in the US from street lights alone, for an inventory of approximately 38 million street lights.[41] Of these 59% are taken to be HPS, or 52% by energy usage, with average wattage of 192W.[42] While this wattage is somewhat higher than the HPS base case of 138W in this study, the LED companies studied here offer higher wattage luminaires. If it is assumed that the minimum energy savings achieved here (50%) could scale for a higher average wattage HPS replacement, and assuming 100% replacement of the installed HPS inventory nationwide with LED luminaires, 8.1 TWh of total annual energy savings would be

[41] Navigant Consulting, Inc. (2002). "US Lighting Market Characterization, Volume I."

[42] Ibid; Tables 5-17 and 5-19

expected.[43] At an EPA non-base load national average emission rate of 778g CO_2 equivalent per kWh, this represents savings of 5.7 million metric tons of CO_2 emissions annually.[44]

Based on a reported estimate of roughly 500,000 total HPS street lights in PG&E service territory (both PG&E and customer owned) and the DOE reported average HPS wattage of 192W, total energy consumption for PG&E HPS street lights would be 394 GWh (at 4100 hours per year). Assuming replacement of all system HPS street lights with LED luminaires at 50% energy savings, annual energy savings of 197 GWh are possible. At a PG&E average emission rate of roughly 240g CO_2 equivalent per kWh[45] this represents savings of 47.3 thousand metric tons of CO_2 emissions annually. Replacing HPS street lights with LEDs throughout PG&E service territory would also eliminate the costly hazardous waste stream of HPS lamps replaced during maintenance every year. Assuming group and burn out replacement rates equal to those estimated for PG&E - maintained street lights, and based on lamp disposal costs from PG&E data,[46] LED street lights could eliminate 73,800 pounds of hazardous waste in PG&E service territory annually.

[43] 50% (Demand Savings) X 52% (Total HPS Energy) X 31 TWh (Total Street Light Energy)

[44] See the EPA's Emissions & Generation Resource Integrated Database, eGRID2007 Version 1.0 http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[45] Estimate based on PG&E's online Carbon Footprint Calculator conversion values. The calculator can be found at: http://www.pge.com/myhome/environment/calculator/

[46] See Annual HPS Luminaire Maintenance Cost Estimates in Appendix D.

Conclusion

This demonstration shows that the potential for energy savings from LED street lighting is vast using current technology. Furthermore, this potential is only expected to increase in the future as LED technology continues to improve. However, this demonstration also shows that the viability of LED street lights to replace conventional technologies depends on careful consideration of both the specific application and the product chosen.

Two of the LED luminaires studied as a part of this demonstration were considered sufficient to replace the base case HPS luminaires. However, the other two LED luminaires were not sufficient in the cases measured in the field. In addition, while two of the LED luminaires performed as well or better in all cases, neither they nor the HPS luminaires were deemed to provide adequate lighting in the 200' spacing. It would be advised that a replacement LED luminaire in the wider spacing be of sufficient power and lumen output to provide significantly increased performance.

Similarly, of the four LED luminaires assessed, two were cost-effective in the scenarios considered in this study. While the cost-effectiveness metrics used were dependant on application-specific estimates of costs and savings, it can be reasonably assumed that this will be true in many cases. Additionally, decreasing luminaire costs and increasing energy savings will result in even more cost-effective scenarios in the future.

Both technical and economic performance of the LED luminaires continues to increase. This, combined with growing industry acceptance of their higher performance as compared to HPS luminaires, may provide early adopters the impetus to invest in the emerging technology. Utility or government incentive programs could also help to tip the scale towards greater adoption of LED luminaires for street light applications by reducing the initial investment. Utility incentive programs should require minimum performance standards for qualifying products in order to ensure long-term energy savings and lighting quality.

Readers of this study are advised to use their own cost and savings estimates, and to consider their own unique installation characteristics before making any final decisions with regard to replacing their existing street lights with LED luminaires. However, we believe that LED luminaires will certainly be a viable, cost effective replacement for HPS street lights in many situations, with the potential for significant energy savings.

Appendix A: Monitoring Data

POWER DATA

Table XXV: Averaged Power Measurements.

Luminaire Type	Voltage (V)	Current (A)	Power (W)	Power Factor
HPS Type II full cutoff (base case)	122.21	1.13	138.32	0.45
HPS dropped-lens[47]	122.20	1.20	144.10	0.44
LED A	123.23	0.48	58.66	0.98
LED B	120.50	0.52	62.22	0.93
LED C	122.29	0.34	41.25	0.98
LED D	121.60	0.57	69.21	0.99

Measured with DENT ElitePro Datalogger

[47] Significant digits vary as a result of different meter used for spot-measurement of HPS dropped-lens type luminaire

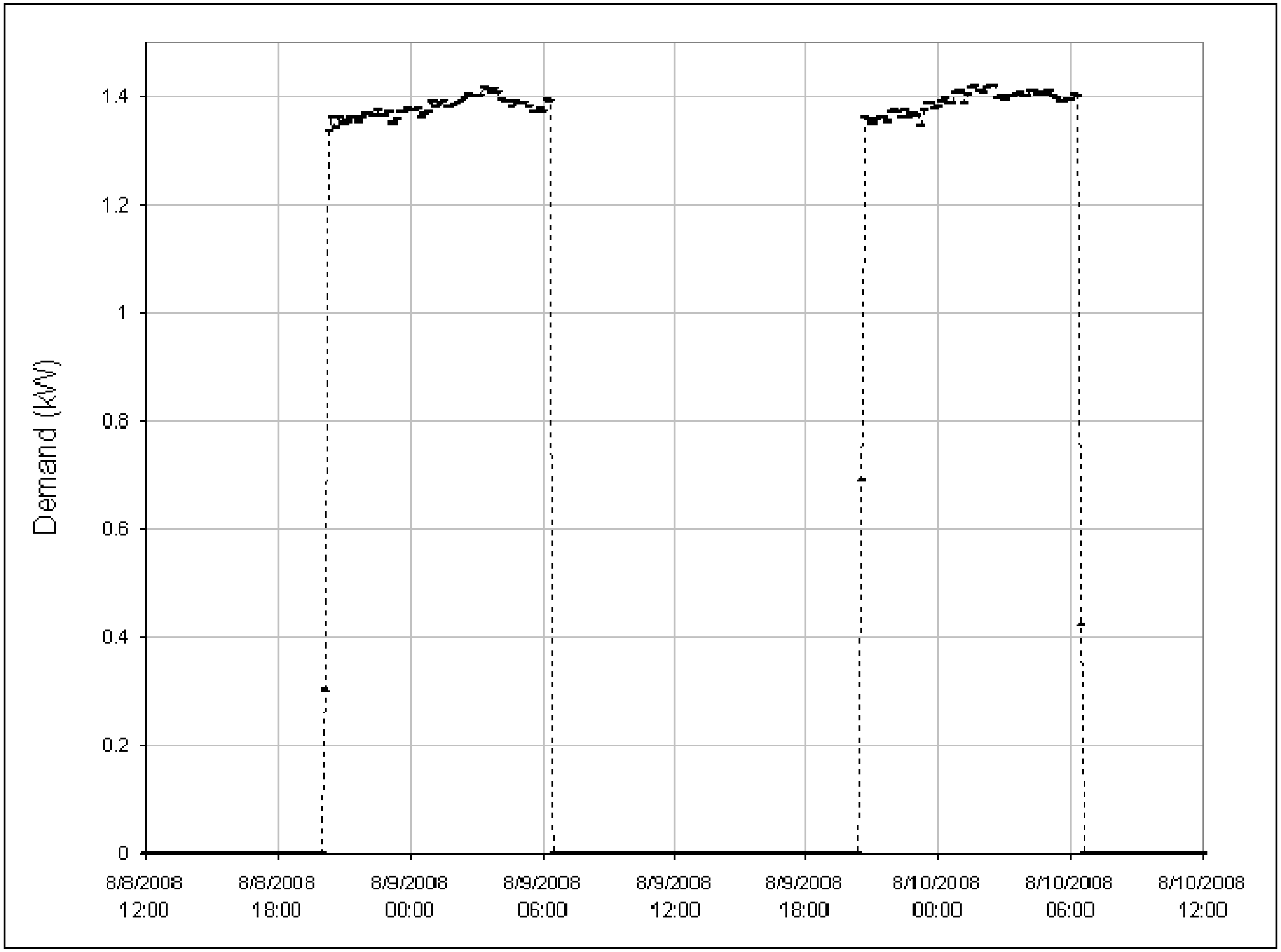


Figure 46: Sample of HPS Power Demand Data Series

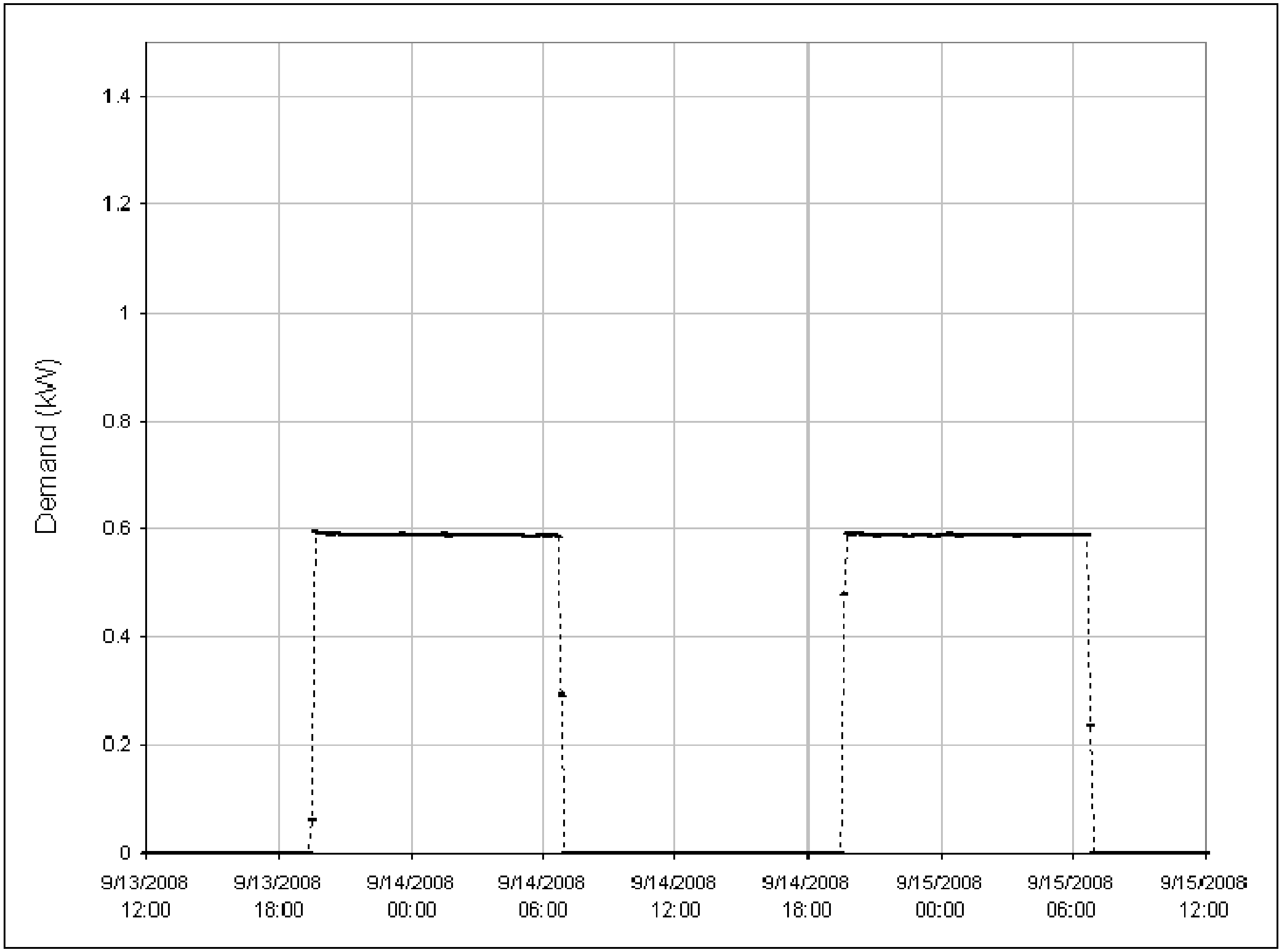


Figure 47: Sample of LED A Power Demand Data Series

(Measured with DENT ElitePro Datalogger)

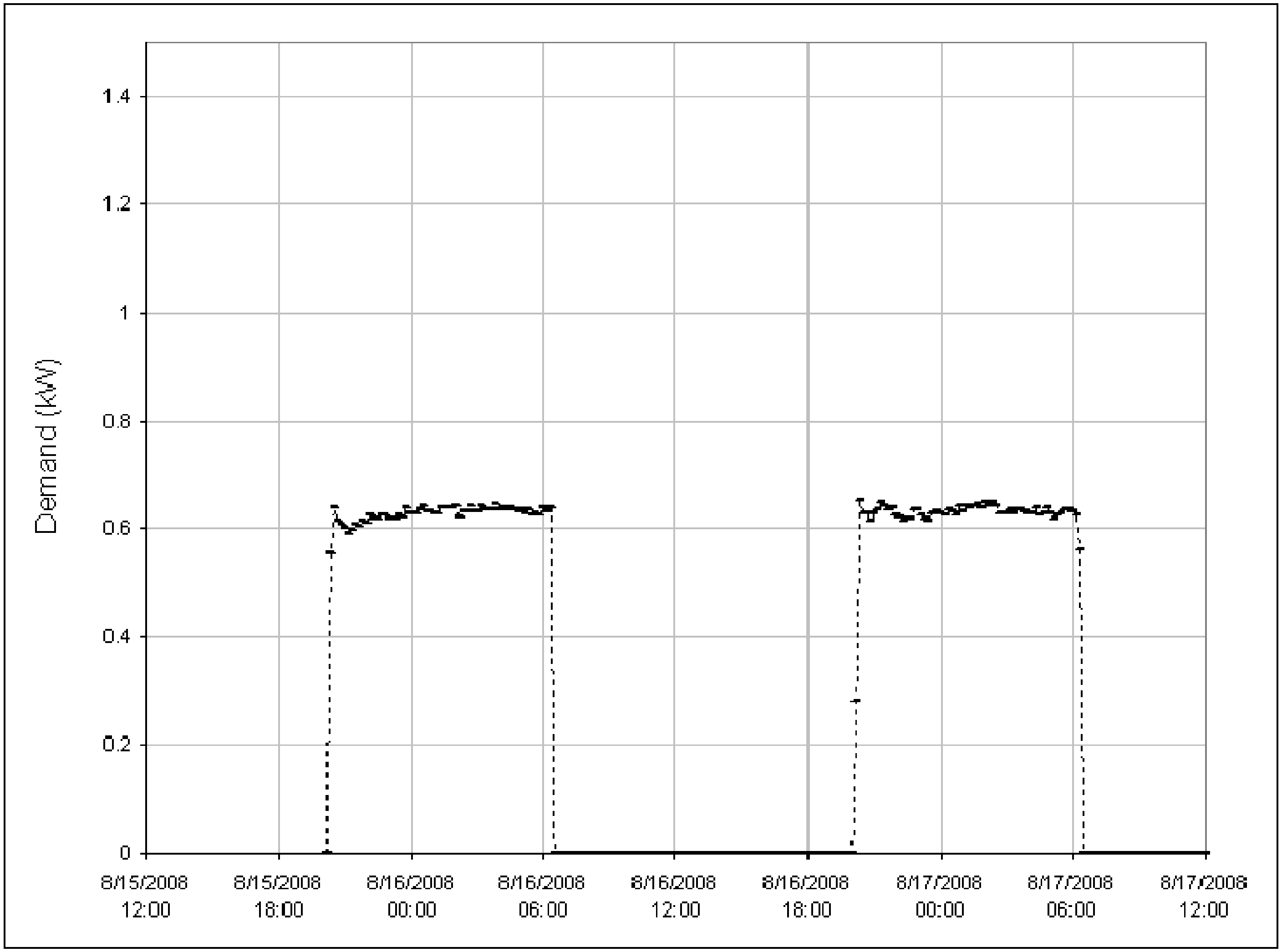


Figure 48: Sample of LED B Power Demand Data Series

(Measured with DENT ElitePro Datalogger)

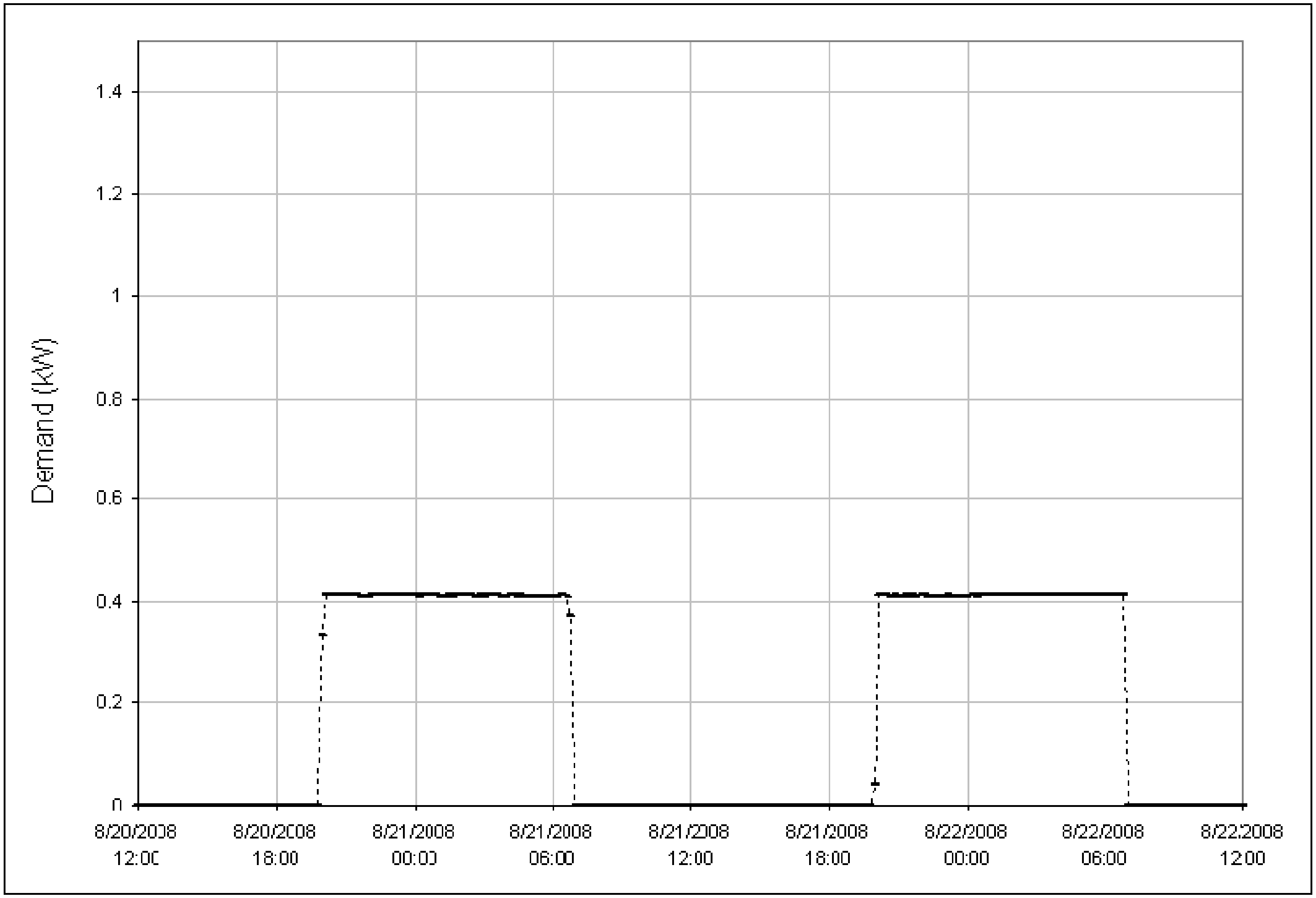


Figure 49: Sample of LED C Power Demand Data Series

(Measured with DENT ElitePro Datalogger)

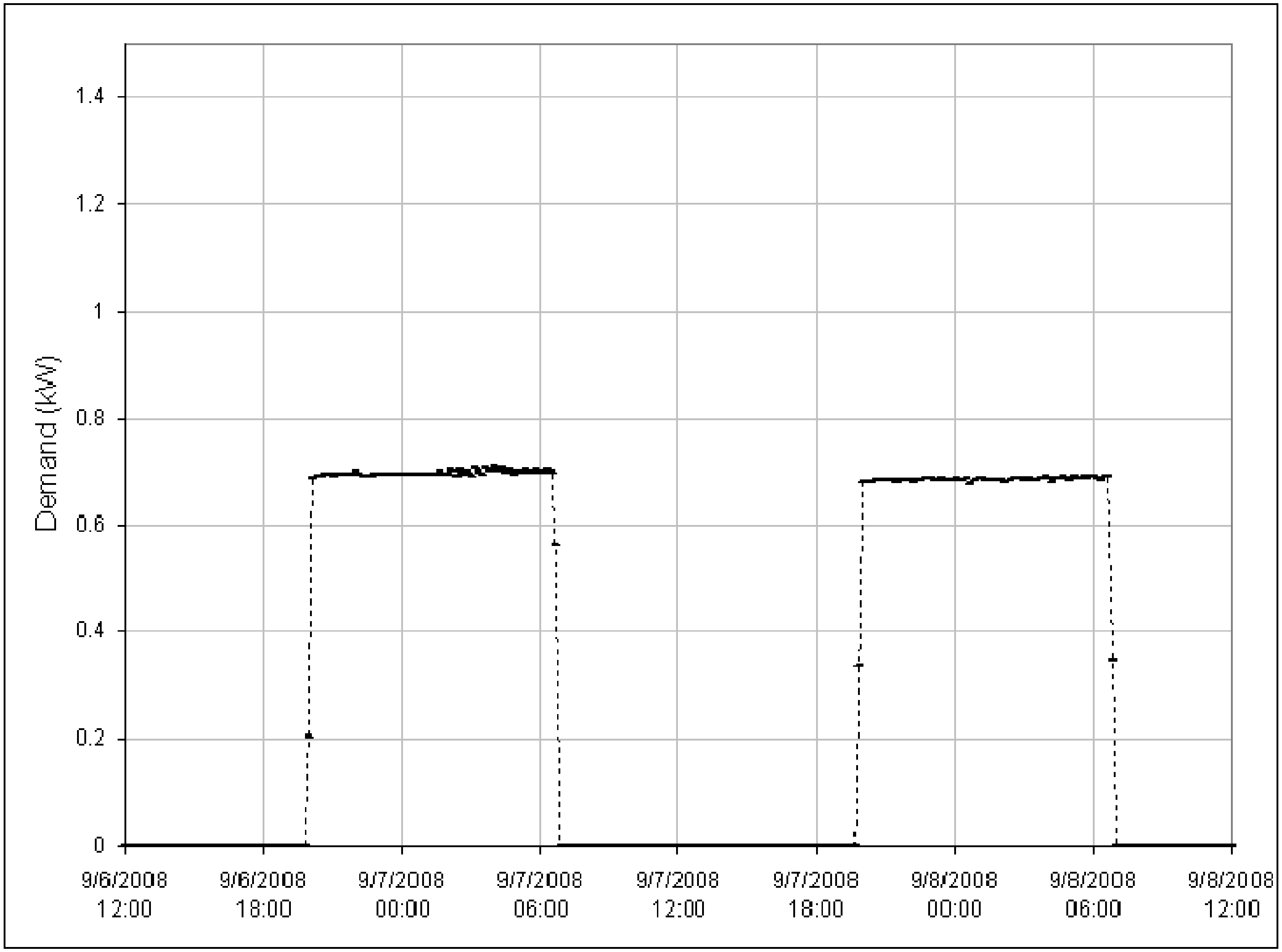


Figure 50: Sample of LED D Power Demand Data Series

(Measured with DENT ElitePro Datalogger)

MEASURED ILLUMINATION DATA

38TH AVE. HPS FIXTURE DATA

Table XXVI: 38th Ave. Photopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	1.0	1.1	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	shadow	0.1	0.1	0.2	shadow	0.2	0.2	0.1	0.2	0.1	0.1	shadow	0.1	0.2	0.4	0.8	1.3	1.4	-2.5'
2	1.2	1.3	car	0.4	car	0.1	car	0.0	0.0	car	0.1	0.1	car	0.2	0.2	0.2	car	0.3	0.2	car	0.2	0.2	car	shadow	car	0.3	car	0.9	car	1.7	2.5'
3	1.4	1.4	0.8	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.1	0.4	0.6	0.5	0.9	1.7	1.8	7.5'
4	1.4	1.4	0.8	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.3	0.3	0.5	0.7	0.7	0.5	0.4	0.5	0.5	0.2	0.2	0.5	0.9	0.6	1.0	1.6	1.8	12.5'
5	1.2	1.3	0.8	0.5	0.6	0.2	0.0	0.0	0.0	0.0	0.1	0.5	0.6	0.5	0.4	0.7	1.1	1.1	0.6	0.4	0.6	0.5	0.2	0.2	0.6	0.9	0.6	0.9	1.4	1.4	17.5'
6	1.0	1.1	0.6	0.5	0.7	0.4	0.0	0.0	0.0	0.0	0.1	0.4	0.7	0.6	0.4	0.8	1.4	1.4	0.7	0.5	0.5	0.5	0.2	0.3	0.6	0.7	0.5	0.7	1.0	1.0	22.5'
7	0.6	0.8	0.5	0.4	0.6	0.4	0.1	0.0	0.0	0.0	0.1	0.3	0.6	0.5	0.5	0.9	1.7	1.6	0.8	0.2	0.4	0.3	0.2	0.3	0.4	0.6	0.4	0.5	0.6	0.6	27.5'
8	0.4	0.6	0.4	0.3	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.5	0.9	1.8	1.6	0.8	0.4	0.3	0.2	0.1	0.2	0.3	0.4	0.3	0.3	0.4	0.5	32.5'
9	car	car	car	shadow	car	shadow	0.2	shadow	0.0	0.0	0.0	0.1	0.2	0.3	shadow	car	car	1.4	0.7	0.3	car	car	car	car	car	car	car	car	car	car	37.5'
10	0.2	0.3	shadow	0.2	0.1	0.1	0.1	shadow	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.7	1.2	1.1	0.6	0.3	0.2	0.1	shadow	0.1	shadow	0.2	shadow	0.2	shadow	0.2	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXVII: 38th Ave. Scotopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.7	0.8	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	shadow	0.1	0.0	0.1	shadow	0.1	0.1	0.1	0.1	0.1	0.1	shadow	0.1	0.2	0.3	0.6	1.0	1.0	-2.5'
2	0.9	0.9	car	0.3	car	0.1	car	0.0	0.0	car	0.0	0.1	car	0.1	0.1	0.1	car	0.2	0.1	car	0.1	0.1	car	shadow	car	0.3	car	0.8	car	1.2	2.5'
3	1.1	1.1	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.5	0.4	0.8	1.4	1.3	7.5'
4	1.0	1.0	0.6	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.2	0.2	0.3	0.5	0.5	0.3	0.3	0.4	0.4	0.1	0.1	0.4	0.7	0.5	0.8	1.3	1.2	12.5'
5	0.9	1.0	0.6	0.4	0.4	0.2	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.4	0.2	0.5	0.8	0.8	0.4	0.3	0.4	0.4	0.1	0.1	0.5	0.8	0.5	0.8	1.1	1.0	17.5'
6	0.7	0.8	0.4	0.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.4	0.3	0.6	1.1	1.1	0.5	0.3	0.4	0.4	0.1	0.2	0.5	0.6	0.4	0.6	0.8	0.7	22.5'
7	0.5	0.6	0.4	0.3	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.2	0.4	0.4	0.3	0.7	1.3	1.2	0.6	0.2	0.3	0.2	0.1	0.2	0.4	0.5	0.3	0.4	0.5	0.4	27.5'
8	0.3	0.5	0.3	0.2	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.7	1.3	1.2	0.5	0.3	0.2	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.3	0.3	32.5'
9	car	car	car	shadow	car	shadow	0.1	shadow	0.0	0.0	0.0	0.0	0.1	0.2	shadow	car	car	1.0	0.5	0.2	car	car	car	car	car	car	car	car	car	car	37.5'
10	0.1	0.2	shadow	0.1	0.1	0.1	0.1	shadow	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.9	0.8	0.4	0.2	0.1	0.1	shadow	0.0	shadow	0.2	shadow	0.2	shadow	0.1	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

38TH AVE. LED B FIXTURE DATA

Table XXVIII: 38th Ave. Photopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	
1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	shadow	0.0	0.0	-2.5'
2	0.3	0.1	car	0.1	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	car	0.0	0.0	2.5'
3	0.8	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5'
4	0.6	0.7	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.2	12.5'
5	0.6	0.6	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	17.5'
6	0.7	0.6	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	22.5'
7	0.6	0.7	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	27.5'
8	0.1	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	32.5'
9	car	0.0	car	shadow	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	shadow	car	shadow	37.5'
10	shadow	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.1	shadow	0.1	0.0	0.1	0.0	0.0	0.0	0.0	shadow	0.0	0.0	0.1	0.1	0.0	-2.5'
2	0.1	car	0.1	0.1	car	0.0	0.0	0.0	0.0	car	0.1	car	car	car	0.3	2.5'
3	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	1.1	1.1	7.5'
4	0.5	0.6	0.6	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.6	0.9	0.8	12.5'
5	0.5	0.7	0.7	0.5	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.6	1.1	1.0	17.5'
6	0.5	0.7	0.7	0.4	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.6	0.8	0.8	22.5'
7	0.5	0.8	0.8	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.4	27.5'
8	0.6	1.1	1.0	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	32.5'
9	car	car	car	car	car	car	shadow	0.0	0.0	car	car	car	0.0	0.0	car	37.5'
10	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	shadow	0.0	0.0	0.0	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXIX: 38th Ave. Scotopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	
1	0.1	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	shadow	0.0	0.0	-2.5'
2	0.7	0.2	car	0.1	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	car	0.0	0.1	2.5'
3	2.1	1.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.5'
4	1.6	1.8	1.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	12.5'
5	1.6	1.4	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	17.5'
6	1.8	1.6	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	22.5'
7	1.6	1.6	1.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	27.5'
8	0.3	0.5	0.4	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	32.5'
9	car	0.1	car	shadow	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	shadow	car	shadow	37.5'
10	shadow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.1	shadow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	shadow	0.0	0.0	0.1	0.1	0.1	-2.5'
2	0.1	car	0.1	0.1	car	0.0	0.0	0.0	0.0	car	0.1	car	car	car	0.7	2.5'
3	0.1	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.2	0.4	1.4	2.8	2.7	7.5'
4	1.0	1.4	1.4	0.9	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.4	1.2	2.2	2.1	12.5'
5	1.2	1.7	1.6	1.0	0.3	0.1	0.1	0.0	0.0	0.1	0.2	0.5	1.4	2.7	2.5	17.5'
6	1.2	1.7	1.7	0.8	0.2	0.1	0.0	0.0	0.0	0.1	0.2	0.4	1.1	1.9	1.9	22.5'
7	1.1	2.0	1.9	1.0	0.3	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.7	1.0	0.7	27.5'
8	1.5	2.8	2.3	1.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	32.5'
9	car	car	car	car	car	car	shadow	0.0	0.0	car	car	car	0.1	0.1	car	37.5'
10	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	shadow	0.1	0.1	0.1	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

41ST AVE. HPS FIXTURE DATA

Table XXX: 41st Ave. Photopic illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	1.6	1.6	0.9	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
2	2.0	1.9	car	car	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.1	car	x
3	2.3	2.1	1.1	0.9	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3
4	2.1	2.1	1.1	0.8	1.1	0.5	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.3
5	1.8	1.8	0.9	0.6	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.2	0.4	0.4	0.3
6	1.3	1.1	0.7	0.4	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.2	0.5	0.6	0.4
7	0.7	0.7	0.4	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.6	0.5
8	0.5	0.4	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5
9	x	0.3	car	0.2	car	shadow	car	0.0	0.0	0.0	0.0	shadow	car	x	car
10	x	0.2	shadow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	shadow	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.8	1.5	1.5	-2.5'
2	car	car	0.2	car	0.1	car	0.1	0.1	0.1	0.2	0.2	0.4	1.0	1.9	car	2.5'
3	0.3	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	1.0	2.1	2.1	7.5'
4	0.4	0.6	0.5	0.3	0.3	0.3	0.3	0.2	0.3	0.5	0.5	0.5	1.1	2.0	2.0	12.5'
5	0.6	0.9	0.8	0.4	0.3	0.4	0.3	0.3	0.4	0.6	0.6	0.5	1.0	1.6	1.7	17.5'
6	0.7	1.2	1.1	0.5	0.3	0.4	0.3	0.3	0.4	0.5	0.5	0.5	0.7	1.0	1.2	22.5'
7	0.8	1.5	1.4	0.6	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.5	0.6	0.7	27.5'
8	0.8	1.6	1.4	0.6	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.5	0.5	32.5'
9	0.8	car	1.3	0.6	0.3	car	0.1	car	car	0.1	shadow	car	0.2	car	0.3	37.5'
10	0.7	1.2	1.0	0.5	0.3	0.2	0.1	0.1	shadow	0.1	shadow	shadow	0.2	0.2	0.2	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXXI: 41ST Ave. Scotopic illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	1.2	1.2	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
2	1.5	1.4	car	car	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	car	car
3	1.7	1.6	0.8	0.7	0.8	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2
4	1.6	1.6	0.8	0.6	0.8	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2
5	1.4	1.3	0.7	0.4	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.2
6	1.0	0.9	0.5	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.4	0.3
7	0.6	0.5	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.3
8	0.4	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3
9	x	0.2	car	0.1	car	shadow	car	0.0	0.0	0.0	0.0	shadow	car	car	car
10	x	0.1	car shadow	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	shadow	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.3	0.7	1.2	1.2	-2.5'
2	car	car	0.2	car	0.1	car	0.1	0.0	0.1	0.1	0.2	0.3	0.8	1.5	car	2.5'
3	0.3	0.3	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.8	1.6	1.6	7.5'
4	0.3	0.5	0.4	0.2	0.2	0.3	0.2	0.1	0.2	0.4	0.4	0.4	0.9	1.5	1.6	12.5'
5	0.5	0.7	0.6	0.3	0.2	0.3	0.2	0.2	0.3	0.5	0.5	0.4	0.8	1.2	1.3	17.5'
6	0.5	0.9	0.9	0.4	0.2	0.4	0.2	0.2	0.3	0.4	0.4	0.4	0.6	0.8	0.9	22.5'
7	0.6	1.2	1.0	0.5	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.4	0.5	0.6	27.5'
8	0.6	1.2	1.0	0.5	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	32.5'
9	0.6	car	0.9	0.4	0.2	car	0.1	car	car	0.1	shadow	car	0.2	car	0.3	37.5'
10	0.6	0.9	0.8	0.4	0.2	0.1	0.0	0.0	shadow	0.0	shadow	shadow	0.1	0.1	0.2	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

41ST AVE. LED A FIXTURE DATA

Table XXXII: 41st Ave. Photopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	1.0	0.9	0.4	0.3	0.3	0.2	0.1	0.0	shadow	0.0	0.0	0.0	0.0	0.1	0.1
2	1.2	1.2	car	car	0.4	0.3	car	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1
3	1.0	0.9	0.7	0.5	0.4	0.3	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
4	0.8	0.8	0.6	0.5	0.3	0.3	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.1	0.2
5	0.8	0.7	0.6	0.4	0.3	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.3	0.2	0.3
6	0.6	0.6	0.5	0.3	0.2	0.2	0.1	0.1	0.0	0.1	0.1	0.1	0.3	0.3	0.4
7	0.5	0.5	0.4	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.3	0.3	0.5
8	0.4	0.3	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.4	0.3	0.5
9	car	0.2	car	0.1	car	0.0	0.0	0.0	car	shadow	car	shadow	car	shadow	car
10	shadow	0.1	shadow	0.1	shadow	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.1	0.1	shadow	0.1	0.0	0.1	0.1	0.1	0.1	shadow	0.2	0.2	0.3	1.0	1.0	-2.5'
2	car	car	car	car	shadow	0.1	0.1	0.1	0.2	0.2	0.2	car	0.5	car	car	2.5'
3	0.3	0.3	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.7	1.0	0.9	7.5'
4	0.5	0.5	0.6	0.4	0.2	0.2	0.2	0.1	0.2	0.2	0.3	0.4	0.6	0.8	0.8	12.5'
5	0.5	0.6	0.6	0.5	0.3	0.3	0.2	0.2	0.1	0.2	0.3	0.4	0.6	0.7	0.7	17.5'
6	0.6	0.8	0.8	0.6	0.4	0.4	0.3	0.1	0.2	0.2	0.2	0.3	0.5	0.6	0.6	22.5'
7	0.7	0.8	0.8	0.6	0.4	0.4	0.3	0.2	0.1	0.2	0.1	0.2	0.4	0.4	0.6	27.5'
8	0.9	0.9	1.1	0.6	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.4	32.5'
9	0.7	1.1	1.2	0.5	0.2	0.2	0.2	car	0.0	0.1	shadow	car	0.2	0.2	0.2	37.5'
10	0.4	1.1	0.7	0.3	0.2	0.1	0.1	0.1	0.0	0.1	shadow	0.1	0.2	0.1	0.1	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXXIII: 41st Ave. Scotopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	2.2	1.9	0.6	0.4	0.5	0.3	0.1	0.1	shadow	0.0	0.0	0.0	0.0	0.1	0.1
2	2.6	2.7	car	car	0.7	0.4	car	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2
3	2.1	1.9	1.6	1.0	0.7	0.4	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.3
4	1.7	1.7	1.4	0.9	0.6	0.3	0.1	0.1	0.0	0.1	0.1	0.2	0.3	0.2	0.3
5	1.6	1.6	1.1	0.7	0.5	0.3	0.2	0.1	0.0	0.1	0.1	0.2	0.4	0.4	0.5
6	1.3	1.2	1.0	0.4	0.3	0.3	0.1	0.1	0.0	0.1	0.1	0.2	0.4	0.6	0.8
7	0.9	0.9	0.7	0.3	0.2	0.1	0.1	0.0	0.0	0.1	0.1	0.2	0.5	0.6	0.9
8	0.8	0.6	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.6	0.6	1.0
9	car	0.3	car	0.1	car	0.0	0.0	0.0	car	shadow	car	shadow	car	shadow	car
10	shadow	0.2	shadow	0.1	shadow	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.2	0.2	shadow	0.2	0.1	0.1	0.1	0.1	0.2	shadow	0.3	0.3	0.7	2.1	2.0	-2.5'
2	car	car	car	car	shadow	0.1	0.1	0.2	0.3	0.3	0.4	car	1.2	car	car	2.5'
3	0.5	0.7	0.7	0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.8	1.5	2.1	2.0	7.5'
4	0.8	1.0	0.9	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.8	1.3	1.8	1.8	12.5'
5	1.0	1.4	1.2	0.9	0.5	0.5	0.3	0.3	0.3	0.3	0.5	0.7	1.1	1.7	1.7	17.5'
6	1.4	1.8	1.6	1.1	0.7	0.6	0.4	0.3	0.3	0.3	0.4	0.5	0.9	1.3	1.3	22.5'
7	1.5	1.9	1.6	1.3	0.7	0.7	0.5	0.3	0.3	0.3	0.2	0.3	0.7	1.0	1.0	27.5'
8	2.0	2.0	2.4	1.5	0.7	0.6	0.5	0.3	0.2	0.1	0.1	0.3	0.4	0.6	0.6	32.5'
9	1.7	2.4	2.6	1.0	0.4	0.3	0.3	car	0.1	0.1	shadow	car	0.3	0.3	0.3	37.5'
10	0.8	2.3	1.5	0.5	0.3	0.2	0.2	0.1	0.1	0.1	shadow	0.1	0.2	0.2	0.2	42.5'
	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

42ND AVE. HPS FIXTURE DATA

Table XXXIV: 42nd Ave. Photopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	1.4	1.6	0.9	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	car shadow	0.2	0.2	0.2	0.2	0.1	car shadow	car shadow	0.1	0.0	0.1	0.2	0.5	0.8	1.6	1.5	-2.5'
2	1.8	car	1.1	car	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	car	0.1	car	0.2	0.3	0.3	0.2	0.2	car	car	car	car	0.1	0.4	car	1.0	x	1.8	2.5'
3	2.0	2.4	1.3	1.1	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.2	0.7	0.9	1.1	2.0	2.0	7.5'
4	1.9	2.3	1.2	1.2	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.6	0.5	0.5	0.5	0.4	0.2	0.1	0.4	1.1	1.1	1.1	2.0	1.9	12.5'
5	1.7	1.9	1.1	0.9	1.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.5	0.8	1.2	1.2	0.7	0.8	0.9	0.5	0.2	0.1	0.5	1.1	1.0	1.0	1.9	1.8	17.5'
6	1.1	1.2	0.8	0.6	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.0	1.1	1.0	2.0	2.0	1.1	1.0	1.1	0.4	0.1	0.1	0.5	0.8	0.7	0.7	1.4	1.4	22.5'
7	0.7	0.8	0.5	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.1	1.8	1.2	2.6	2.7	1.2	0.9	0.9	0.3	0.1	0.1	0.3	0.4	0.5	0.5	0.9	1.1	27.5'
8	0.4	0.5	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	1.2	1.3	2.8	2.8	1.2	0.6	0.4	0.2	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	32.5'
9	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	car	1.1	car	2.3	1.0	0.5	0.2	0.1	0.1	x	x	0.2	0.2	x	x	x	37.5'
10	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.9	1.6	1.7	0.9	0.4	0.2	0.0	0.0	0.0	0.1	0.1	car shadow	car shadow	0.2	0.2	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXXV: 42nd Ave. Scotopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	1.1	1.2	0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	car shadow	0.1	0.1	0.1	0.1	0.1	shadow	car	0.1	0.0	0.0	0.2	0.4	0.7	1.2	1.1	-2.5'
2	1.4	x	0.9	car	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	car	0.0	car	0.1	0.2	0.2	0.2	0.1	x	x	x	x	0.1	0.3	car	0.7	x	1.4	2.5'
3	1.5	1.8	1.0	0.8	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.1	0.0	0.1	0.5	0.7	0.8	1.7	1.5	7.5'
4	1.5	1.8	0.9	0.9	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.6	0.5	0.4	0.4	0.4	0.3	0.1	0.0	0.2	0.8	0.8	0.8	1.6	1.4	12.5'
5	1.3	1.4	0.8	0.7	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.4	0.6	0.9	0.9	0.6	0.6	0.7	0.4	0.1	0.0	0.3	0.8	0.8	0.8	1.5	1.4	17.5'
6	0.9	0.9	0.6	0.4	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	0.9	0.8	1.6	1.5	0.8	0.8	0.8	0.3	0.1	0.1	0.3	0.6	0.5	0.6	1.1	1.1	22.5'
7	0.5	0.6	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.9	1.4	0.9	2.0	2.0	0.9	0.7	0.7	0.2	0.0	0.1	0.2	0.3	0.4	0.4	0.7	0.8	27.5'
8	0.3	0.4	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	1.0	2.6	2.0	0.9	0.5	0.3	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.5	32.5'
9	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	car	0.9	car	1.9	0.8	0.4	0.2	0.1	0.0	x	x	0.1	0.1	x	x	x	37.5'
10	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.7	1.6	1.3	0.7	0.3	0.1	0.1	0.0	0.0	0.0	0.1	car shadow	car shadow	0.2	0.2	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

42ND AVE. LED C FIXTURE DATA

Table XXXVI: 42nd Ave. Photopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.4	0.5	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	shadow	0.2	shadow	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.3	0.3	0.6	0.5	-2.5'
2	0.5	car	0.4	car	shaow	car	shadow	car	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	car	0.3	car	0.2	0.1	0.1	car	0.1	car	0.2	car	0.4	car	0.6	2.5'
3	0.6	0.6	0.4	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.3	0.2	0.2	0.1	0.1	0.0	0.1	0.1	0.2	0.2	0.4	0.6	0.6	7.5'
4	0.6	0.6	0.5	0.3	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.6	0.6	12.5'
5	0.5	0.6	0.5	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.6	0.5	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.4	0.6	0.5	17.5'
6	0.5	0.6	0.4	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.4	0.6	0.6	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.4	0.5	22.5'
7	0.3	0.5	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.4	0.6	0.6	0.4	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.4	27.5'
8	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.4	0.7	0.6	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	32.5'
9	0.3	0.3	0.3	0.2	0.2	0.1	0.0	car	0.0	0.0	0.0	0.1	shadow	car	shadow	0.4	0.6	car	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	car	0.2	0.2	37.5'
10	0.3	0.3	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.5	0.6	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXXVII: 42nd Ave. Scotopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.7	0.8	0.4	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	shadow	0.3	shadow	0.3	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.9	0.7	-2.5'
2	0.7	car	0.5	car	shadow	car	shadow	car	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	car	0.4	car	0.3	0.2	0.1	car	0.1	car	0.3	car	0.5	car	0.8	2.5'
3	0.8	1.0	0.7	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.6	0.9	0.9	7.5'
4	0.9	1.0	0.7	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.7	0.6	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.6	0.9	0.9	12.5'
5	0.8	1.0	0.7	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.5	1.0	0.8	0.5	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.6	0.9	0.8	17.5'
6	0.7	0.9	0.6	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.6	1.0	1.0	0.6	0.3	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.5	0.7	0.7	22.5'
7	0.6	0.6	0.5	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.6	1.0	1.1	0.6	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.4	0.6	0.6	27.5'
8	0.4	0.5	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.6	1.1	1.0	0.6	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.4	32.5'
9	0.3	0.4	0.3	0.3	0.2	0.1	0.0	car	0.0	0.0	0.0	0.1	shadow	car	shadow	car	1.0	car	0.5	0.3	0.2	0.1	0.2	0.1	0.1	0.2	0.3	car	0.3	0.3	37.5'
10	0.3	0.3	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.5	0.8	0.8	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

44TH AVE. HPS FIXTURE DATA

Table XXXVIII: 44th Ave. Photopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	1.2	1.2	0.7	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	shadow	0.1	0.1	0.1	0.1	shadow	0.0	0.1	0.3	0.5	0.9	1.5	1.4	-2.5'
2	1.5	car	0.8	0.4	car	0.1	0.1	0.0	0.0	car	0.1	car	0.1	0.2	0.2	0.3	0.3	car	0.2	0.2	0.2	car	shadow	car	0.2	0.5	0.6	1.0	1.8	car	2.5'
3	1.6	1.7	0.8	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.2	0.1	0.1	0.4	0.9	0.7	1.1	2.1	2.0	7.5'
4	1.6	1.6	0.9	0.5	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.5	0.7	0.6	0.4	0.5	0.5	0.4	0.1	0.1	0.5	0.9	0.7	1.0	2.0	1.9	12.5'
5	1.4	1.5	0.8	0.4	0.4	0.4	0.3	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.7	1.1	1.0	0.7	0.7	0.9	0.5	0.1	0.2	0.4	0.5	0.6	0.9	1.6	1.6	17.5'
6	0.9	1.1	0.6	0.4	0.3	0.4	0.2	0.2	0.1	0.1	0.1	0.3	0.5	0.5	0.5	1.0	1.8	1.7	0.8	0.7	0.7	0.4	0.1	0.1	0.2	0.3	0.4	0.6	1.0	1.0	22.5'
7	0.6	0.8	0.4	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.2	0.4	0.5	0.5	1.1	2.2	2.0	0.9	0.7	0.9	0.3	0.1	0.1	0.1	0.2	0.3	0.4	0.6	0.7	27.5'
8	0.3	0.5	0.3	0.3	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.3	0.4	0.5	1.1	2.3	2.1	0.9	0.5	0.4	0.2	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4	32.5'
9	0.2	0.3	0.2	car	0.1	car	0.1	car	shadow	car	0.1	0.1	shadow	car	0.5	car	2.1	1.8	0.8	car	0.2	0.1	0.0	car	0.1	car	0.2	car	0.3	car	37.5'
10	0.2	0.2	0.2	shadow	0.2	shadow	0.1	shadow	shadow	shadow	shadow	0.1	0.2	0.2	0.4	0.9	1.6	1.5	0.7	0.4	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XXXIX: 44th Ave. Scotopic Illumination over HPS Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	0.9	0.9	0.5	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	shadow	0.1	0.1	0.1	0.1	shadow	0.0	0.1	0.2	0.3	0.7	1.2	1.1	-2.5'
2	1.1	car	0.6	0.3	car	0.1	0.1	0.0	0.0	car	0.0	car	0.1	0.1	0.2	0.1	0.2	car	0.1	0.1	0.1	car	shadow	car	0.2	0.4	0.4	0.8	1.4	car	2.5'
3	1.2	1.3	0.6	0.3	0.2	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.3	0.7	0.6	0.8	1.5	1.5	7.5'
4	1.2	1.2	0.6	0.4	0.2	0.2	0.2	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.4	0.6	0.5	0.3	0.4	0.4	0.3	0.1	0.1	0.4	0.6	0.5	0.8	1.5	1.4	12.5'
5	1.1	1.1	0.5	0.4	0.3	0.3	0.2	0.1	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.5	0.9	0.8	0.5	0.5	0.7	0.4	0.1	0.1	0.3	0.4	0.4	0.7	1.2	1.2	17.5'
6	0.7	0.8	0.4	0.3	0.2	0.3	0.2	0.1	0.0	0.1	0.1	0.2	0.4	0.4	0.3	0.7	1.3	1.2	0.6	0.5	0.6	0.3	0.1	0.0	0.1	0.2	0.3	0.4	0.7	0.8	22.5'
7	0.5	0.6	0.3	0.2	0.2	0.2	0.2	0.1	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.8	1.6	1.5	0.7	0.5	0.7	0.2	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.5	27.5'
8	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.8	1.7	1.5	0.7	0.4	0.3	0.1	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.3	32.5'
9	0.1	0.2	0.1	car	0.1	car	0.1	car	shadow	car	0.0	0.1	shadow	car	0.3	car	1.6	1.4	0.6	car	0.1	0.1	0.0	car	0.0	car	0.1	car	0.2	car	37.5'
10	0.1	0.1	0.1	shadow	0.1	shadow	0.0	shadow	shadow	shadow	shadow	0.0	0.1	0.2	0.3	0.6	1.2	1.1	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

44TH AVE. LED D FIXTURE DATA

Table XL: 44th Ave. Photopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	1.1	1.2	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	shadow	0.4	0.4	0.2	0.2	0.1	0.1	shadow	0.0	0.0	0.1	0.3	1.0	1.2	1.0	-2.5'
2	1.3	car	0.6	0.2	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	car	0.6	0.6	0.3	0.3	0.1	car	shadow	0.0	0.1	car	shadow	car	car	1.3	2.5'
3	1.5	1.3	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.7	0.7	0.4	0.2	0.1	0.1	0.0	0.0	0.1	0.2	0.3	0.7	1.4	1.4	7.5'
4	1.7	1.3	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.5	0.8	1.1	0.5	0.3	0.2	0.1	0.1	0.0	0.2	0.2	0.3	0.6	1.6	1.3	12.5'
5	1.7	1.1	0.6	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	1.0	1.5	0.6	0.3	0.2	0.1	0.0	0.0	0.2	0.2	0.3	0.6	1.7	1.1	17.5'
6	1.4	0.9	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.7	1.3	1.7	0.6	0.3	0.2	0.0	0.0	0.0	0.1	0.2	0.3	0.6	1.4	0.9	22.5'
7	1.0	0.6	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.7	1.5	1.4	0.7	0.3	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.5	1.0	0.6	27.5'
8	0.7	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.8	1.7	1.3	0.7	0.3	0.2	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.7	0.5	32.5'
9	0.6	0.5	0.3	0.2	0.2	car	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.5	car	0.7	car	0.1	0.0	car	0.1	0.1	0.2	0.2	car	0.6	car	37.5'
10	0.5	0.4	0.2	0.2	0.2	shadow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	1.2	1.1	0.7	0.2	0.1	0.0	0.0	0.1	0.1	0.2	0.2	0.4	0.5	shadow	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XLI: 44th Ave. Scotopic Illumination over LED Test Area. (In fc)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	
1	2.1	2.2	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	shadow	0.7	0.7	0.3	0.3	0.2	0.1	shadow	0.0	0.0	0.2	0.4	1.8	2.2	1.9	-2.5'
2	2.6	car	1.3	0.4	car	shadow	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	car	1.0	1.0	0.4	0.3	0.2	car	shadow	0.0	0.0	car	shadow	car	car	2.4	2.5'
3	2.8	2.6	1.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.6	1.3	1.4	0.6	0.3	0.2	0.1	0.0	0.0	0.1	0.3	0.6	1.3	2.6	2.5	7.5'
4	3.0	2.5	1.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.9	1.6	2.1	0.9	0.4	0.3	0.1	0.0	0.0	0.1	0.3	0.5	1.3	2.8	2.5	12.5'
5	3.2	2.2	1.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	1.1	1.8	2.8	1.0	0.5	0.3	0.1	0.0	0.0	0.1	0.3	0.5	1.1	3.3	2.2	17.5'
6	2.7	1.6	1.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.4	2.4	3.0	1.3	0.6	0.3	0.1	0.0	0.0	0.2	0.3	0.4	1.0	2.6	1.7	22.5'
7	2.0	1.3	0.8	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	1.5	2.9	2.9	1.5	0.6	0.3	0.0	0.0	0.1	0.1	0.3	0.4	0.8	1.9	1.2	27.5'
8	1.4	1.0	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	1.5	3.0	2.8	1.4	0.6	0.2	0.0	0.0	0.1	0.2	0.2	0.3	0.7	1.3	1.0	32.5'
9	1.0	0.9	0.5	0.3	0.2	car	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.4	2.8	car	1.5	car	0.1	0.0	car	0.1	0.1	0.2	0.3	car	1.0	car	37.5'
10	0.7	0.7	0.3	0.3	0.2	shadow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.0	2.2	2.0	1.5	0.3	0.1	0.0	0.0	0.1	0.1	0.2	0.3	0.7	0.7	shadow	42.5'
	-6.25'	6.25'	18.75'	31.25'	43.75'	56.25'	68.75'	81.25'	93.75'	106.25'	118.75'	131.25'	143.75'	156.25'	168.75'	181.25'	193.75'	206.25'	218.75'	231.25'	243.75'	256.25'	268.75'	281.25'	293.75'	306.25'	318.75'	331.25'	343.75'	356.25'	

Table XLII: HPS Photopic Illuminance Summary

Spacing	Avenue	% Grid Illuminated	Max (fc) - Illuminated Area	Min (fc) - Illuminated Area	Avg (fc) - Illuminated Area	Avg UR - Illuminated Area	Max UR - Illuminated Area		Avg (fc) - Entire Area	Min (fc) - Entire Area	Avg UR - Entire Area	Max UR - Entire Area	Coeff. Of Variation
150'	38th	100%	1.7	0.1	0.6	5.7:1	17.0:1		0.6	0.1	5.7:1	17.0:1	0.66
	41st	100%	2.1	0.2	0.5	2.5:1	10.5:1		0.5	0.2	2.5:1	10.5:1	0.79
	42nd	100%	2.8	0.1	0.7	7.1:1	28.0:1		0.7	0.1	7.1:1	28.0:1	0.84
	44th	97%	2.1	0.1	0.6	5.9:1	21.0:1		0.6	0.0	>11.5:1	>42.0:1	0.87
200'	38th	76%	1.8	0.1	0.5	5.3:1	18.0:1		0.4	0.0	>8.1:1	>36.0:1	0.99
	41st	73%	2.1	0.1	0.6	5.6:1	21.0:1		0.4	0.0	>8.1:1	>42.0:1	1.15
	42nd	63%	2.8	0.1	0.8	8.0:1	28.0:1		0.5	0.0	>10:1	>56.0:1	1.32
	44th	100%	2.3	0.1	0.4	4.4:1	23.0:1		0.4	0.1	4.4:1	23.0:1	1.03
Entire Area	38th	86%	1.8	0.1	0.5	5.5:1	18.0:1		0.5	0.0	>9.5:1	>36.0:1	0.84
	41st	85%	2.1	0.1	0.5	5.3:1	21.0:1		0.5	0.0	>9.0:1	>42.0:1	0.98
	42nd	79%	2.8	0.1	0.8	7.5:1	28.0:1		0.6	0.0	>11.8:1	>56.0:1	1.08
	44th	99%	2.3	0.1	0.5	5.0:1	23.0:1		0.5	0.0	>9.9:1	>46.0:1	0.96

Table XLIII: LED Photopic Illuminance Summary

Spacing	Avenue	% Grid Illuminated	Max (fc) - Illuminated Area	Min (fc) - Illuminated Area	Avg (fc) - Illuminated Area	Avg UR - Illuminated Area	Max UR - Illuminated Area		Avg (fc) - Entire Area	Min (fc) - Entire Area	Avg UR - Entire Area	Max UR - Entire Area	Coeff. Of Variation
150'	38th	63%	1.1	0.1	0.4	4.0:1	12.0:1		0.2	0.0	>4.7:1	>22.3:1	1.18
	41st	100%	1.1	0.1	0.3	3.6:1	12.0:1		0.3	0.1	3.6:1	12.0:1	0.61
	42nd	99%	0.6	0.1	0.2	2.4:1	7.0:1		0.2	0.0	>4.4:1	>13.0:1	0.62
	44th	83%	1.7	0.1	0.5	5.2:1	18.0:1		0.4	0.0	>8.1:1	>33.4:1	0.95
200'	38th	51%	1.1	0.1	0.3	3.4:1	12.0:1		0.2	0.0	>3.3:1	>22.3:1	1.51
	41st	92%	0.9	0.1	0.3	3.2:1	10.0:1		0.3	0.0	>5.4:1	>18.6:1	0.91
	42nd	72%	0.7	0.1	0.2	2.7:1	8.0:1		0.2	0.0	>3.6:1	>14.9:1	1.03
	44th	53%	1.7	0.1	0.5	5.1:1	18.0:1		0.3	0.0	>5.0:1	>33.4:1	1.53
Entire Area	38th	56%	1.1	0.1	0.3	3.7:1	12.0:1		0.2	0.0	>3.9:1	>22.3:1	1.42
	41st	95%	1.1	0.1	0.3	3.4:1	12.0:1		0.3	0.0	>5.9:1	>22.3:1	0.82
	42nd	83%	0.7	0.1	0.2	2.5:1	8.0:1		0.2	0.0	>3.9:1	>14.9:1	0.90
	44th	66%	1.7	0.1	0.5	5.2:1	18.0:1		0.3	0.0	>6.3:1	>33.4:1	1.34

Table XLIV: HPS Scotopic Illuminance Summary

Spacing	Avenue	% Grid Illuminated	**Max** (fc) - Illuminated Area	**Min** (fc) - Illuminated Area	**Avg** (fc) - Illuminated Area	**Avg UR** - Illuminated Area	**Max UR** - Illuminated Area		**Avg** (fc) - Entire Area	**Min** (fc) - Entire Area	**Avg UR** - Entire Area	**Max UR** - Entire Area	Coeff. Of Variation
150'	38th	100%	1.4	0.1	0.4	4.4:1	14.0:1		0.4	0.1	4.4:1	14.0:1	0.70
	41st	100%	1.6	0.1	0.4	3.9:1	16.0:1		0.4	0.1	3.9:1	16.0:1	0.80
	42nd	94%	2.0	0.1	0.6	5.6:1	20.0:1		0.5	0.0	>10.6:1	>40.0:1	0.86
	44th	90%	1.5	0.1	0.5	4.7:1	15.0:1		0.4	0.0	>8.5:1	>30.0:1	0.88
200'	38th	72%	1.3	0.1	0.4	4.0:1	13.0:1		0.3	0.0	>5.8:1	>26.0:1	1.05
	41st	67%	1.6	0.1	0.4	4.5:1	16.0:1		0.3	0.0	>6.0:1	>32.0:1	1.20
	42nd	57%	2.6	0.1	0.7	6.7:1	26.0:1		0.4	0.0	>7.7:1	>52.0:1	1.38
	44th	95%	1.7	0.1	0.3	3.4:1	17.0:1		0.3	0.0	>6.5:1	>34.0:1	1.02
Entire Area	38th	84%	1.4	0.1	0.4	4.2:1	14.0:1		0.4	0.0	>7.1:1	>28.0:1	0.88
	41st	81%	1.6	0.1	0.4	4.2:1	16.0:1		0.3	0.0	>6.7:1	>32.0:1	1.01
	42nd	73%	2.6	0.1	0.6	6.1:1	26.0:1		0.4	0.0	>9:1	>52.0:1	1.12
	44th	93%	1.7	0.1	0.4	4.0:1	17.0:1		0.4	0.0	>7.4:1	>34.0:1	0.96

Table XLV: LED Scotopic Illuminance Summary

Spacing	Avenue	% Grid Illuminated	**Max** (fc) - Illuminated Area	**Min** (fc) - Illuminated Area	**Avg** (fc) - Illuminated Area	**Avg UR** - Illuminated Area	**Max UR** - Illuminated Area		**Avg** (fc) - Entire Area	**Min** (fc) - Entire Area	**Avg UR** - Entire Area	**Max UR** - Entire Area	Coeff. Of Variation
150'	38th	71%	2.8	0.1	0.7	8.7:1	35.0:1		0.5	0.0	>9.9:1	>56.4:1	1.30
	41st	100%	2.4	0.1	0.7	7.6:1	28.0:1		0.7	0.1	7.6:1	28.0:1	0.67
	42nd	100%	1.1	0.1	0.3	4.0:1	13.0:1		0.3	0.1	4.0:1	13.0:1	0.61
	44th	83%	3.3	0.1	0.9	10.1:1	38.0:1		0.7	0.0	>14.5:1	>65.9:1	1.01
200'	38th	51%	2.8	0.1	0.7	8.5:1	32.0:1		0.4	0.0	>7.5:1	>55.5:1	1.59
	41st	91%	2.0	0.1	0.6	6.5:1	23.0:1		0.5	0.0	>10.2:1	>39.9:1	1.07
	42nd	73%	1.1	0.1	0.4	4.4:1	13.0:1		0.3	0.0	>5.6:1	>22.5:1	1.08
	44th	51%	3.0	0.1	0.9	10.6:1	35.0:1		0.5	0.0	>9.4:1	>60.7:1	1.58
Entire Area	38th	60%	2.8	0.1	0.7	8.9:1	35.0:1		0.4	0.0	>8.5:1	>56.4:1	1.53
	41st	95%	2.4	0.1	0.6	7.0:1	28.0:1		0.6	0.0	>11.5:1	>48.5:1	0.93
	42nd	85%	1.1	0.1	0.4	4.2:1	13.0:1		0.3	0.0	>6.2:1	>22.5:1	0.93
	44th	65%	3.3	0.1	0.9	10.3:1	38.0:1		0.6	0.0	>11.6:1	>65.9:1	1.41

CORRELATED COLOR TEMPERATURE

Table XLVI: Color Correlated Temperature of HPS and LED Luminaires

41st Ave.		38th Ave.		42nd Ave.		44th Ave.	
HPS Luminaires	**Correlated Color Temp (K)**	**HPS Luminaires**	**Correlated Color Temp (K)**	**HPS Luminaires**	**Correlated Color Temp (K)**	**HPS Luminaires**	**Correlated Color Temp (K)**
1	2142	1	2053	1	2043	1	2042
2	2139	2	2154	2	2050	2	2033
3	2140	3	2043	3	2053	3	2029
Avg	*2140*	*Avg*	*2083*	*Avg*	*2049*	*Avg*	*2034*
LED A Luminaires		**LED B Luminaires**		**LED C Luminaires**		**LED D Luminaires**	
1	6565	1	11486	1	4637	1	5765
2	6694	2	12986	2	4552	2	5820
3	6460	3	13659	3	4558	3	5759
Avg	*6573*	*Avg*	*12710*	*Avg*	*4582*	*Avg*	*5781*

Appendix B: Mesopic Illuminance

While light levels have traditionally only been measured by photopic illuminance, human perception of light follows two distinct spectral response curves depending on the light level. The photopic spectral response curve dominates during typical daytime, and results from the "cones" in human eyes. During very low light conditions, perception follows the scotopic response curve, which results from the "rods" in the human eye. At modestly low light levels however, such as those typical under nighttime roadway lighting, both the photopic response curve and the scotopic response curve are important. This is known as the 'mesopic' range.

Unfortunately, the relative importance of scotopic illuminance and photopic illuminance in the mesopic range is still uncertain. However, due to the significant import of this range for roadway lighting, one of the competing models was used to calculate 'mesopic illuminance' levels despite the controversy.

The model used to calculate mesopic illuminance in this study is the Mesopic Optimization of Visual Efficiency (MOVE) model. The MOVE model is a performance-based model developed at the Lighting Laboratory at the Helsinki University of Technology for the European Community. It was developed using the results of vision experiments which evaluated subjects' ability to complete various tasks required for night-time driving.

The MOVE model uses photopic and scotopic luminance values to calculate mesopic luminance values. The photopic and scotopic illuminance data recorded during the course of this assessment were converted into luminance, assuming that the roadway was a lambertian reflective surface with a reflectance value of 0.07. The conversion formula is as follows: L (luminance) = E (illuminance) * P (reflectance of the surface) / Π. The resulting photopic and scotopic luminance values were then used to calculate mesopic luminance values, which were then converted to mesopic illuminance values by the same formula.

Mesopically, LED luminaire A provided measurable illumination over an equivalent or larger area, and which was more uniform, than the base case HPS luminaires. This is evidenced by the increased percentage of grid points illuminate, and the decreased coefficients of variation. Average mesopic illuminance values were decreased with the LED luminaires. As previously discussed however, this does not necessarily denote inferior light performance. High MMU values for the HPS luminaires in the 200' spacing and over the entire testing area indicate that the increased average illuminance values may be the result of hotspots. The lower MMU value in the 150' than the 200' spacing is the result of overlapping light from the two bounding luminaires slightly raising the minimum illuminance level which, at very low light levels, can have a significant impact.

Table XLVII: LED A Mesopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Avg** (fc)	**Coeff. Of Variation**	**Avg. to Min. Uniformity, Illum. Points Only**	**Max to Min Uniformity, Illum. Points Only**
HPS (150')	100%	0.57	0.85	2.67	11.15
LED A (150')	100%	0.38	0.67	3.82	12.15
HPS (200')	75%	0.47	1.17	7.49	27.79
LED A (200')	92%	0.31	0.88	4.31	13.37
HPS (Entire Area)	86%	0.51	1.02	7.13	27.79
LED A (Entire Area)	96%	0.34	0.78	6.55	14.53

As compared to the base case HPS luminaires, LED luminaire B provided a smaller area of measurable illumination and reduced uniformity mesopically. This is evidenced by a decreased percentage of grid points illuminated, and the increased coefficients of variation in all cases. While AMU and MMU values similar or slightly were improved by the LEDs, this is likely the result of generally decreased mesopic light output as opposed to increased uniformity.

Table XLVIII: LED B Mesopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Avg** (fc)	**Coeff. Of Variation**	**Avg. to Min. Uniformity, Illum. Points Only**	**Max to Min Uniformity, Illum. Points Only**
HPS (150')	100%	0.56	0.67	5.63	17.05
LED A (150')	65%	0.28	1.22	5.02	14.54
HPS (200')	77%	0.44	0.98	6.75	21.70
LED A (200')	54%	0.20	1.38	4.79	14.54
HPS (Entire Area)	87%	0.51	0.85	7.02	21.72
LED A (Entire Area)	59%	0.23	1.31	8.10	14.54

Like LED luminaire A, LED luminaire C generally provided measurable mesopic illumination over a larger area, and which was more uniform, than the base case HPS luminaires. This is evidenced by the maintained or increased percentage of grid points illuminated as compared to the HPS luminaires in all cases, and the decreased coefficients of variation in all cases. The LED luminaires also provided decreased AMU and MMU values in all cases, further indicating better uniformity than the base case HPS luminaires. The LED luminaires did, however, have decreased average mesopic illuminance values compared to the base case HPS luminaires. As mentioned above and previously discussed, this does not necessarily denote inferior light performance. High AMU and MMU and values for the HPS luminaire in all cases, combined with high CV values, indicate that at least a portion of their increased average illuminance values may be the result of hotspots.

Table XLIX: LED C Mesopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Avg** (fc)	**Coeff. Of Variation**	**Avg. to Min. Uniformity, Illum. Points Only**	**Max to Min Uniformity, Illum. Points Only**
HPS (150')	100%	0.76	0.82	8.44	33.94
LED A (150')	99%	0.25	0.69	2.51	7.22
HPS (200')	65%	0.55	1.26	10.15	33.65
LED A (200')	74%	0.20	0.97	3.54	9.78
HPS (Entire Area)	80%	0.64	1.04	9.58	33.94
LED A (Entire Area)	84%	0.22	0.84	5.63	9.78

LED luminaire D, similar to luminaire B, provided a smaller area of measurable mesopic illumination and reduced uniformity compared to the base case HPS luminaires. The LED luminaires provided a decreased percentage of grid points illuminated, and the increased coefficients of variation in all cases. Mesopic AMU and MMU values were similar with the LEDs and the HPS luminaires. The LED luminaires also provided decreased average mesopic illuminance values.

Table L: LED D Mesopic Illuminance

Luminaire (Spacing)	**Grid Points Illuminated**	**Avg** (fc)	**Coeff. Of Variation**	**Avg. to Min. Uniformity, Illum. Points Only**	**Max to Min Uniformity, Illum. Points Only**
HPS (150')	97%	0.63	0.88	7.06	25.37
LED A (150')	85%	0.45	1.04	6.39	21.45
HPS (200')	100%	0.47	1.02	5.64	27.79
LED A (200')	56%	0.32	1.43	7.45	21.45
HPS (Entire Area)	99%	0.54	0.96	6.52	27.79
LED A (Entire Area)	68%	0.38	1.24	9.67	21.45

Appendix C: Monitoring Layout

PROJECT LAYOUT

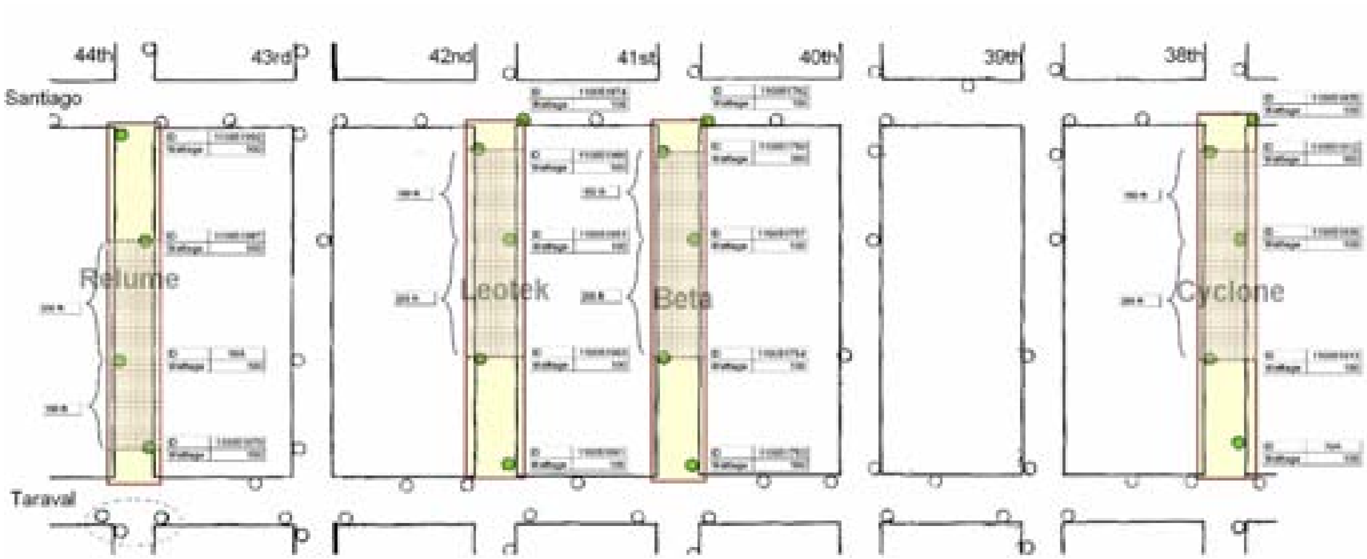


Figure 51: Test Site and Measurement Area

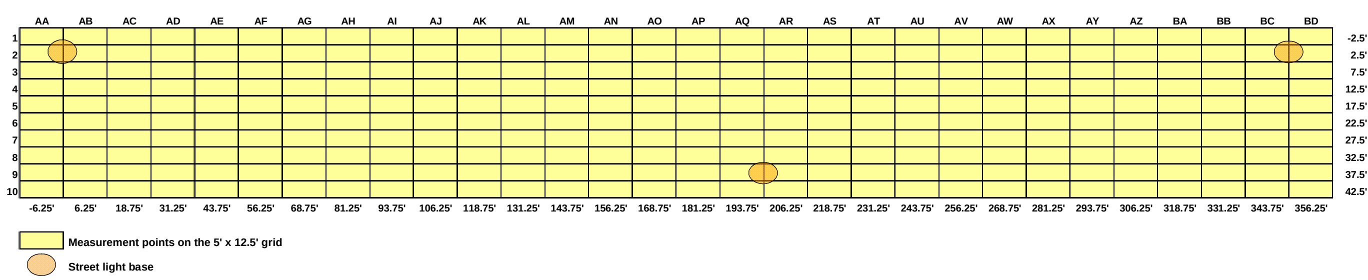


Figure 52: Schematic of Measurement Grid

Appendix D: Economic Data and Calculations

Table LI: Annual Luminaire Energy Costs

Estimated Annual Energy Costs

100 Watt HPS		
Monthly Fixed Charge[1]	4.9220	$/fixture
Annual Cost[2]	59.06	$/yr

LED	*A*	*B*	*C*	*D*	
Demand	58.66	62.22	41.25	69.21	W
Usage[3]	240.51	255.10	169.13	283.76	kWh
Rate[4]	0.1200	0.1200	0.1200	0.1200	$/kWh
Annual Cost[5]	28.86	30.61	20.30	34.05	$/yr
Estimated Annual Savings:[6]	**30.20**	**28.45**	**38.77**	**25.01**	$/fixture

[1] Based on PG&E LS-2 2008 Rate Structure

[2] Monthly Fixed Charge x 12

[3] Assuming 4,100 hr/yr. From PG&E LS-2 Rate Structure

[4] Based on PG&E LS-2 Rate Structure for HPS Luminaires

[5] Usage x Rate + Monthly Fixed Charge x 12

[6] 100W HPS Annual Cost - LED Annual Cost

Table LII: Annual HPS Luminaire Maintenance Costs

HPS Luminaire Maintenance Cost Estimates

Details

	Maintenance Category		
	Group	Burn Out	
Cost per Replacement[1]	51.57	245.42	$/fixture
Annual Replacement Frequency[2]	8.20	8.16	%/yr
Annualized Replacement Cost[3]	4.23	20.03	$/yr

Annualized Cost per Luminaire[4]	$24.26
Annualized Hazardous Disposal Cost per Lamp[5]	$0.18
Total Annualized Cost per Luminaire:	**$24.44**

[1] Jan - Sept '08 Maintenance Spending in Each Category / Reported System Wide Replacements in Each Category
Includes material and labor cost, does not include administrative overhead

[2] (Average Replacements per Month for Jan - Sept, '08 X 12) / PG&E System Wide HPS Street Light Total
Calculated for each maintenance category seperately

[3] Cost per Replacement X Annual Replacement Frequency

[4] Sum of Annualized Replacement Costs for Each Maintenance Category

[5] HID lamps incur hazardous waste disposal costs, calculated at $1.07 per lamp (from PG&E data)
Annualized cost based on sum of replacement frequencies for lamps in group and burn out categories

Table LIII: Annual LED Luminaire Maintenance Costs

LED Luminaire Maintenance Cost Estimates

Assumptions		
Failure Rate (before end of rated lamp life[1])	10%	
Luminaire Operating Hours	4,100	hr/yr
Emergency Replacement Labor Cost[2]	223	$
Routine Service Labor Cost[3]	25	$
Routine Service Cycle	5	yr

	LED Manufacturer				
	LED A	LED B	LED C	LED D	
Warranty and Replacement Frequency Details					
Assumed Luminaire Life[4]	65,600	65,600	65,600	65,600	hr
	16	16	16	16	yr
Manufacturer Warranty	5	2	5	7	yr
Annual Probability of Failure[5]	0.66%	0.66%	0.66%	0.66%	
Probability of Failure Outside of Warranty[6]	6.99%	8.81%	6.99%	5.75%	
Probability of Failure Within Warranty[7]	3.24%	1.31%	3.24%	4.50%	
Economic Details					
Luminaire Cost (Bulk Rate)	400.00	675.00	310.00	725.00	$/luminaire
Annualized Cost of Failure Outside of Warranty[8]	2.72	4.94	2.33	3.41	$/luminaire
Annualized Cost of Failure Within Warranty[9]	0.45	0.18	0.45	0.63	$/luminaire
Total Annualized Cost of Failure	3.17	5.13	2.78	4.04	$/yr
Total Annualized Cost of Routine Service[10]	5.00	5.00	5.00	5.00	$/yr
Total Annual Maintenance Cost	8.17	10.13	7.78	9.04	$/yr

[1] Best guess estimate that assumes some fraction of luminaires will fail catastrophically before LED lamp failure due to normal wear and tear

[2] Cost equal to cost of labor only for emergency HPS lamp replacement, see HPS Luminaire Maintenance Cost Estimates table

[3] Cost equal to cost of labor only for routine group HPS lamp replacement, see HPS Luminaire Maintenance Cost Estimates table

[4] Due to lack of data available to verify manufacturers' L70 values, a 16 year (65,600 hrs) luminaire life was assumed for each LED

[5] Based on assumed luminaire life and failure rate: 1 - (1 - *Failure Rate)* ^ (1 / *Assumed Luminaire Life)*

[6] Based on annual probability of failure, assumed luminaire life, and length of warranty:
1 - (1 - Annual Probability of Failure) ^ (Assumed Luminaire Life - Length of Warranty)

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

[8] (Emergency Replacement Cost + Luminaire Cost) * Probability of Failure Outside Warranty / Assumed Luminaire Life

[9] (Emergency Replacement Cost) * Probability of Failure Within Warranty / Assumed Luminaire Life

[10] Cost based on Routine Service Cost x [1 / Routine Service Cycle]

Table LIV: New Construction Economics

Simple Payback and Net Present Value Calculations: New Construction Scenario

	LED Manufacturer				
	LED A	LED B	LED C	LED D	
Costs and Savings					
Incremental Cost[1]	293.00	568.00	203.00	618.00	$/fixture
Annual Maintenance Savings	16.27	14.31	16.66	15.40	$/fixture
Annual Energy Savings	30.20	28.45	38.77	25.01	$/fixture
Economic Evaluation					
Simple Payback[2]	**6.3**	**13.3**	**3.7**	**15.3**	yr
Real Discount Rate[3]	5%	5%	5%	5%	/yr
Cost Escalation	3%	3%	3%	3%	/yr
Term of Analysis	15	15	15	15	yr
Equivalent Discount Rate[4]	1.94%	1.94%	1.94%	1.94%	/yr
PVF[5]	12.91	12.91	12.91	12.91	
NPV[6]	**306.72**	**-16.09**	**512.34**	**-96.43**	$

[1] LED Luminaire Cost - HPS Luminaire Cost

[2] Incremental Cost / [Annual Maintenance Savings + Annual Energy Savings]

[3] Rate used in this analysis is an estimate of municipal or utility scale customer expected rate of return on large capital investments

[4] [Real Discount Rate - Cost Escalation] / [1 + Cost Escalation]

[5] [[[1 + Equivalent Discount Rate]^y] - 1] / [Equivalent Discount Rate x [[1 + Equivalent Discount Rate]^y]]

[6] [[Annual Maintenance Savings + Annual Energy Savings] x PVF] - Incremental Cost

Table LV: Retrofit Economics

Simple Payback and Net Present Value Calculations: Retrofit Scenario

	LED Manufacturer				
	LED A	LED B	LED C	LED D	
Costs and Savings					
Incremental Cost[1]	500.00	775.00	410.00	825.00	$/fixture
Annual Maintenance Savings	16.27	14.31	16.66	15.40	$/fixture
Annual Energy Savings	30.20	28.45	38.77	25.01	$/fixture
Economic Evaluation					
Simple Payback[2]	**10.8**	**18.1**	**7.4**	**20.4**	yr
Real Discount Rate[3]	5%	5%	5%	5%	/yr
Cost Escalation	3%	3%	3%	3%	/yr
Term of Analysis	15	15	15	15	yr
Equivalent Discount Rate[4]	1.94%	1.94%	1.94%	1.94%	/yr
PVF[5]	12.91	12.91	12.91	12.91	
NPV[6]	**99.72**	**-223.09**	**305.34**	**-303.43**	$

[1] LED Luminaire Cost + Installation Cost

[2] Incremental Cost / [Annual Maintenance Savings + Annual Energy Savings]

[3] Rate used in this analysis is an estimate of municipal or utility scale customer expected rate of return on large capital investments

[4] [Real Discount Rate - Cost Escalation] / [1 + Cost Escalation]

[5] [[[1 + Equivalent Discount Rate]^y] - 1] / [Equivalent Discount Rate x [[1 + Equivalent Discount Rate]^y]]

[6] [[Annual Maintenance Savings + Annual Energy Savings] x PVF] - Incremental Cost

Appendix E: PG&E LS-2 Rate Schedule

Pacific Gas and Electric Company
San Francisco, California
U 39

	Revised	Cal. P.U.C. Sheet No.	27233-E
Cancelling	Revised	Cal. P.U.C. Sheet No.	26974-E*

ELECTRIC SCHEDULE LS-2 Sheet 1
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

APPLICABILITY: This schedule is applicable to services for lighting installations which illuminate streets, highways, and other outdoor ways and places where the Customer is a Governmental Agency (Agency) and owns the lighting fixtures, poles and interconnecting circuits. This schedule is also applicable for service to those installations where service is initially established in the name of a developer who has installed such systems as required by an Agency and, where ownership of facilities and responsibility for service will be transferred to an Agency. Where the Agency does not accept facilities or where no transfer is intended, service will be provided under an otherwise appropriate rate schedule and rule. The Customer's facilities must be of good construction acceptable to PG&E and in satisfactory condition to qualify for Class C rates. Class C is closed to new installations and additional lamps in existing accounts. (T)

TERRITORY: The entirety of PG&E's service territory. (T)

RATES: The total monthly charge per lamp is equal to the sum of the facility charge and the energy charge. The monthly charge per lamp used for billing is calculated using unrounded facility and energy charges.

Monthly facility charges include the costs of owning, operating and maintaining the various lamp types and size. Monthly energy charges are based on the kWh usage of each lamp.

Monthly energy charges per lamp are calculated using the following formula: (Lamp wattage + ballast wattage) x 4,100 hours/12 months/1000 x streetlight energy rate per kilowatt hour (kWh). Ballast wattage = ballast factor x lamp wattage.

Total bundled monthly facility and energy charges are shown below.

The various ballast wattages used in the monthly energy charge calculations can be found in the Ballast Factor table following the monthly energy charges. Ballast factors are averaged within each grouping (range of wattages). The same ballast factor is applied to all of the lamps that fall within its watt range. Applicant or Customer must provide third party documentation where manufacturer's information is not available for rated wattage consumption before PG&E will accept lamps for this schedule.

Direct Access (DA) and Community Choice Aggregation (CCA) charges shall be calculated in accordance with Condition 13, Billing, below.

Advice Letter No: 3223-E	*Issued by*	*Date Filed*	March 3, 2008
Decision No.	***Brian K. Cherry***	*Effective*	April 2, 2008
1C4	*Vice President* *Regulatory Relations*	*Resolution No.*	

ELECTRIC SCHEDULE LS-2
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

Sheet 2

RATES: (Cont'd.)

Facilities Charge Per Lamp Per Month

CLASS:	A	C**
	PG&E supplies energy and service only.	PG&E supplies the energy and maintenance service as described in Special Condition 8
	$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	$2.401	(I)			$0.109	(I)
92	31	1,000	$3.721	|			$0.169	|
189	65	2,500	$7.803	|			$0.355	|
295	101	4,000**	$12.124	|			$0.551	|
405	139	6,000**	$16.686	|			$0.758	|
620	212	10,000**	$25.448	|			$1.157	|
860	294	15,000**	$35.292	(I)			$1.604	(I)
MERCURY VAPOR LAMPS:								
40	18	1,300	$2.161	(I)			$0.098	(I)
50	22	1,650	$2.641	|			$0.120	|
100	40	3,500	$4.802	|			$0.218	|
175	68	7,500	$8.163	|			$0.371	|
250	97	11,000	$11.644	|			$0.529	|
400	152	21,000	$18.246	|			$0.829	|
700	266	37,000	$31.931	|			$1.451	|
1,000	377	57,000	$45.255	(I)			$2.057	(I)
LIGHT EMITTING DIODE (LED) LAMPS: 120 VOLTS								
42	14	837	$1.681	(I)			$0.076	(I)

* Latest published information should be consulted on best available lumens.

** Service for incandescent lamps over 2,500 lumens will be closed to new installations after September 11, 1978.

*** Closed to new installations and new lamps on existing circuits, see Condition 8A.

(Continued)

ELECTRIC SCHEDULE LS-2
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

RATES: (Cont'd.)

HIGH PRESSURE SODIUM VAPOR LAMPS AT: 120 VOLTS						
35	15	2,150	$1.801	(I)	$0.082	(I)
50	21	3,800	$2.521	|	$0.115	|
70	29	5,800	$3.481	|	$0.158	|
100	41	9,500	$4.922	|	$0.224	|
150	60	16,000	$7.202	|	$0.327	|
200	80	22,000	$9.603	(I)	$0.437	(I)
250	100	26,000	$12.004	(N)	$0.546	(N)
400	154	46,000	$18.486	(N)	$0.840	(N)
HIGH PRESSURE SODIUM VAPOR LAMPS AT: 240 VOLTS						
50	24	3,800	$2.881	(I)	$0.131	(I)
70	34	5,800	$4.081	|	$0.186	|
100	47	9,500	$5.642	|	$0.256	|
150	69	16,000	$8.283	|	$0.377	|
200	81	22,000	$9.723	|	$0.442	|
250	100	25,500	$12.004	|	$0.546	|
310	119	37,000	$14.285	|	$0.649	|
360	144	45,000	$17.286	|	$0.786	|
400	154	46,000	$18.486	(I)	$0.840	(I)
LOW PRESSURE SODIUM VAPOR LAMPS:						
35	21	4,800	$2.521	(I)	$0.115	(I)
55	29	8,000	$3.481	|	$0.158	|
90	45	13,500	$5.402	|	$0.246	|
135	62	21,500	$7.442	|	$0.338	|
180	78	33,000	$9.363	(I)	$0.426	(I)
METAL HALIDE LAMPS:						
70	30	5,500	$3.601	(I)	$0.164	(I)
100	41	8,500	$4.922	|	$0.224	|
150	63	13,500	$7.563	|	$0.344	|
175	72	14,000	$8.643	|	$0.393	|
250	105	20,500	$12.604	|	$0.573	|
400	162	30,000	$19.446	|	$0.884	|
1,000	387	90,000	$46.455	(I)	$2.112	(I)
INDUCTION LAMPS:						
40	14	2,200	$1.681	(N)	$0.076	(N)
55	19	3,000	$2.281	(I)	$0.104	(I)
80	27	4,500	$3.241	(N)	$0.147	(N)
85	30	4,800	$3.601	(I)	$0.164	(I)
120	42	8,500	$4.983	(N)	$0.227	(N)
150	51	10,900	$6.122	(N)	$0.278	(N)
165	58	12,000	$6.962	(I)	$0.316	(I)

(Continued)

ELECTRIC SCHEDULE LS-2
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

Sheet 4

RATES: (Cont'd.)

Ballast Factors by Lamp Type and Wattage Range

Watt Range			Ballast Factor
MERCURY VAPOR			
1	to	75	31.00%
76	to	125	17.07%
126	to	325	13.69%
326	to	800	11.22%
801	+		10.34%
LOW PRESSURE SODIUM VAPOR			
1	to	40	75.61%
41	to	75	54.32%
76	to	110	46.34%
111	to	160	34.42%
161	+		26.83%
METAL HALIDE			
1	to	85	25.44%
86	to	200	20.39%
201	to	375	22.93%
376	to	700	18.54%
701	+		13.27%

Watt Range			Ballast Factor	
HIGH PRESSURE SODIUM VAPOR				
120 Volts				
1	to	40	25.44%	
41	to	60	22.93%	
61	to	85	21.25%	
86	to	125	20.00%	
126	+		17.07%	
240 Volts				(T)
1	to	60	40.49%	
61	to	85	42.16%	
86	to	125	37.56%	
126	to	175	34.63%	
176	to	225	18.54%	
226	to	280	17.07%	
281	to	380	12.35%	
381	+		12.68%	

(Continued)

ELECTRIC SCHEDULE LS-2
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

RATES: (Cont'd.)

TOTAL ENERGY RATES

Total Energy Charge Rate ($ per kWh) $0.12004 (I)

UNBUNDLING OF TOTAL ENERGY CHARGES

The total energy charge is unbundled according to the component rates shown below.

Energy Rate by Components ($ per kWh)		
Generation	$0.07458	(I)
Distribution	$0.02413	
Transmission*	$0.00676	
Transmission Rate Adjustments*	($0.00033)	
Reliability Services*	($0.00051)	
Public Purpose Programs	$0.00657	
Nuclear Decommissioning	$0.00027	
Competition Transition Charge	$0.00022	
Energy Cost Recovery Amount	$0.00318	
DWR Bond	$0.00477	

* Transmission, Transmission Rate Adjustments, and Reliability Service charges are combined for presentation on customer bills.

(Continued)

ELECTRIC SCHEDULE LS-2
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS:

1. **TYPE OF SERVICE**: This schedule is applicable to multiple lighting systems to which PG&E will deliver current at secondary voltage. Multiple current will normally be supplied at 120/240 Volt, single-phase. In certain localities PG&E may supply service from 120/208 Volt, wye-systems, polyphase lines in place of 240 Volt service. Unless otherwise agreed, existing series current will be delivered at 6.6 amperes. Single-phase service from 480 Volt sources and series circuits will be available in certain areas at the option of PG&E when this type of service is practical from PG&E's engineering standpoint. All currents and voltages stated herein are nominal, reasonable variations being permitted. (T)

   New lights will normally be supplied as multiple systems. Series service to new lights will be made only when it is practical from PG&E's engineering standpoint to supply them from existing series systems.

2. **SERVICE REQUIREMENTS**: (N)

   a) **PHOTO CONTROLS**

   This rate schedule is predicated on an electronic type photo controls meeting ANSI standard C136.10, with a turn on value of 1.0 foot-candles and a turn off value of 1.5 foot-candles. Electro-mechanical or thermal type photo controls are not acceptable for this rate schedule.

   b) **LIGHT or POLE NUMBERING**

   As agreed upon by the parties, pole number sequencing and coding for single lights or multiple lights on a single pole, shall be provided by either party and must conform to PG&E's billing system. Customer will provide physical numbering on lights or poles for LS-2 installations in order to facilitate accurate billing and inventory reporting. Numbering is required prior to energizing facilities. Numbering must be legible from the ground.

   c) **SERVICE REQUESTS**

   Service request shall include form 79-1007 for installation and energizing, and form 79-1008 for removing or de-energizing Customer's facilities. (N)

(L)

(Continued)

ELECTRIC SCHEDULE LS-2

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

3. **SERVICE INSTALLATION**

PG&E will establish service delivery points within close proximity to its distribution system.

a) **Overhead:** In an overhead area, a single drop will be installed. For an overhead to underground system, service will be established in a PG&E box at the base of the riser pole or other agreed upon location within close proximity. PG&E will connect Customer's conductors at the service delivery point.

b) **Underground:** In an underground area, service will be established at the nearest existing secondary box. Where no secondary facilities exist, a new service, transformer and secondary splice box, as required, will be installed in the shortest most practical configuration from the connection on the distribution line source. Customer shall install and own all facilities from the service delivery point on PG&E's system.

c) **Customer Installation Responsibility:** Customer shall install, own and maintain all facilities beyond the service delivery point. For PG&E's serving facilities, Customer or Applicant, at its expense, shall perform all necessary trenching, backfill and paving, and shall furnish and install all necessary conduit and substructures (including substructures for transformer installations, if necessary, for street lights only) in accordance with PG&E's specifications. Riser material shall be installed by PG&E at the Customer's expense. Upon acceptance by PG&E, ownership of the conduit and substructures shall vest in PG&E. Customer shall provide rights of way as provided in electric Rule 16.

d) **PG&E Installation Responsibility:** PG&E shall furnish and install the underground or overhead service conductor, transformers and necessary facilities to complete the service to the distribution line source, subject to the payment provisions of Special Condition 4. Only duly authorized employees of PG&E shall connect Customer's loads to, or disconnect the same from, PG&E's electrical distribution facilities.

e) **Rearrangements:** Customer or Applicant shall pay, in advance, PG&E's estimated cost for any relocation or rearrangement of PG&E's existing street light or service facilities requested by Customer or Applicant and agreed to by PG&E.

f) **Non-Conforming Load:** Applicant or Customer must be a governmental agency. Any load, other then the lighting loads listed in the Rate table above, is non conforming load. Non conforming load may be connected to customer circuits not to exceed 150 watts per circuit, or light for individually connected lights. Loads will conform to the requirements of Agreement form 79-1048 available on PG&E's web site, http://www.pge.com/tariffs/EF.SHTML#EF for electric forms. All other non conforming load connected to unmetered LS-2 facilities exceeding this limitation requires metering of the Customer's system at PG&E's service delivery point. (N)

(D)

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 8
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

4. **NON REFUNDABLE PAYMENT FOR SERVICE INSTALLATION:** (N)

   a) Customer or Applicant shall pay in advance the estimated installed cost necessary to establish a service delivery point. A one-time revenue allowance will be provided based on Customer's kWh usage and the distribution component of the energy rate posted in the Rate Schedule for the lamps installed. The total allowance shall be determined by taking the annual equivalent kWh times the Distribution component of this rate divided by the cost of service factor shown in Electric Rule 15.C.

   b) The allowance will only be provided where PG&E must install capital assets to connect load. No allowance will be provided where a simple connection is required. Only lights on a minimum 11 hour All Night (AN) schedule for permanent service shall be granted an allowance. Where Applicant received allowances based upon 11 hour AN operation, no billing adjustments, as otherwise provided for in Special Condition 7, shall be made for the first three (3) years following commencement of service.

   Line or service extensions in excess of the above shall be installed under special condition 9.

5. **TEMPORARY SERVICE:** Temporary services will be installed under electric Rule 13.

6. **ANNUAL OPERATING SCHEDULES**: The above rates for AN service assume 11 hours operation per night and apply to lamps which will be turned on and off once each night in accordance with a regular operating schedule selected by the Customer but not exceeding 4,100 hours per year. (N)

(Continued)

ELECTRIC SCHEDULE LS-2

Sheet 9

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

7. **OPERATING SCHEDULES OTHER THAN ALL-NIGHT:** Rates for regular operating schedules other than full all-night will be the AN rate, plus or minus, respectively, the half-hour adjustment for each half-hour more or less than an average of 11 hours per night. This adjustment will apply only to lamps on regular operating schedules of not less than 1,095 hours per year, or 3 hours per night, and may be applied for 24-hour operation. Photo control devices used for more or less than AN must be approved by PG&E prior to adjustments in billing. (T)

8. **MAINTENANCE, ACCESS, CLEARANCES**

   a) Maintenance

      The Class B and C rates include all labor and material necessary for the inspection, cleaning, or replacement by PG&E of lamps and glassware. Replacement is limited to certain glassware such as is commonly used and manufactured in reasonably large quantities. A commensurate extra charge will be made for maintenance of glassware of a type entailing unusual expense. The Class C rate also includes all labor and material necessary for replacement by PG&E of photoelectric controls. Class B and C rates are closed to new installations and to additional lamps in existing accounts as of March 1, 2006.

   b) Under the grand fathered Class B and C rates, the following shall apply:

      1) At Customer's request, where PG&E's resources permit, PG&E will paint poles for Customer on a time and material basis. This service will only be offered for poles that have been designed to be painted.

      2) PG&E will isolate any trouble in the Customer's system which has resulted in an outage or diminished light output.

      3) PG&E will make necessary repairs which do not require wiring replacement on accessible wiring between poles and on equipment and wiring in and on poles to keep the system in operating condition.

      4) PG&E will provide labor for the replacement of material such as ballasts, relays, fixtures, individual cable runs between poles where such runs are in conduit, and other individual parts of the system that are not capital items.

      5) Customer shall compensate PG&E for any material furnished by PG&E not included in 8.A. above. The exception for Class B is that photo control replacement is not included in the rate. Customer must have been on Class C for this service.

      6) PG&E shall not be responsible for excavation or any major replacement of circuits, conduits, poles, or fixtures owned by the Customer.

      7) Tree trimming is the responsibility of the Customer for installation of new lights or for maintaining lighting patterns of existing lights.

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 10
CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

8. **MAINTENANCE, ACCESS, CLEARANCES** (Cont'd.): (T)

c) Access (N)

Customer will maintain adequate access for PG&E's standard equipment used in maintaining facilities and for installation of its facilities. PG&E reserves the right to collect additional maintenance costs due to obstructed access or other conditions preventing PG&E from maintaining its equipment with standard operating procedures. Applicant or Customer shall be responsible for rearrangement charges as provided for in Special Condition 3.e.

d) Clearances

Customer applicant shall, at its expense, correct all access or clearance infractions, or pay PG&E its total estimated cost for PG&E to relocate facilities to a new location which is acceptable to PG&E. Failure to comply with corrective measures within a reasonable time may result in discontinuance of service in accordance with electric Rule 11. Applicant or Customer shall be responsible for tree trimming to maintain lighting patterns of existing lights. (N)

(D)
(D)

(Continued)

ELECTRIC SCHEDULE LS-2

Sheet 11

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

9. **LINE EXTENSIONS**

   A. Where PG&E extends its facilities to street light installations in advance of subdivision projects where subdivision maps have been approved by local authorities, extensions will be installed under the provisions of electric Rule 15, except as noted below. (N)

   B. Where PG&E extends its facilities to street light installations in the absence of any approved subdivision maps, applicant shall pay PG&E's estimated cost, plus cost of ownership and applicable tax. Standard form contract 62-4527, Agreement to Perform Tariff Schedule Related Work, shall be used for these installations. (N)

10. **STREET LIGHT LAMPS – STANDARD AND NONSTANDARD RATINGS:** The rates under Classes B and C are applicable to both standard and group replacement street lamps. Standard and group replacement street lamps have reference only to street lamps having wattage and operating life ratings within three percent of those specified in the EEI-NEMA Standards for Filament Lamps Used in Street Lighting. Where Class A service is supplied to lamps of other ratings than those specified in EEI-NEMA Standards an adjustment will be made in the lamp rates proportionate to the difference between the wattage of the lamps and the standard lamps of the same lumen rating. (D)

11. **CONTRACT:** Except as otherwise provided in this rate schedule, or where lighting service is installed in conjunction with facilities installed under the provisions of Rules 15 or 16, standard form contract 62-4527, Agreement to Perform Tariff Schedule Related Work shall be used for installations, rearrangements or relocations.

12. **POLE CONTACT AGREEMENT:** Where Customer requests to have a portion or all Customer owned street lighting facilities in contact with PG&E's distribution poles, a Customer-Owned Streetlights PG&E Pole Contact Agreement (Form 79 938) will be required.

(Continued)

ELECTRIC SCHEDULE LS-2 Sheet 12

CUSTOMER-OWNED STREET AND HIGHWAY LIGHTING

SPECIAL CONDITIONS: (Cont'd.)

13. **BILLING:** This Rate Schedule is subject to PG&E's other rules governing billing issues, as may be applicable. PG&E performs regular auditing as part of this rate schedule.

Limited testing of Energy Efficient Street Light Technology will be allowed under this Rate Schedule where a light of the type and wattage of the fixture and lamp to be tested are not presently included in the rate tables. Such test installations are subject to approval by PG&E. Following approval, test installations will be billed at the customer's currently billed rate. Customer will provide a monthly inventory of streetlights that will be tested. The format and content of the inventory must be approved by PG&E. The Company reserves the right to audit customer. PG&E also reserves the right to collect the cost of any such audit from the customer. Testing is limited to existing street light fixtures and the total energy consumption per fixture must not exceed current energy use per fixture. Additional energy efficient street light fixtures installed will also be subject to billing under the current rate upon the approval of PG&E. The test period will not exceed 12 months.

Bundled Service Customers receive supply and delivery service solely from PG&E. The Customer's bill is based on the Total Rate set forth above.

Transitional Bundled Service Customers take transitional bundled service as prescribed in Rules 22.1 and 23.1, or take bundled service prior to the end of the six (6) month advance notice period required to elect bundled portfolio service as prescribed in Rules 22.1 and 23.1. These customers shall pay charges for transmission, transmission rate adjustments, reliability services, distribution, nuclear decommissioning, public purpose programs, the FTA (where applicable), the RRBMA (where applicable), the applicable Cost Responsibility Surcharge (CRS) pursuant to Schedule DA CRS or Schedule CCA CRS, and short-term commodity prices as set forth in Schedule TBCC.

Direct Access (DA) and Community Choice Aggregation (CCA) Customers purchase energy from their non-utility provider and continue receiving delivery services from PG&E. Bills are equal to the sum of charges for transmission, transmission rate adjustments, reliability services, distribution, public purpose programs, nuclear decommissioning, the FTA (where applicable), the RRBMA (where applicable), the franchise fee surcharge, and the applicable CRS. The CRS is equal to the sum of the individual charges set forth below. Exemptions to the CRS are set forth in Schedules DA CRS and CCA CRS.

	DA CRS	CCA CRS
Energy Cost Recovery Amount Charge (per kWh)	$0.00318	$0.00318
Power Charge Indifference Adjustment (per kWh)	($0.00018) (I)	$0.01978 (I)
DWR Bond Charge (per kWh)	$0.00477	$0.00477
CTC Charge (per kWh)	$0.00022 (R)	$0.00022 (R)
Total CRS (per kWh)	$0.00799	$0.02795

14. **DWR BOND CHARGE:** The Department of Water Resources (DWR) Bond Charge was imposed by California Public Utilities Commission Decision 02-10-063, as modified by Decision 02-12-082, and is property of DWR for all purposes under California law. The Bond Charge applies to all retail sales, excluding CARE and Medical Baseline sales. The DWR Bond Charge (where applicable) is included in customers' total billed amounts.

Appendix F: Lab Test Results for Demonstrated LED Technologies

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL NUMBER: 14230 DATE: 11-17-2008

PREPARED FOR: PACIFIC NORTHWEST NATIONAL LABORATORY/BATTELLE

CATALOG NUMBER: CALIPER 08-108

LUMINAIRE: CAST ALUMINUM HOUSING, EXTRUDED ALUMINUM HEATSINK, NO ENCLOSURE.

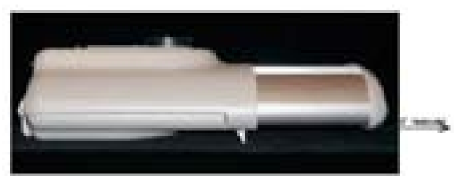
LAMP: 30 WHITE LEDS WITH CLEAR PLASTIC OPTICS BELOW EACH

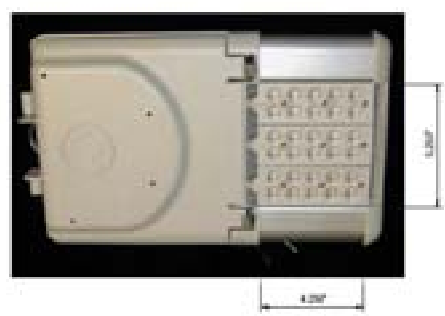
LED POWER SUPPLY: ONE ADVANCE LEDINTA1400C50F30M

ELECTRICAL VALUES: 120.0VAC, 0.4921A, 58.60W

LUMINAIRE EFFICACY: 53.0 LUMENS/WATT

NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*





IES CLASSIFICATION: **TYPE II**
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	1159.99	0.00	1159.99
STREET SIDE	1947.54	0.00	1947.54
TOTALS	3107.53	0.00	3107.53

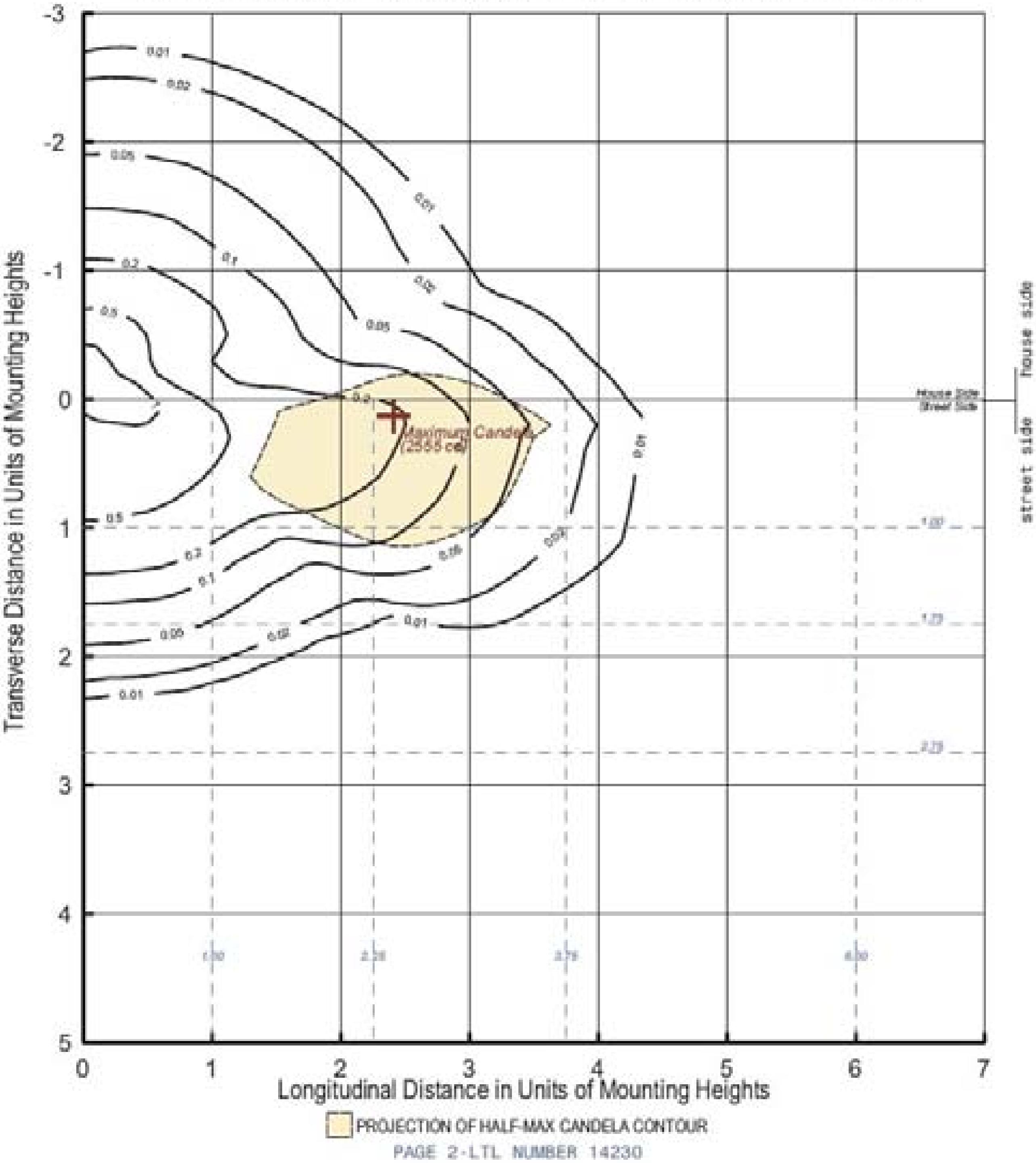
Approved By: MG

*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.

LTL LUMINAIRE TESTING LABORATORY, INC.
905 Harrison Street - Allentown, PA 18103 - 610-770-1044 - Fax 610-770-8912 - www.LuminaireTesting.com

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



CANDELA DISTRIBUTION

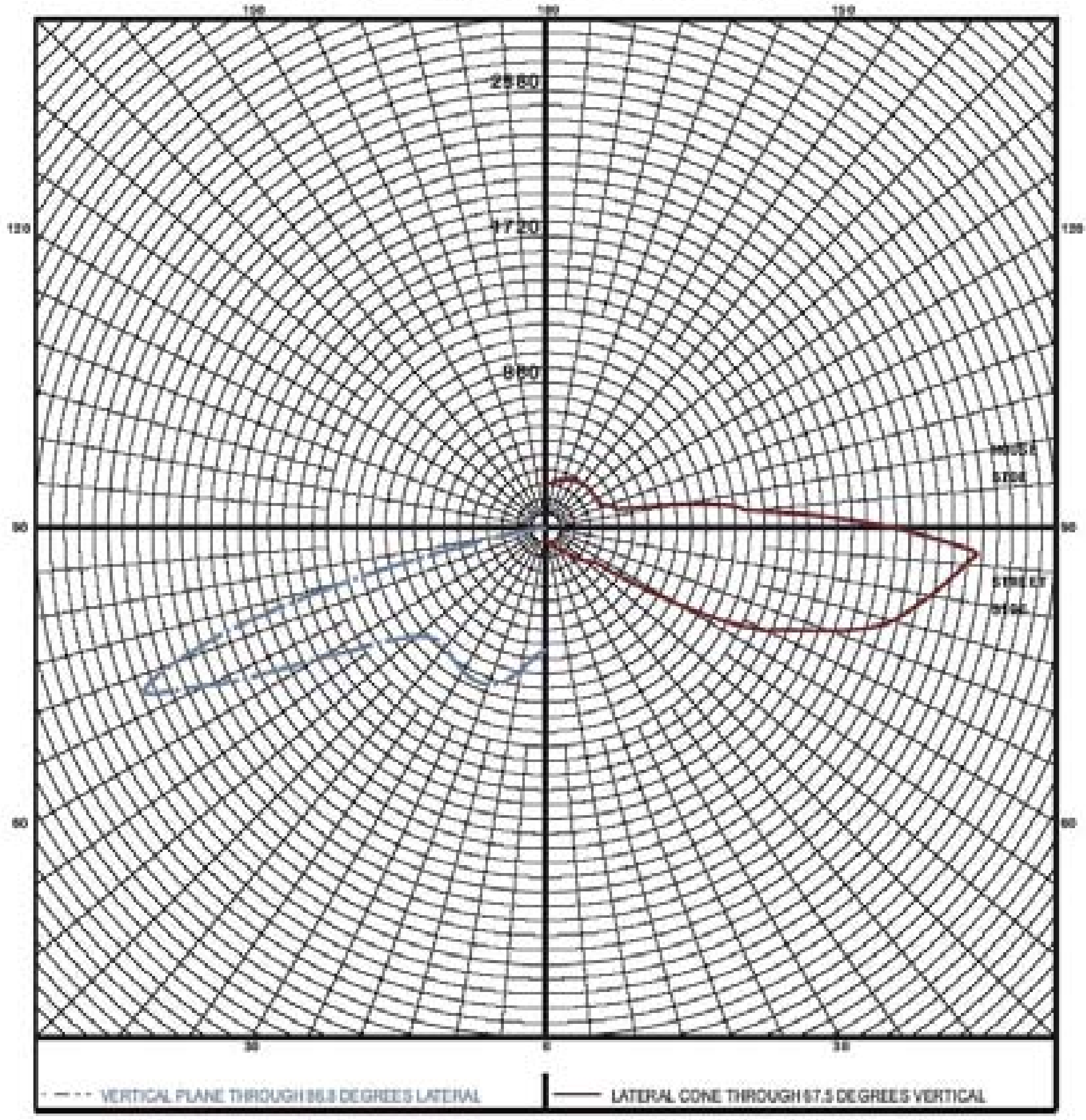
	0	5	15	25	35	45	55	65	75	85	86.8
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0
87.5	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	1	9	13
82.5	9	7	6	6	6	6	13	13	34	59	74
80	27	24	24	21	21	21	22	46	174	183	227
77.5	24	24	19	19	22	39	37	166	473	454	534
75	36	36	36	36	40	56	43	456	904	1008	1158
72.5	38	39	40	43	59	64	89	888	1468	1713	1855
70	62	58	61	68	80	99	248	1257	1904	2220	2328
67.5	80	79	86	116	163	237	362	1439	2119	2487	2555
65	202	186	223	267	303	334	432	1478	2073	2223	2201
62.5	312	307	328	350	371	407	537	1465	1904	1882	1855
60	359	359	380	427	460	509	721	1438	1665	1543	1526
57.5	421	421	451	551	597	669	902	1368	1437	1358	1346
55	519	519	561	677	767	844	1012	1278	1257	1189	1178
52.5	662	662	709	800	911	945	1066	1195	1187	1086	1073
50	775	779	816	877	962	979	1071	1125	1159	1014	1005
47.5	828	837	859	884	942	979	1033	1079	1129	965	954
45	822	830	844	865	910	960	984	1046	1097	941	930
40	801	809	837	876	889	902	930	960	1046	928	925
35	864	864	870	871	870	864	835	886	1025	948	948
30	855	852	853	841	809	770	743	850	1003	969	974
25	778	775	763	741	712	696	711	850	988	985	990
20	668	669	668	665	662	663	712	859	962	975	984
15	632	632	632	632	640	665	752	856	917	930	936
10	603	604	613	625	657	711	770	810	838	847	855
5	650	662	674	689	706	723	743	755	761	766	766
0	731	731	731	731	731	731	731	731	731	731	731

PAGE 3-LTL NUMBER 14230

CANDELA DISTRIBUTION

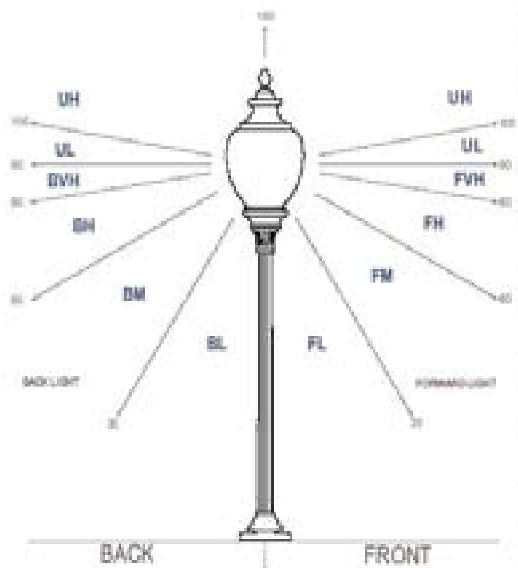
	90	95	105	115	125	135	145	155	165	175	180
180	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0
87.5	0	0	0	0	0	0	0	0	0	0	0
85	9	0	0	0	0	0	0	0	0	0	0
82.5	47	28	18	10	12	6	0	0	0	0	0
80	147	77	27	21	21	19	15	15	13	15	6
77.5	383	218	56	34	30	30	18	21	25	27	24
75	840	494	135	82	56	43	37	43	37	36	39
72.5	1407	824	254	194	154	110	82	61	47	46	36
70	1840	1119	361	295	300	273	230	203	174	157	125
67.5	2039	1178	424	353	344	343	332	315	288	264	255
65	1702	930	466	407	371	353	340	337	313	294	288
62.5	1368	773	499	459	390	367	353	356	331	312	303
60	1153	709	524	497	421	384	374	377	349	331	326
57.5	1066	663	530	524	456	401	395	396	370	356	347
55	941	589	503	527	481	426	405	408	375	368	362
52.5	858	522	456	513	500	447	417	420	390	381	380
50	795	476	404	496	513	472	436	430	398	393	389
47.5	766	467	370	470	521	505	469	448	414	404	401
45	760	488	353	450	524	530	502	466	441	429	421
40	798	573	359	424	505	558	562	531	503	490	481
35	862	697	420	436	500	564	591	594	589	586	573
30	922	833	551	484	530	583	628	657	675	686	677
25	966	932	757	586	589	640	689	733	764	785	781
20	969	963	911	788	689	697	743	787	818	837	834
15	932	936	932	905	858	812	791	803	816	827	825
10	852	861	861	865	861	855	844	840	840	840	834
5	770	770	776	776	778	779	779	781	779	779	778
0	731	731	731	731	731	731	731	731	731	731	731

MAXIMUM PLANE AND CONE PLOTS OF CANDELA

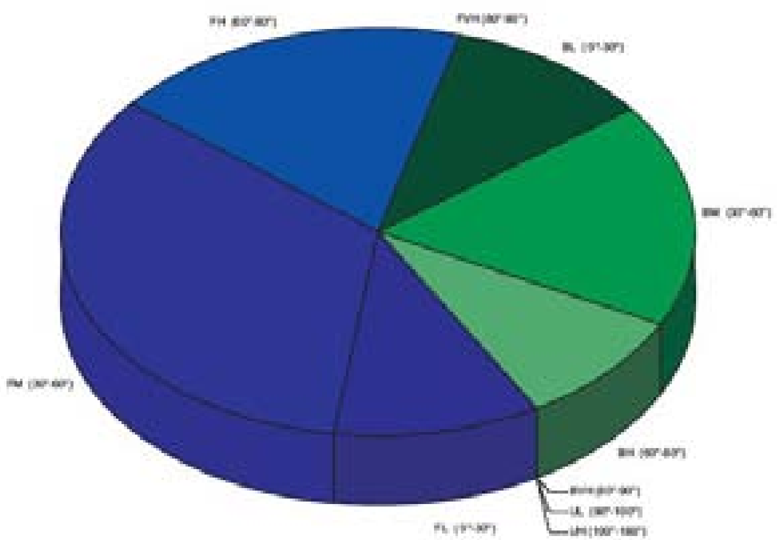


PAGE 5 - LTL NUMBER 14230

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



ZONE	FLUX LUMINAIRE LUMENS	FLUX % OF LUMINAIRE LUMENS
FORWARD LIGHT	1948	62.7
FL (0°-30°)	326	10.5
FM (30°-60°)	1050	33.8
FH (60°-80°)	566	18.2
FVH (80°-90°)	6	0.2
BACK LIGHT	1160	37.3
BL (0°-30°)	323	10.4
BM (30°-60°)	556	17.9
BH (60°-80°)	278	9
BVH (80°-90°)	2	0.1
UPLIGHT	0	0
UL (90°-100°)	0	0
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



PAGE 6-LTL NUMBER 14230

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL Number: 14231

Date: 11-03-2008

Prepared For: Pacific Northwest National Laboratory/Battelle

PNNL Catalog Number: CALiPER 08-108

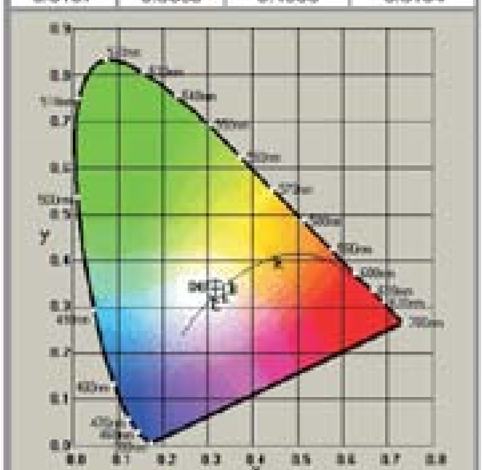
Luminaire: Cast aluminum housing, extruded aluminum heatsink housing, no enclosure.

Lamp: 30 White LEDs with clear plastic optics below each.

LED Power Supply: One Advance LEDINTA1400C50F30M

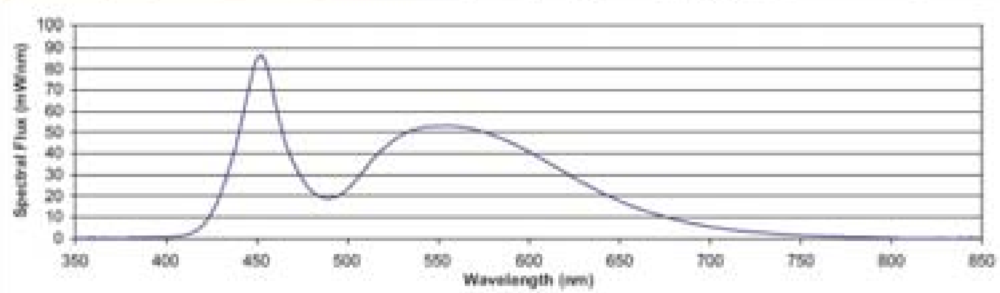
Luminaire Efficacy: 54.7 Lumens/Watt

Lamp Arc Voltage	Lamp Current	Lamp Watts	Frequency
120.0VAC	0.4887A	58.14W	60Hz
Radiant Flux mW	**Luminous Flux lumen**	**Corr.Color Temperature K**	**Color Rend. Index Ra**
9952.025	3178.750	6227	75.2
Chroma x	**Chroma y**	**Chroma u**	**Chroma v**
0.3167	0.3398	0.1966	0.3164



Chromaticity Diagram CIE 1931, 2 degree

Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
350	0.0000	610	36.1060
360	0.3539	620	31.0690
370	0.2509	630	26.1880
380	0.3406	640	21.6170
390	0.3596	650	17.7600
400	0.5536	660	14.2980
410	1.5096	670	11.4570
420	6.0208	680	8.9855
430	21.0610	690	7.0300
440	49.2310	700	5.5595
450	84.4720	710	4.4002
460	64.8830	720	3.4757
470	36.1710	730	2.6184
480	22.5860	740	1.9237
490	18.8730	750	1.5303
500	23.1770	760	1.0975
510	32.9750	770	0.8369
520	42.4480	780	0.5229
530	48.7650	790	0.6157
540	51.9480	800	0.1606
550	52.9290	810	0.0000
560	52.7860	820	0.0000
570	51.4190	830	0.2384
580	48.6560	840	0.0000
590	45.2880	850	0.0000
600	40.8510		



TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08. Approved By: MG

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL NUMBER: 14232 DATE: 11-10-2008
PREPARED FOR: PACIFIC NORTHWEST NATIONAL LABORATORY/BATTELLE
CATALOG NUMBER: CALIPER 08-107
LUMINAIRE: CAST AND FORMED ALUMINUM HOUSING, FORMED SPECULAR ALUMINUM REFLECTOR, CLEAR PLASTIC ENCLOSURE.
LAMP: 14 WHITE LEDS
ONE UNMARKED LED POWER SUPPLY
ELECTRICAL VALUES: 120.0VAC, 0.4887A, 54.35W
LUMINAIRE EFFICACY: 18.4 LUMENS/WATT
NOTE: THIS TEST WAS PERFORMED USING THE CALIBRATED PHOTODETECTOR METHOD OF ABSOLUTE PHOTOMETRY.*

15.375"

0 Horizontal

IES CLASSIFICATION: **TYPE II**
LONGITUDINAL CLASSIFICATION: **SHORT**
CUTOFF CLASSIFICATION: **FULL-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	72.02	0.00	72.02
STREET SIDE	929.43	0.00	929.43
TOTALS	1001.45	0.00	1001.45

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.

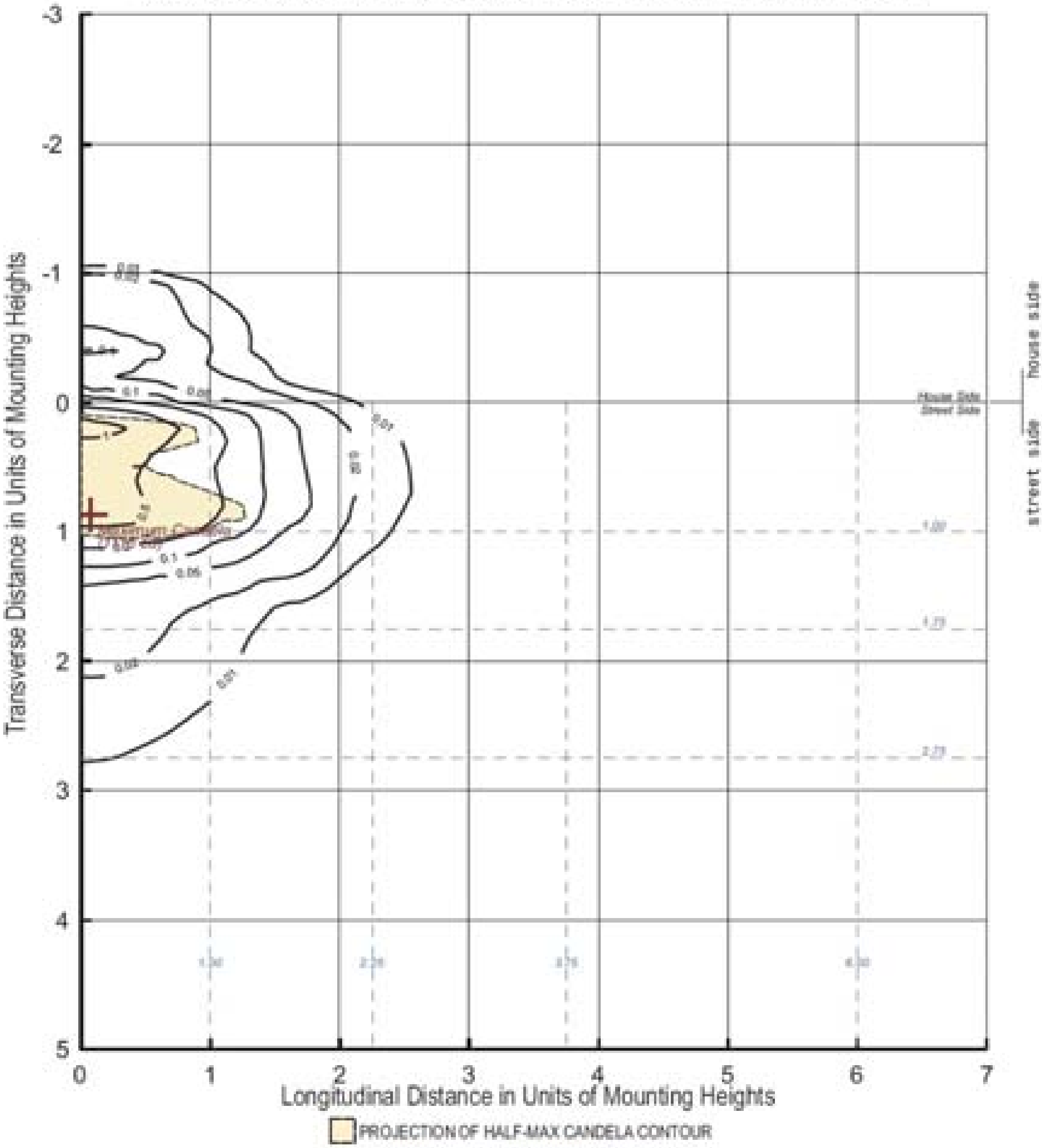
TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08.
TEST ANGULAR INCREMENTS AND REPORT FORMATTING WAS BASED ON IES LM-31-95.

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

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



PAGE 2-LTL NUMBER 14232

LTL LUMINAIRE TESTING LABORATORY, INC.
SUSTAINING MEMBER of the IESNA
905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

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	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0
87.5	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0
82.5	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	3	7	3	0
77.5	0	0	0	0	0	3	10	10	18	7	7
75	0	0	0	0	28	34	24	24	46	31	10
72.5	4	6	46	90	72	51	37	73	99	58	28
70	162	160	138	109	84	63	57	124	135	94	51
67.5	163	165	150	124	91	70	109	141	159	117	64
65	162	163	148	117	90	91	202	248	191	145	79
62.5	147	147	138	112	102	141	244	358	224	175	96
60	135	135	126	112	132	250	362	368	274	211	102
57.5	132	132	127	135	215	317	579	390	322	260	111
55	159	157	157	197	341	488	612	401	346	283	118
52.5	217	215	254	349	447	750	579	410	399	298	117
50	373	378	417	459	726	815	552	422	456	301	123
47.5	443	452	509	660	960	721	516	443	510	305	112
45	586	600	893	996	857	643	516	470	558	307	120
41	1111	1115	1040	862	703	586	527	524	645	293	123
40	1070	1071	984	818	679	571	530	543	657	290	126
35	776	781	735	640	583	558	540	636	679	293	129
30	622	628	598	574	563	558	601	718	639	275	145
25	587	597	591	568	591	628	726	776	565	253	160
20	604	612	621	628	666	736	815	717	468	230	162
15	710	723	750	758	805	820	745	563	371	208	153
10	824	829	832	778	742	649	536	404	284	196	168
5	536	527	506	464	413	361	307	253	211	175	163
0	180	180	180	180	180	180	180	180	180	180	180

PAGE 3 - LTL NUMBER 14232

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

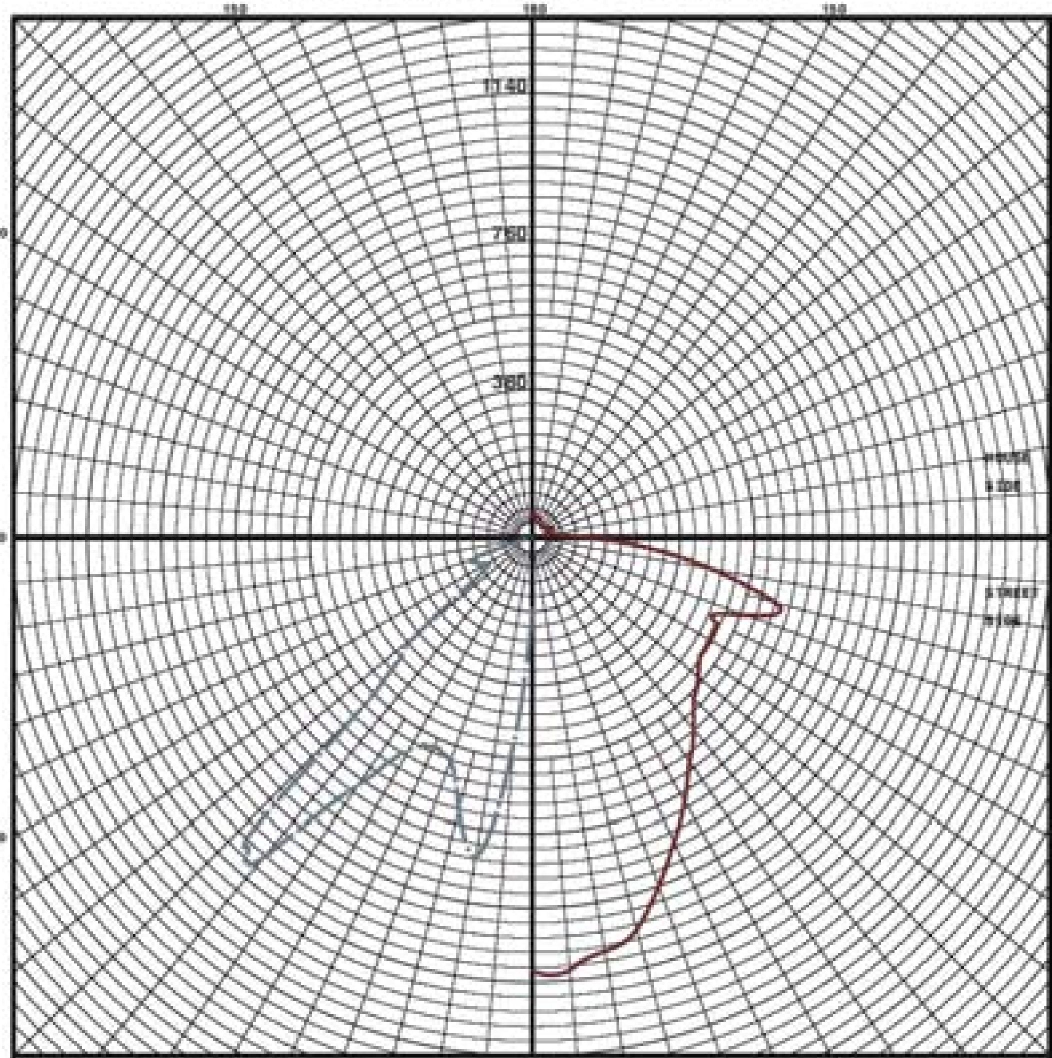
CANDELA DISTRIBUTION

	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	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0
82.5	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0
77.5	3	0	0	0	0	0	0	0	0	0
75	7	3	0	0	0	0	0	0	0	0
72.5	10	9	2	0	0	0	0	0	0	0
70	12	9	3	0	0	0	0	0	0	0
67.5	13	16	4	0	0	0	0	0	0	0
65	16	24	10	0	0	0	0	0	0	0
62.5	21	31	12	4	0	0	0	0	0	0
60	27	28	22	7	0	0	0	0	0	0
57.5	34	27	30	22	2	0	0	0	0	0
55	49	33	33	28	15	2	0	0	0	0
52.5	61	31	37	33	34	10	0	0	0	0
50	58	33	40	34	42	28	10	0	0	0
47.5	60	30	40	34	37	45	30	10	7	6
45	73	31	51	39	36	45	54	48	36	33
41	81	34	57	45	36	40	48	57	61	57
40	79	37	49	49	42	43	51	57	64	63
35	76	39	45	82	54	46	45	49	54	54
30	93	34	42	48	90	57	46	45	48	48
25	120	49	39	51	58	72	96	75	70	72
20	130	63	31	36	52	60	60	60	60	63
15	127	76	55	39	37	43	49	51	55	54
10	151	120	88	64	46	39	36	36	36	36
5	153	139	127	114	103	91	85	81	85	87
0	180	180	180	180	180	180	180	180	180	180

L

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

MAXIMUM PLANE AND CONE PLOTS OF CANDELA



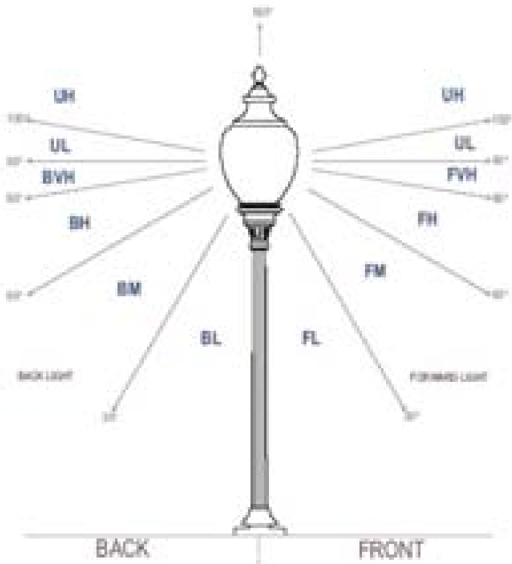
VERTICAL PLANE THROUGH 5.0 DEGREES LATERAL | LATERAL CONE THROUGH 41.0 DEGREES VERTICAL

LTL LUMINAIRE TESTING LABORATORY, INC.

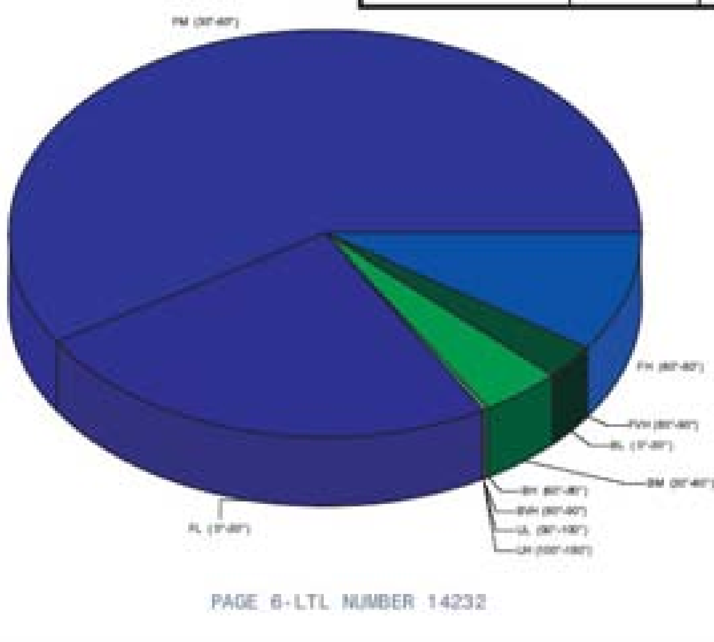
SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

FLUX DISTRIBUTION TABLE BASED ON THE IESNA LUMINAIRE CLASSIFICATION SYSTEM



ZONE	FLUX: LUMINAIRE LUMENS	FLUX: % OF LUMINAIRE LUMENS
FORWARD LIGHT	929	92.8
FL (0°-30°)	245	24.5
FM (30°-60°)	589	58.8
FH (60°-80°)	96	9.5
FVH (80°-90°)	0	0
BACK LIGHT	72	7.2
BL (0°-30°)	28	2.8
BM (30°-60°)	40	4
BH (60°-80°)	4	0.4
BVH (80°-90°)	0	0
UPLIGHT	0	0
UL (90°-100°)	0	0
UH (100°-180°)	0	0
TRAPPED LIGHT	NA	NA



PAGE 6-LTL NUMBER 14232

LTL LUMINAIRE TESTING LABORATORY, INC.

SUSTAINING MEMBER of the IESNA

905 Harrison Street · Allentown, PA 18103 · 610-770-1044 · Fax 610-770-8912 · www.LuminaireTesting.com

LTL Number: 14233 Date: 11-19-2008

Prepared For: Pacific Northwest National Laboratory/Battelle

PNNL Catalog Number: CALiPER 08-107

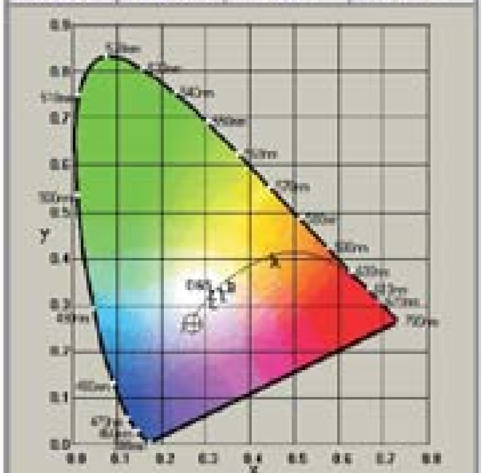
Luminaire: Cast and formed aluminum housing, formed specular aluminum reflector, clear plastic enclosure.

Lamp: 14 White LEDs

LED Power Supply: Unmarked LED power supply

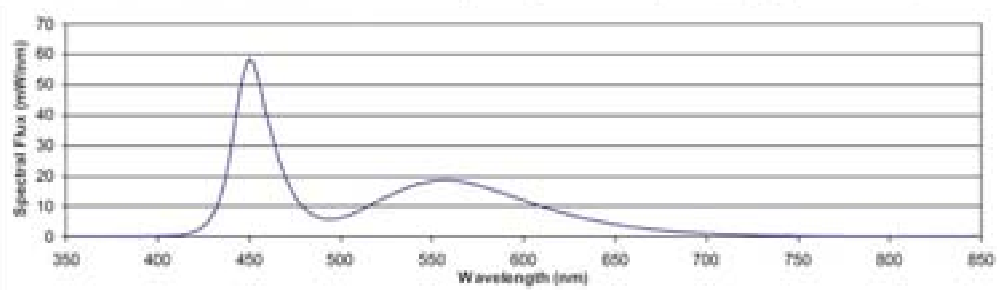
Luminaire Efficacy: 18.7 Lumens/Watt

Lamp Arc Voltage	Lamp Current	Lamp Watts	Frequency
120.0VAC	0.4940A	54.95W	60Hz
Radiant Flux mW	**Luminous Flux lumen**	**Corr.Color Temperature K**	**Color Rend. Index Ra**
3752.518	1028.195	14628	74.3
Chroma x	**Chroma y**	**Chroma u**	**Chroma v**
0.2709	0.2603	0.1941	0.2798



Chromaticity Diagram CIE 1931, 2 degree

Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
350	0.1980	610	9.9887
360	0.1263	620	8.2077
370	0.1542	630	6.5808
380	0.1680	640	5.2409
390	0.1947	650	4.1579
400	0.2824	660	3.2426
410	0.4985	670	2.4790
420	1.6715	680	1.9256
430	7.2301	690	1.4608
440	29.3180	700	1.1061
450	58.5730	710	0.8811
460	38.8600	720	0.7144
470	19.5010	730	0.5542
480	9.4941	740	0.4217
490	6.0865	750	0.3404
500	6.2916	760	0.2592
510	8.5137	770	0.1905
520	11.6560	780	0.1737
530	14.5530	790	0.1880
540	16.9710	800	0.1409
550	18.3970	810	0.0813
560	18.6750	820	0.0927
570	17.8030	830	0.1016
580	16.1500	840	0.1185
590	14.1200	850	0.2769
600	12.0340		



TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08. Approved By: MG

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

PREPARED FOR: RDS

CATALOG NUMBER: CALIPER 08-110

LUMINAIRE: CAST METAL HOUSING WITH FINNED TOP SECTION, ONE WHITE CIRCUIT BOARD WITH 36 LEDS, 12 CLEAR MOLDED PLASTIC INTERIOR LENSES ATTACHED TO CIRCUIT BOARD EACH WITH 9 OPTICS, ONLY 36 OPTICS OF INTERIOR LENSES HAS A CORRESPONDING LED, MOLDED GRAY PLASTIC REFLECTOR, CLEAR MOLDED PLASTIC EXTERIOR SAG LENS, FABRICATED SPECULAR METAL LENS FRAME.

LAMP: THIRTY-SIX WHITE LIGHT EMITTING DIODES (LEDS), VERTICAL BASE-UP POSITION.

LED DRIVER: LEOTEK ELECTRONICS CORP. LP1090-24-GG-170

GONIOMETRIC INSTRUMENTATION:
ITL Moving Mirror Goniophotometer - 25.25' Test Distance
Yokogawa WT210 Digital Power Meter
Elgar CW2501 AC Power Source
Omega HH-81 Digital Thermometer with Type J thermocouple

SPECTRORADIOMETRIC INSTRUMENTATION:
Yokogawa WT210 Digital Power Meter
Optronic Laboratories OL770 Spectroradiometer
1.5 meter integrating sphere
Elgar CW2501 AC Power Source

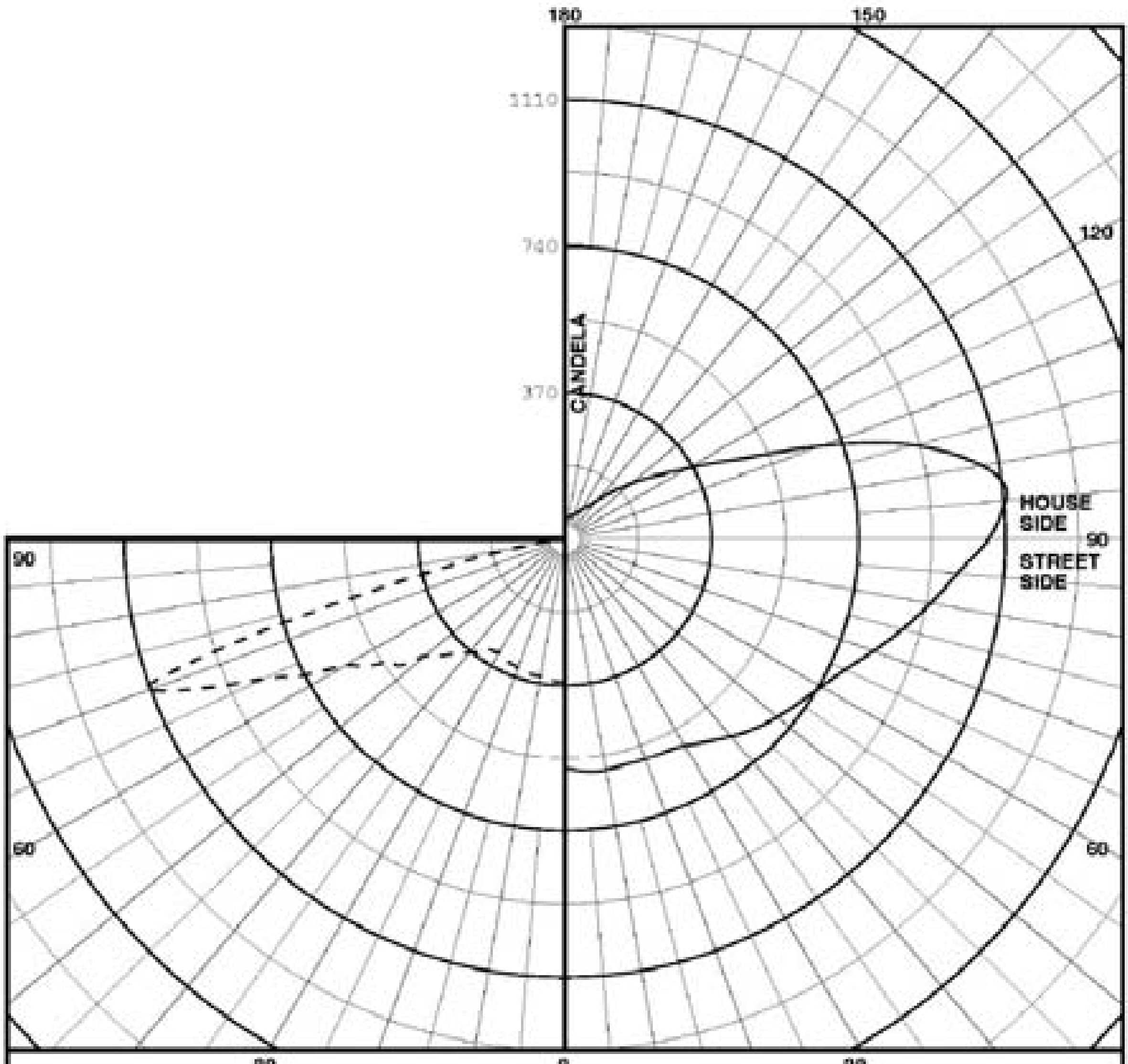
OBJECT OF TEST: Measure distribution photometry and input electrical parameters on the goniophotometer. Report candela distribution and calculated lumen output. Measure the total flux output in lumens, Correlated Color Temperature (CCT), Color Rendering Index (CRI), Chromaticity Coordinates (x/y; u'/v'), and Spectral Power Distribution (SPD) of the luminaire and input electrical parameters when operated in the integrating sphere. Measure temperature of the luminaire at one location.

PROCEDURE: The luminaire was supplied by client with an unknown number of burn hours. The luminaire was prewarmed overnight before each test. Stabilization data was recorded to assure stabile operation (stabilization data available on request). Distribution photometry and input electrical data were measured with the unit mounted on the goniophotometer. CCT, CRI, x/y and u'/v' chromaticity coordinates, SPD, total flux, and input electrical data were measured with the unit operating in the integrating sphere. In order to measure the mean performance, twenty data sets were averaged using the Optronics OL770. A Type J thermocouple was attached to the surface of the unit to measure operating temperature (see photograph in the report for location). All data are traceable to the National Institute of Standards and Technology. All testing performed with the unit operated at 120V AC in a 25 +/-1 degree Celsius free air ambient.

Checked: *R BERGIN*
Approved: *R BEATTIE*

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1956
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

MAXIMUM PLANE AND MAXIMUM CONE PLOTS OF CANDELA

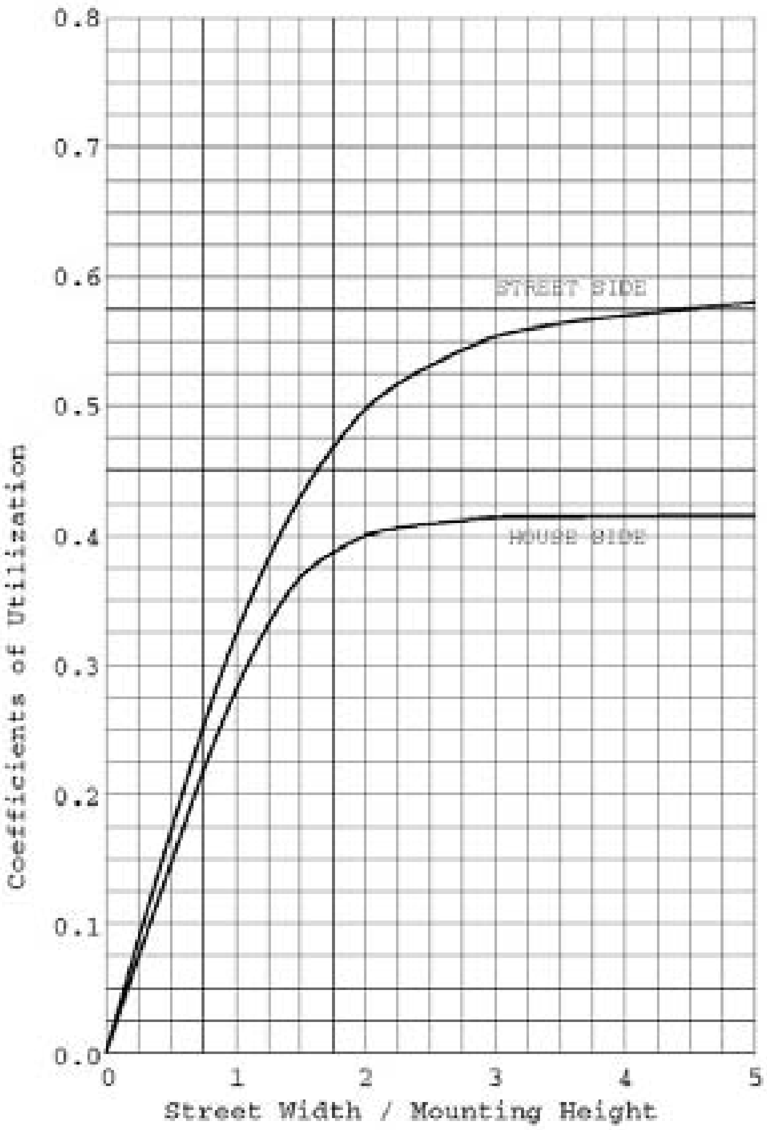


VERTICAL PLANE THROUGH MAXIMUM CANDELA
70.0 (Degrees Vertical)

CONE THROUGH MAXIMUM CANDELA
96.0 (Degrees Horizontal) = 1120

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

COEFFICIENTS OF UTILIZATION AND FLUX DISTRIBUTION



	LUMENS	PERCENT OF FIXTURE
DOWNWARD STREET SIDE	1521	58.2
DOWNWARD HOUSE SIDE	1090	41.7
DOWNWARD TOTAL	2611	99.9
UPWARD STREET SIDE	2	0.1
UPWARD HOUSE SIDE	0	0.0
UPWARD TOTAL	3	0.1
TOTAL FLUX	2614	100.0

EFFICACY = 71.23 Lm/W

ALL CANDELA AND LUMENS IN THIS REPORT ARE BASED ON ABSOLUTE PHOTOMETRY.
THE COEFFICIENT OF UTILIZATION VALUES ARE BASED ON THE TOTAL ABSOLUTE LUMEN OUTPUT OF THIS LUMINAIRE SAMPLE.

FLUX DISTRIBUTION BY SOLID ANGLE

(PER IESNA TM-15-07, LUMINAIRE CLASSIFICATION SYSTEM FOR OUTDOOR LUMINAIRES)

	LUMENS	PERCENT OF FIXTURE
FORWARD LIGHT	1521.	58.2
FL (0- 30)		7.0
FM (30- 60)		26.4
FH (60- 80)		23.9
FVH (80- 90)		0.9
BACK LIGHT	1090.	41.7
BL (0- 30)		5.6
BM (30- 60)		22.9
BH (60- 80)		13.0
BVH (80- 90)		0.2
UPLIGHT	3.	0.1
UL (90-100)		0.1
UH (100-180)		0.0
TRAPPED LIGHT	0.	0.0
TOTAL FLUX	2614.	100.0

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

CANDELA TABULATION

	STREET SIDE	LATERAL ANGLE										
		0.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	90.0
	180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	175.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	165.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	155.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	145.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	135.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	125.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	115.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	105.0	0.	0.	0.	0.	1.	0.	1.	1.	1.	0.	0.
	95.0	3.	3.	3.	3.	3.	4.	4.	4.	3.	2.	2.
	90.0	7.	7.	7.	7.	7.	7.	6.	6.	5.	3.	2.
	87.5	9.	9.	9.	8.	8.	8.	8.	8.	7.	6.	4.
	85.0	11.	11.	11.	12.	14.	12.	12.	11.	10.	9.	7.
	82.5	39.	43.	77.	84.	102.	73.	88.	75.	53.	37.	28.
	80.0	68.	96.	162.	179.	197.	214.	221.	205.	193.	152.	117.
	77.5	150.	195.	262.	278.	289.	304.	360.	381.	376.	314.	261.
	75.0	287.	320.	349.	384.	402.	422.	458.	499.	560.	623.	563.
	72.5	424.	433.	458.	471.	504.	534.	591.	648.	721.	887.	896.
	70.0<<	582.	593.	593.	594.	625.	677.	721.	780.	881.	993.	1068.
V	67.5 |	719.	723.	719.	758.	767.	816.	832.	854.	885.	918.	938.
E	65.0 |	816.	820.	811.	829.	842.	869.	846.	855.	816.	785.	794.
R	62.5 |	816.	810.	827.	829.	820.	818.	803.	756.	714.	689.	703.
T	60.0 |	787.	802.	795.	806.	805.	770.	739.	698.	660.	624.	631.
I	57.5 |	789.	761.	789.	788.	766.	722.	694.	661.	609.	578.	581.
C	55.0 |	746.	743.	753.	754.	722.	699.	660.	616.	593.	539.	542.
A	52.5 |	716.	730.	736.	708.	687.	663.	632.	587.	551.	511.	500.
L	50.0 |	702.	685.	695.	676.	669.	648.	600.	569.	527.	486.	483.
	47.5 |	676.	686.	666.	655.	642.	636.	595.	543.	518.	475.	444.
A	45.0 |	656.	655.	655.	636.	624.	602.	577.	535.	476.	443.	434.
N	42.5 |	640.	644.	632.	628.	596.	571.	548.	522.	483.	433.	410.
G	40.0 |	626.	623.	629.	601.	581.	555.	524.	512.	463.	423.	397.
L	37.5 |	606.	608.	599.	588.	557.	530.	498.	474.	446.	406.	386.
E	35.0 |	589.	590.	579.	561.	537.	519.	483.	459.	418.	383.	363.
	32.5 |	573.	561.	557.	551.	525.	500.	470.	442.	407.	373.	354.
	30.0 |	551.	552.	543.	528.	512.	484.	460.	433.	396.	367.	350.
	27.5 |	532.	529.	523.	515.	493.	467.	451.	425.	397.	366.	350.
	25.0 |	510.	512.	507.	494.	479.	461.	440.	418.	395.	369.	354.
	20.0 |	476.	477.	473.	465.	453.	438.	418.	405.	390.	373.	361.
	15.0 |	446.	445.	444.	440.	427.	413.	401.	386.	378.	365.	360.
	10.0 |	419.	419.	416.	411.	403.	395.	389.	378.	367.	360.	356.
	5.0 |	387.	387.	387.	384.	381.	378.	376.	372.	368.	363.	361.
	0.0 |	362.	362.	362.	362.	362.	362.	362.	362.	362.	362.	362.

CONE OF MAXIMUM CANDELA

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

CANDELA TABULATION

	HOUSE SIDE	LATERAL ANGLE 95.0	96.0 ‖	105.0	115.0	125.0	135.0	145.0	155.0	165.0	175.0	180.0
	180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	175.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	165.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	155.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	145.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	135.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	125.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	115.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	105.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	95.0	1.	1.	1.	1.	1.	0.	0.	0.	0.	0.	0.
	90.0	2.	2.	2.	1.	1.	1.	1.	0.	0.	0.	0.
	87.5	4.	4.	3.	2.	2.	1.	1.	1.	0.	0.	0.
	85.0	6.	6.	5.	4.	3.	3.	3.	2.	0.	0.	0.
	82.5	24.	24.	27.	22.	18.	14.	8.	3.	1.	0.	0.
	80.0	110.	113.	109.	64.	40.	28.	14.	4.	1.	0.	0.
	77.5	253.	250.	218.	142.	69.	38.	17.	5.	4.	3.	3.
	75.0	502.	492.	337.	211.	118.	52.	24.	7.	6.	5.	4.
	72.5	906.	875.	534.	299.	176.	99.	53.	27.	17.	13.	13.
	70.0<<	1115.	1120.	514.	475.	278.	168.	101.	75.	60.	54.	54.
V	67.5	970.	983.	973.	731.	475.	291.	190.	145.	127.	126.	125.
E	65.0	819.	836.	895.	810.	663.	495.	351.	267.	237.	230.	227.
R	62.5	727.	744.	782.	829.	758.	640.	497.	404.	356.	330.	327.
T	60.0	631.	640.	707.	741.	766.	698.	604.	499.	468.	430.	427.
I	57.5	595.	599.	616.	672.	727.	746.	669.	596.	549.	504.	505.
C	55.0	538.	539.	555.	628.	665.	716.	721.	654.	612.	581.	587.
A	52.5	512.	526.	527.	558.	606.	658.	695.	664.	640.	654.	654.
L	50.0	466.	460.	464.	498.	556.	598.	635.	663.	698.	689.	679.
	47.5	432.	440.	430.	459.	501.	549.	585.	614.	666.	694.	701.
A	45.0	419.	411.	410.	413.	454.	494.	530.	560.	606.	672.	689.
N	42.5	393.	391.	375.	386.	407.	446.	485.	514.	579.	634.	651.
G	40.0	380.	376.	358.	355.	366.	402.	447.	481.	542.	602.	603.
L	37.5	365.	359.	335.	325.	336.	366.	409.	444.	511.	569.	569.
E	35.0	343.	339.	317.	304.	314.	342.	377.	415.	471.	529.	536.
	32.5	337.	335.	306.	293.	302.	326.	357.	388.	438.	503.	504.
	30.0	333.	331.	304.	288.	294.	319.	347.	370.	421.	474.	481.
	27.5	336.	333.	308.	290.	295.	318.	338.	362.	411.	455.	465.
	25.0	343.	341.	314.	295.	298.	316.	335.	355.	399.	441.	448.
	20.0	348.	346.	330.	311.	307.	317.	337.	357.	391.	411.	414.
	15.0	353.	352.	339.	327.	327.	329.	341.	357.	374.	381.	382.
	10.0	352.	352.	347.	342.	339.	342.	347.	352.	355.	357.	358.
	5.0	359.	359.	356.	353.	351.	350.	350.	350.	352.	352.	352.
	0.0	362.	362.	362.	362.	362.	362.	362.	362.	362.	362.	362.

‖ PLANE OF MAXIMUM CANDELA

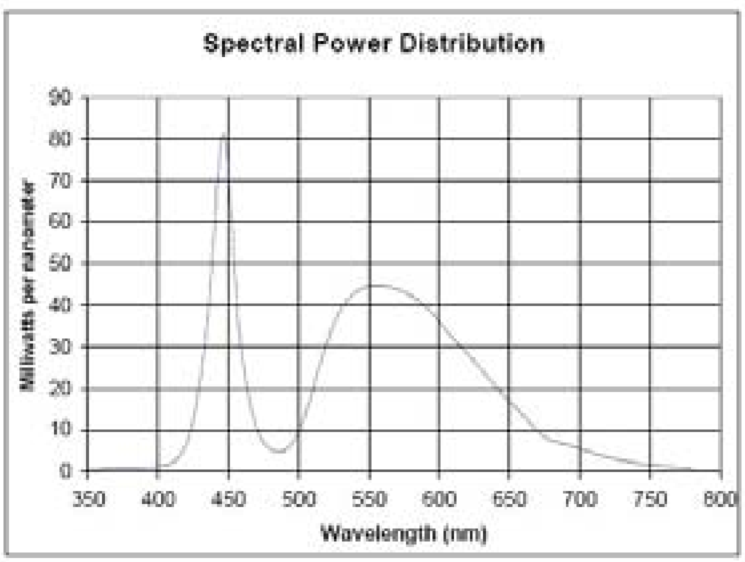
| CONE OF MAXIMUM CANDELA

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1966
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

PREPARED FOR: RDS
CATALOG NUMBER: CALIPER 08-110

RESULTS:

SPECTRORADIOMETRIC TESTING IN INTEGRATING SPHERE	
PHOTOMETRIC	
Total Integrated Flux (Lumens)	2588*
SPECTRORADIOMETRIC	
Observer	CIE 1931 2 degree
Chromaticity Ordinate x	0.3394
Chromaticity Ordinate y	0.3467
Observer	CIE 1976 2 degree
Chromaticity Ordinate u'	0.2095
Chromaticity Ordinate v'	0.4814
Correlated Color Temp CCT (K)	5210
Color Rendering Index (CRI)	68
Total Radiant Flux (milliWatts)	7908*
ELECTRICAL	
Input Voltage (Volts AC RMS)	120.0
Input Current (mA AC RMS)	310
Input Power (Watts)	36.7
EFFICACY	
Lumens/Watt	70.5



*NOTE: Proper calibration of integrating spheres for measuring total flux output of non-directional lamps will produce reliable, repeatable results within the calibration tolerances of the equipment used. However, measurement of lamps with significant self absorption and/or directional output, even when these effects are compensated for, are likely to have a greater variation in results compared to the flux output calculated from a goniophotometric exploration since these artifacts do not affect the goniophotometric results. For this test, due to the distribution of the luminaire under test, the integrating sphere was calibrated using a directional incandescent flux standard.

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

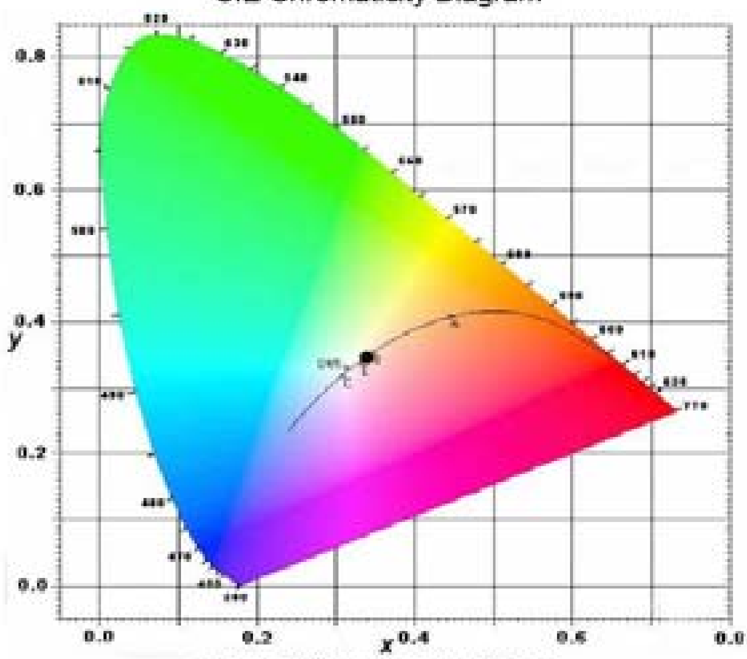
CATALOG NUMBER: CALIPER 08-110

RESULTS:

Tabulated Spectral Power Distribution

Wavelength (nm)	mWatts/nm	Wavelength (nm)	mWatts/nm
350.0	0.66095	570.0	43.96020
360.0	0.75996	580.0	42.25637
370.0	0.82395	590.0	39.75934
380.0	0.82350	600.0	36.16654
390.0	0.85965	610.0	32.02430
400.0	1.17052	620.0	28.43790
410.0	2.17137	630.0	24.61299
420.0	6.56835	640.0	20.56902
430.0	22.43037	650.0	16.87060
440.0	58.79927	660.0	13.50467
450.0	71.78030	670.0	9.82009
460.0	26.95901	680.0	7.48323
470.0	10.62614	690.0	6.56771
480.0	5.39707	700.0	5.55165
490.0	5.04055	710.0	4.42417
500.0	9.73091	720.0	3.46792
510.0	19.60676	730.0	2.70442
520.0	30.87657	740.0	2.09296
530.0	39.04257	750.0	1.62307
540.0	43.04005	760.0	1.26268
550.0	44.65242	770.0	0.97707
560.0	44.74364	780.0	0.76168

CIE Chromaticity Diagram



Temperature Measurements

At thermocouple #1 location (front top): 38.0°C
Thermocouple was placed on top of the luminaire above the center of the LED array.

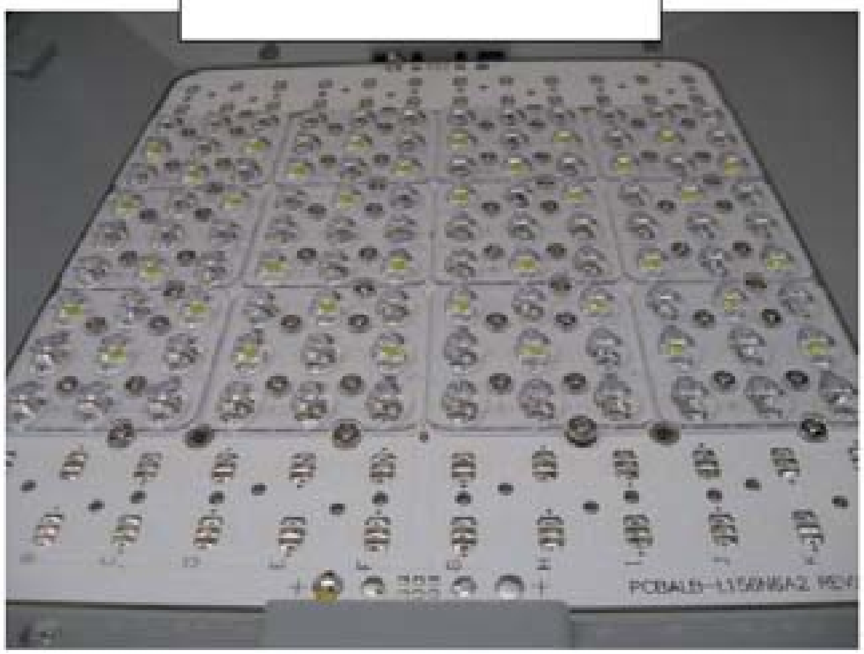
PHOTOGRAPHS

LUMINAIRE – FULL VIEW

LUMINAIRE – SIDE VIEW

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

LUMINAIRE – CLOSE-UP VIEW



ADDITIONAL NOTES: Stabilization data was recorded for approximately one hour prior to each test on each apparatus to ensure complete stabilization prior to testing. If RDS would like this data supplied, please notify ITL and we will supply the data needed.

Total time this unit was energized for all testing is 144.0 hours.

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

REPORT NUMBER: ITL61162 DATE: 10/24/08
PREPARED FOR: RDS

CATALOG NUMBER: CALIPER 08-109

LUMINAIRE: EXTRUDED GRAY PAINTED METAL HOUSING WITH MOLDED GRAY PLASTIC END CAPS AND TOP, FOUR GRAY CIRCUIT BOARDS EACH WITH 6 LEDS AND BLACK PAINTED CENTER STRIP PARALLEL WITH 0-DEGREE PLANE, ONE FORMED REFLECTOR/SHIELD NEXT TO EACH LED WITH SPECULAR INTERIOR AND BLACK PAINTED EXTERIOR, ONE CLEAR PLASTIC DROP LENS BELOW EACH CIRCUIT BOARD.

LAMP: TWENTY-FOUR WHITE LIGHT EMITTING DIODES (LEDS) EACH WITH CLEAR HEMISPHERICAL INTEGRAL LENS, TILTED 35-DEGREES FROM VERTICAL BASE-UP POSITION.

LED DRIVER: ADVANCE LEDINTA0024V41FO

GONIOMETRIC INSTRUMENTATION: ITL Moving Mirror Goniophotometer - 25.25' Test Distance
Yokogawa WT210 Digital Power Meter
Elgar CW2501 AC Power Source
Omega HH-81 Digital Thermometer with Type J thermocouples

SPECTRORADIOMETRIC INSTRUMENTATION: Yokogawa WT210 Digital Power Meter
Optronic Laboratories OL770 Spectroradiometer
1.5 meter integrating sphere
Elgar CW2501 AC Power Source

OBJECT OF TEST: Measure distribution photometry and input electrical parameters on the goniophotometer. Report candela distribution and calculated lumen output. Measure the total flux output in lumens, Correlated Color Temperature (CCT), Color Rendering Index (CRI), Chromaticity Coordinates (x/y; u'/v'), and Spectral Power Distribution (SPD) of the luminaire and input electrical parameters when operated in the integrating sphere. Measure temperature of the luminaire at one location.

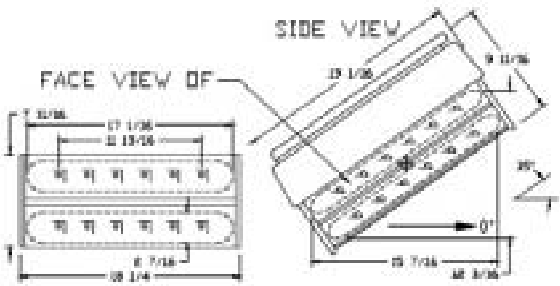
PROCEDURE: The luminaire was supplied by client with an unknown number of burn hours. The luminaire was prewarmed overnight before each test. Stabilization data was recorded to assure stabile operation (stabilization data available on request). Distribution photometry and input electrical data were measured with the unit mounted on the goniophotometer. CCT, CRI, x/y and u'/v' chromaticity coordinates, SPD, total flux, and input electrical data were measured with the unit operating in the integrating sphere. In order to measure the mean performance, twenty data sets were averaged using the Optronics OL770. A Type J thermocouple was attached to the surface of the unit to measure operating temperature (see photograph in the report for location). All data are traceable to the National Institute of Standards and Technology. All testing performed with the unit operated at 120V AC in a 25 +/-1 degree Celsius free air ambient.

Checked: *R BERGIN*
Approved: *R BEATTIE*

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1966
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

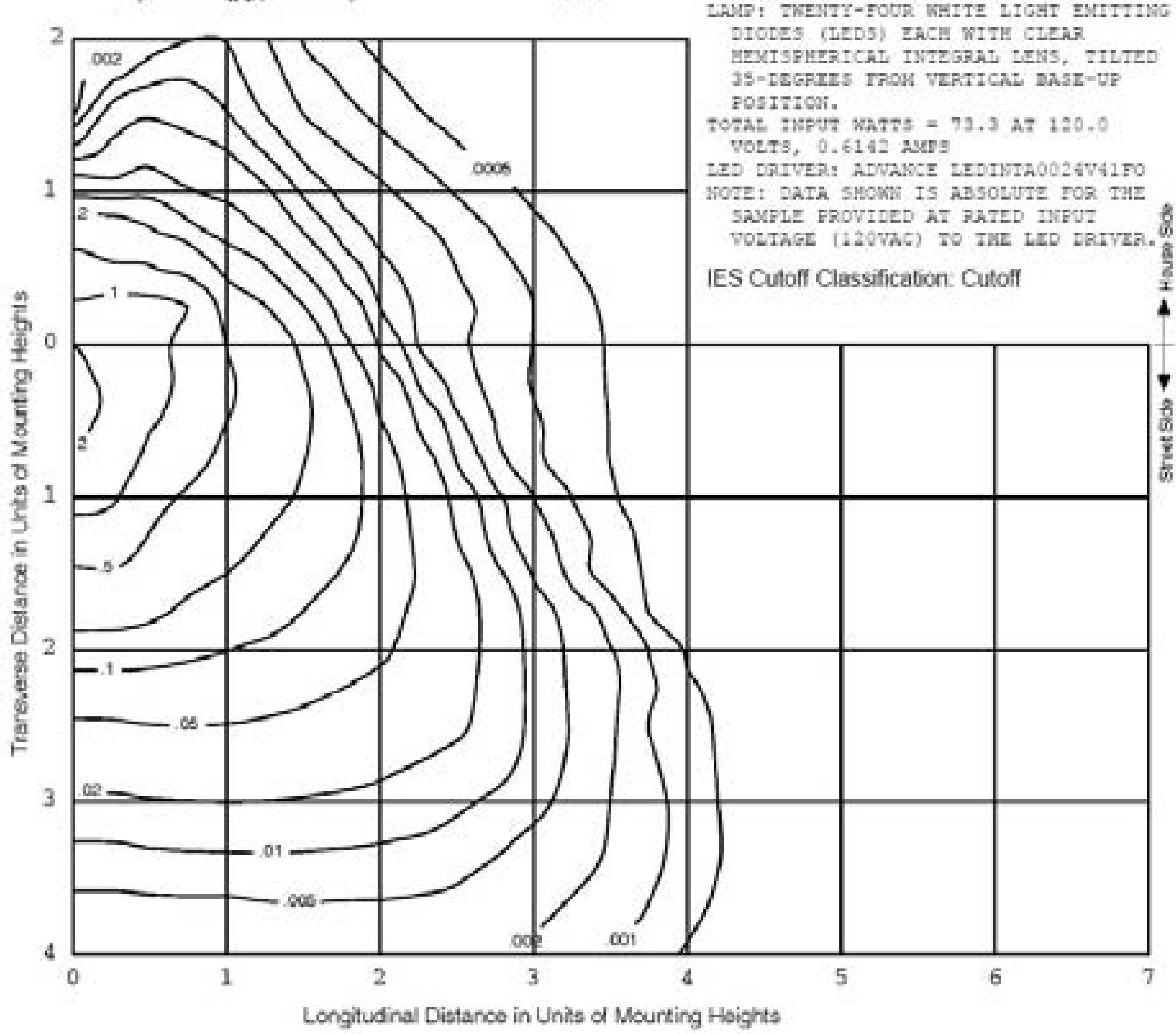
ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Values based on 25 foot mounting height.



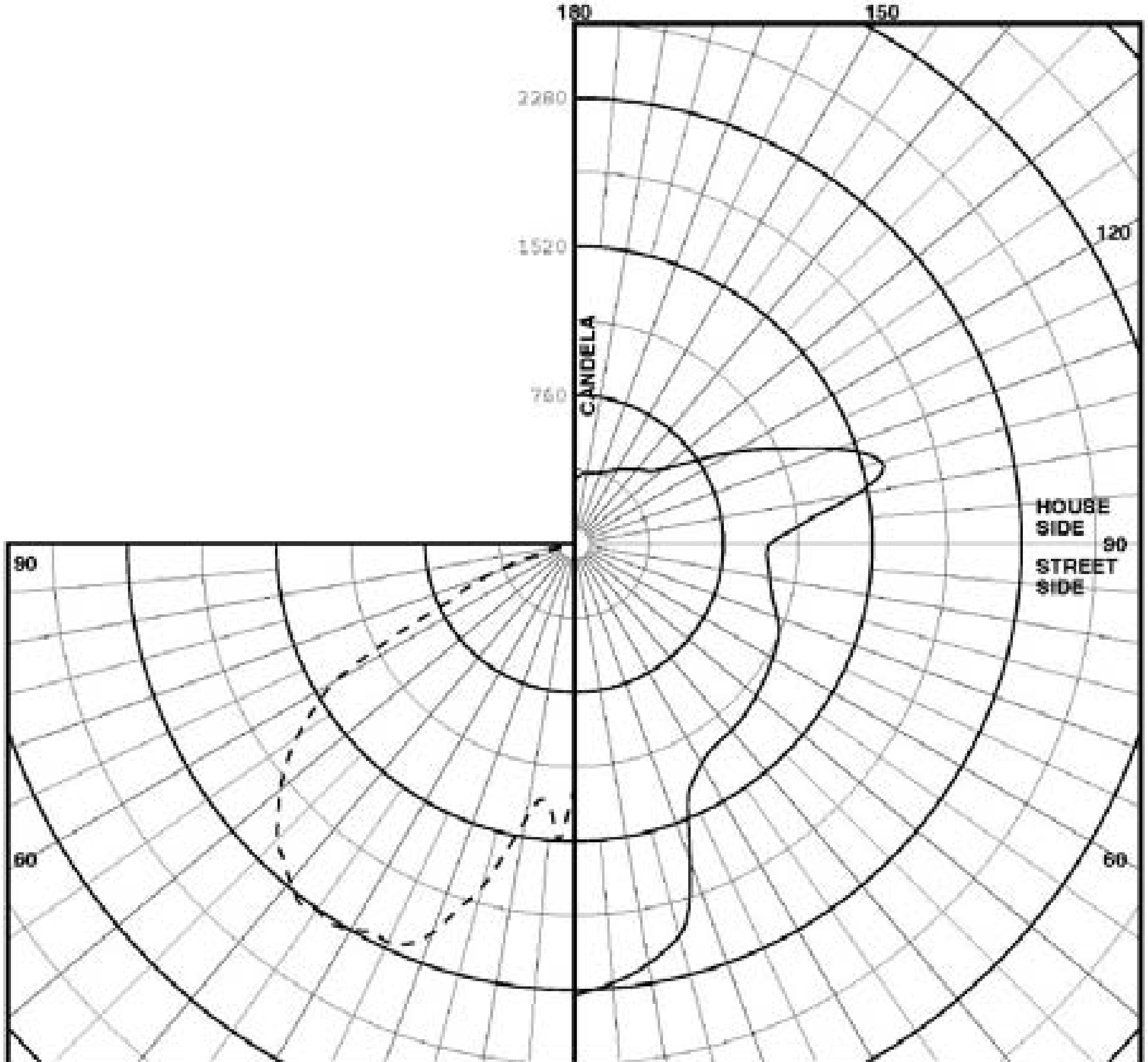
CATALOG NUMBER: CALIPER 08-109
LUMINAIRE: EXTRUDED GRAY PAINTED METAL HOUSING WITH MOLDED GRAY PLASTIC END CAPS AND TOP, FOUR GRAY CIRCUIT BOARDS EACH WITH 6 LEDS AND BLACK PAINTED CENTER STRIP PARALLEL WITH 0-DEGREE PLANE, ONE FORMED REFLECTOR/ SHIELD NEXT TO EACH LED WITH SPECULAR INTERIOR AND BLACK PAINTED EXTERIOR, ONE CLEAR PLASTIC DROP LENS BELOW EACH CIRCUIT BOARD.
LAMP: TWENTY-FOUR WHITE LIGHT EMITTING DIODES (LEDS) EACH WITH CLEAR HEMISPHERICAL INTEGRAL LENS, TILTED 35-DEGREES FROM VERTICAL BASE-UP POSITION.
TOTAL INPUT WATTS = 73.3 AT 120.0 VOLTS, 0.6142 AMPS
LED DRIVER: ADVANCE LEDINTA0024V41FO
NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT VOLTAGE (120VAC) TO THE LED DRIVER.

IES Cutoff Classification: Cutoff



INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

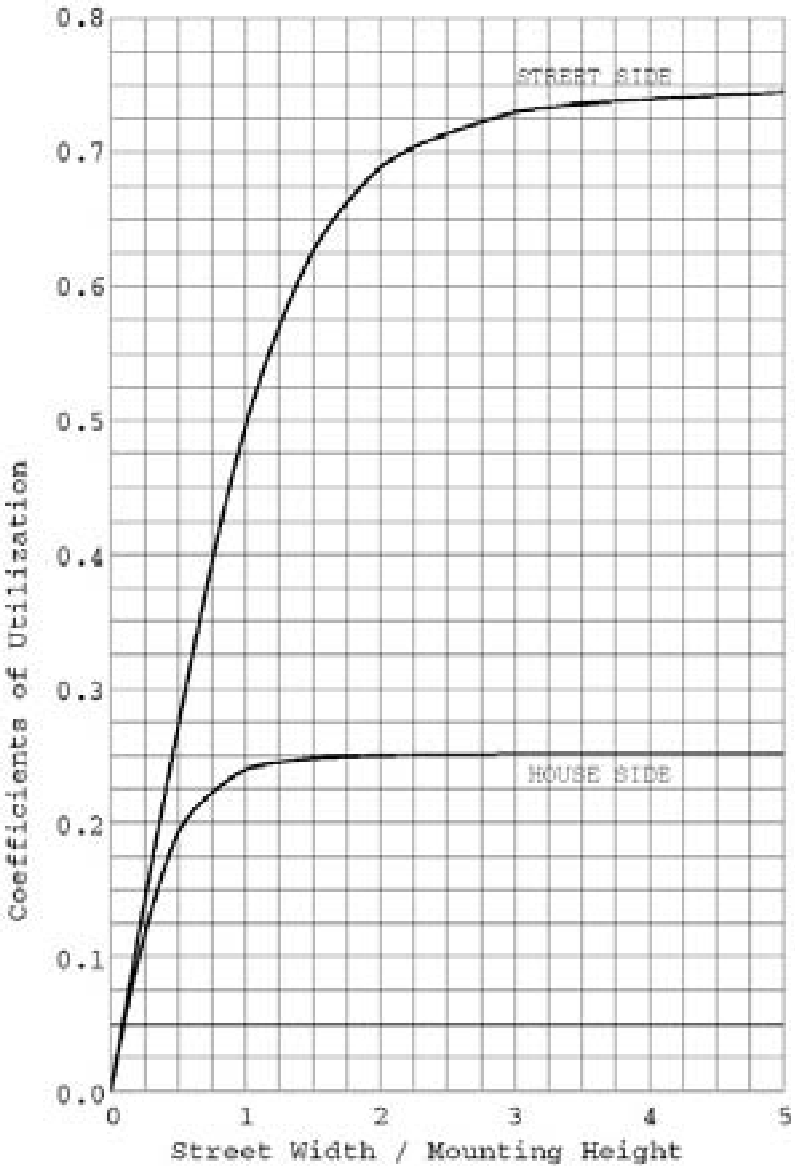
MAXIMUM PLANE AND MAXIMUM CONE PLOTS OF CANDELA



VERTICAL PLANE THROUGH MAXIMUM CANDELA
37.5 (Degrees Vertical)

CONE THROUGH MAXIMUM CANDELA
0.0 (Degrees Horizontal) = 2308

COEFFICIENTS OF UTILIZATION AND FLUX DISTRIBUTION



	LUMENS	PERCENT OF FIXTURE
DOWNWARD STREET SIDE	2564	74.7
DOWNWARD HOUSE SIDE	863	25.1
DOWNWARD TOTAL	3427	99.8
UPWARD STREET SIDE	5	0.1
UPWARD HOUSE SIDE	2	0.1
UPWARD TOTAL	6	0.2
TOTAL FLUX	3434	100.0

EFFICACY = 46.85 Lm/W

ALL CANDELA AND LUMENS IN THIS REPORT ARE BASED ON ABSOLUTE PHOTOMETRY.
THE COEFFICIENT OF UTILIZATION VALUES ARE BASED ON THE TOTAL ABSOLUTE LUMEN OUTPUT OF THIS LUMINAIRE SAMPLE.

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1956
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

FLUX DISTRIBUTION BY SOLID ANGLE

(PER IESNA TM-15-07, LUMINAIRE CLASSIFICATION SYSTEM FOR OUTDOOR LUMINAIRES)

	LUMENS	PERCENT OF FIXTURE
FORWARD LIGHT	2570.	74.8
FL (0- 30)		16.6
FM (30- 60)		43.4
FH (60- 80)		14.6
FVH (80- 90)		0.2
BACK LIGHT	858.	25.0
BL (0- 30)		10.9
BM (30- 60)		13.5
BH (60- 80)		0.6
BVH (80- 90)		0.0
UPLIGHT	6.	0.2
UL (90-100)		0.1
UH (100-180)		0.1
TRAPPED LIGHT	0.	0.0
TOTAL FLUX	3434.	100.0

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1986
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

CANDELA TABULATION

	STREET SIDE	LATERAL ANGLE 0.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	90.0
	180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	175.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	165.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	155.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	145.0	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	0.
	135.0	0.	0.	0.	0.	0.	0.	1.	1.	2.	1.	1.
	125.0	0.	0.	0.	0.	0.	0.	1.	1.	2.	2.	1.
	115.0	0.	0.	0.	0.	1.	1.	1.	2.	2.	2.	2.
	105.0	2.	2.	2.	2.	1.	2.	2.	3.	3.	3.	3.
	95.0	4.	4.	4.	4.	4.	3.	4.	4.	4.	3.	3.
	90.0	6.	6.	6.	6.	6.	5.	4.	5.	5.	4.	4.
	87.5	7.	7.	7.	8.	8.	7.	6.	5.	5.	5.	4.
	85.0	9.	9.	10.	15.	17.	16.	10.	7.	5.	5.	4.
	82.5	16.	17.	23.	28.	29.	30.	15.	9.	6.	5.	5.
	80.0	34.	36.	41.	44.	54.	52.	25.	13.	8.	6.	5.
	77.5	61.	61.	66.	92.	222.	198.	65.	17.	12.	9.	7.
	75.0	120.	121.	165.	306.	495.	613.	244.	29.	15.	13.	12.
	72.5	275.	283.	398.	569.	756.	876.	504.	87.	21.	17.	17.
	70.0	451.	465.	621.	762.	881.	937.	754.	259.	41.	22.	23.
V	67.5	596.	604.	750.	860.	956.	980.	914.	506.	140.	33.	29.
E	65.0	713.	741.	845.	946.	1031.	989.	960.	734.	319.	94.	53.
R	62.5	1071.	1088.	1079.	1050.	1076.	1002.	1004.	877.	575.	241.	154.
T	60.0	1409.	1437.	1532.	1115.	1102.	1035.	1010.	925.	760.	470.	329.
I	57.5	1573.	1624.	1848.	1163.	1128.	1083.	1019.	957.	879.	672.	549.
C	55.0	1727.	1745.	1922.	1202.	1143.	1119.	1028.	1009.	924.	794.	688.
A	52.5	1851.	1848.	1933.	1210.	1162.	1133.	1046.	1035.	948.	842.	769.
L	50.0	1956.	1943.	1936.	1257.	1185.	1155.	1077.	1042.	981.	875.	809.
	47.5	2046.	2010.	1978.	1281.	1202.	1172.	1138.	1051.	1022.	911.	840.
A	45.0	2145.	2104.	2020.	1318.	1213.	1198.	1169.	1048.	1026.	941.	870.
N	42.5	2194.	2165.	2044.	1347.	1245.	1204.	1188.	1088.	1035.	973.	909.
G	40.0	2254.	2233.	2058.	1376.	1257.	1209.	1183.	1134.	1024.	986.	971.
L	37.5<<	2308.	2254.	2074.	1389.	1257.	1232.	1189.	1147.	1045.	989.	1000.
E	35.0	2286.	2277.	2051.	1419.	1264.	1231.	1206.	1140.	1103.	997.	997.
	32.5	2305.	2282.	2043.	1431.	1282.	1247.	1204.	1150.	1102.	1054.	1032.
	30.0	2277.	2268.	2001.	1459.	1308.	1256.	1203.	1174.	1098.	1062.	1064.
	27.5	2237.	2249.	1950.	1473.	1329.	1241.	1202.	1167.	1123.	1064.	1049.
	25.0	2249.	2215.	1893.	1489.	1306.	1248.	1185.	1162.	1110.	1069.	1051.
	20.0	2119.	2052.	1740.	1450.	1290.	1226.	1168.	1111.	1089.	1062.	1053.
	15.0	1818.	1783.	1580.	1375.	1260.	1183.	1124.	1091.	1066.	1058.	1043.
	10.0	1435.	1440.	1389.	1335.	1291.	1258.	1178.	1106.	1071.	1048.	1046.
	5.0	1369.	1382.	1421.	1438.	1449.	1421.	1355.	1284.	1212.	1157.	1139.
	0.0	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.

|| PLANE OF MAXIMUM CANDELA (0.0 lateral angle column)

CONE OF MAXIMUM CANDELA (vertical angles 35.0 to 0.0)

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

CANDELA TABULATION

	HOUSE SIDE	LATERAL ANGLE									
		95.0	105.0	115.0	125.0	135.0	145.0	155.0	165.0	175.0	180.0
	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	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	125.0	1.	1.	1.	0.	0.	0.	0.	0.	0.	0.
	115.0	2.	1.	1.	1.	0.	0.	0.	0.	0.	0.
	105.0	2.	2.	2.	2.	0.	0.	0.	0.	0.	0.
	95.0	3.	2.	2.	2.	1.	0.	0.	0.	0.	0.
	90.0	3.	3.	3.	3.	1.	1.	0.	0.	0.	0.
	87.5	4.	3.	3.	3.	2.	2.	0.	0.	0.	0.
	85.0	4.	4.	4.	3.	2.	3.	0.	0.	0.	0.
	82.5	4.	3.	4.	3.	2.	2.	1.	0.	0.	0.
	80.0	5.	4.	4.	3.	3.	2.	1.	0.	0.	0.
	77.5	6.	4.	4.	4.	3.	2.	3.	1.	1.	1.
	75.0	10.	6.	4.	4.	3.	3.	5.	2.	4.	4.
	72.5	17.	11.	6.	5.	5.	5.	8.	4.	10.	11.
	70.0	25.	18.	10.	7.	7.	8.	17.	7.	11.	11.
V	67.5	32.	27.	17.	11.	11.	13.	34.	11.	14.	16.
E	65.0	44.	37.	25.	18.	15.	22.	57.	17.	14.	19.
R	62.5	101.	54.	37.	29.	26.	42.	66.	28.	8.	10.
T	60.0	222.	115.	67.	55.	58.	65.	64.	53.	9.	5.
I	57.5	418.	231.	131.	104.	102.	91.	72.	83.	14.	4.
C	55.0	578.	368.	211.	157.	133.	106.	81.	106.	20.	10.
A	52.5	660.	452.	271.	186.	148.	117.	113.	86.	31.	22.
L	50.0	718.	496.	306.	207.	168.	145.	152.	72.	45.	44.
	47.5	748.	551.	344.	234.	192.	213.	169.	82.	74.	77.
A	45.0	788.	602.	403.	308.	299.	278.	207.	138.	137.	138.
N	42.5	836.	686.	562.	496.	392.	312.	262.	245.	218.	204.
G	40.0	1010.	1007.	927.	647.	444.	381.	342.	340.	295.	259.
L	37.5<<	1168.	1620.	1149.	734.	527.	464.	409.	372.	354.	329.
E	35.0 |	1137.	1691.	1159.	814.	617.	516.	447.	382.	395.	395.
	32.5 |	1094.	1423.	1100.	840.	645.	544.	442.	420.	450.	473.
	30.0 |	1109.	1408.	1145.	917.	721.	571.	485.	458.	519.	530.
	27.5 |	1087.	1349.	1174.	944.	734.	609.	529.	515.	597.	598.
	25.0 |	1053.	1237.	1159.	972.	771.	675.	575.	592.	669.	669.
	20.0 |	1042.	1124.	1161.	1061.	906.	783.	744.	713.	669.	661.
	15.0 |	1022.	1022.	1078.	1113.	1003.	879.	793.	738.	716.	712.
	10.0 |	1031.	1015.	1018.	1005.	948.	860.	797.	764.	745.	738.
	5.0 |	1116.	1057.	1012.	953.	886.	819.	770.	754.	728.	736.
	0.0 |	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.	1239.

CONE OF MAXIMUM CANDELA

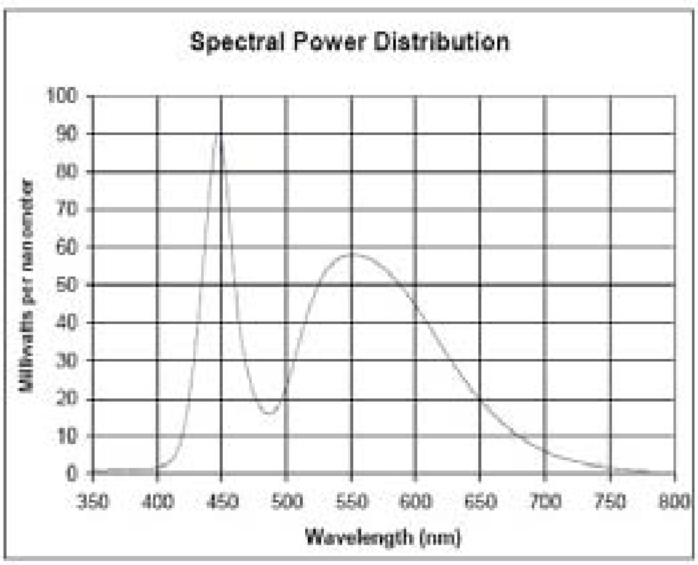
itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955
INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

PREPARED FOR: RDS

CATALOG NUMBER: CALIPER 08-109

RESULTS:

SPECTRORADIOMETRIC TESTING IN INTEGRATING SPHERE	
PHOTOMETRIC	
Total Integrated Flux (Lumens)	3440*
SPECTRORADIOMETRIC	
Observer	CIE 1931 2 degree
Chromaticity Ordinate x	0.3204
Chromaticity Ordinate y	0.3405
Observer	CIE 1976 2 degree
Chromaticity Ordinate u'	0.1988
Chromaticity Ordinate v'	0.4755
Correlated Color Temp CCT (K)	6052
Color Rendering Index (CRI)	72
Total Radiant Flux (milliWatts)	10793*
ELECTRICAL	
Input Voltage (Volts AC RMS)	120.0
Input Current (mA AC RMS)	614
Input Power (Watts)	73.3
EFFICACY	
Lumens/Watt	46.9



*NOTE: Proper calibration of integrating spheres for measuring total flux output of non-directional lamps will produce reliable, repeatable results within the calibration tolerances of the equipment used. However, measurement of lamps with significant self absorption and/or directional output, even when these effects are compensated for, are likely to have a greater variation in results compared to the flux output calculated from a goniophotometric exploration since these artifacts do not affect the goniophotometric results. For this test, due to the distribution of the luminaire under test, the integrating sphere was calibrated using a directional incandescent flux standard.

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
THE LIGHT CENTER OF THE INDUSTRY SINCE 1966
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

CATALOG NUMBER: CALIPER 08-109

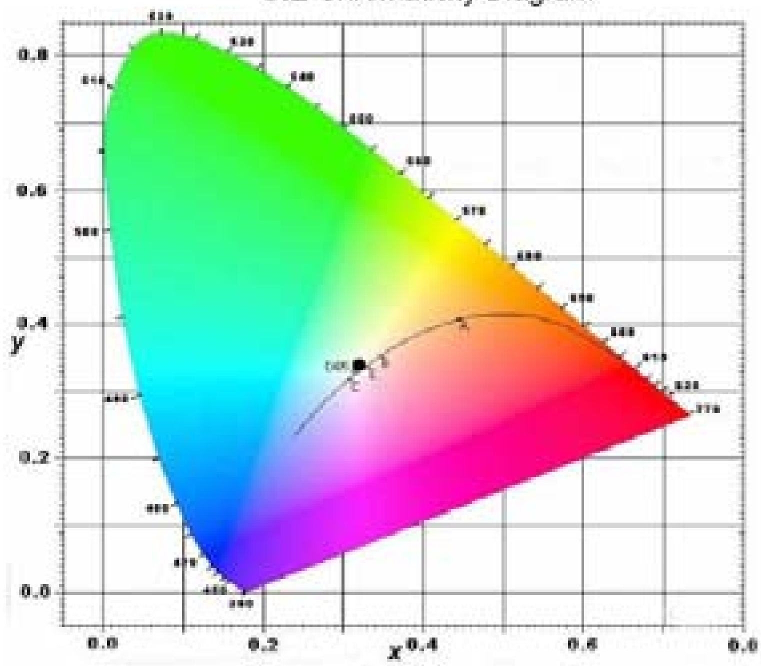
RESULTS:

Tabulated Spectral Power Distribution

Wavelength (nm)	mWatts/nm	Wavelength (nm)	mWatts/nm
350.0	0.92160	570.0	55.87169
360.0	1.06275	580.0	53.01552
370.0	1.22357	590.0	49.19236
380.0	1.26145	600.0	44.53839
390.0	1.34887	610.0	39.35009
400.0	1.78779	620.0	33.94053
410.0	3.40454	630.0	28.75201
420.0	11.15958	640.0	23.92835
430.0	35.34396	650.0	19.57859
440.0	72.79235	660.0	15.86772
450.0	87.78937	670.0	12.69664
460.0	50.54042	680.0	10.04564
470.0	26.98758	690.0	7.88161
480.0	17.46034	700.0	6.15240
490.0	16.47233	710.0	4.78870
500.0	23.39528	720.0	3.69996
510.0	35.10289	730.0	2.86234
520.0	46.24138	740.0	2.20851
530.0	53.71854	750.0	1.70432
540.0	57.02065	760.0	1.32504
550.0	58.12224	770.0	1.02023
560.0	57.58650	780.0	0.79741

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

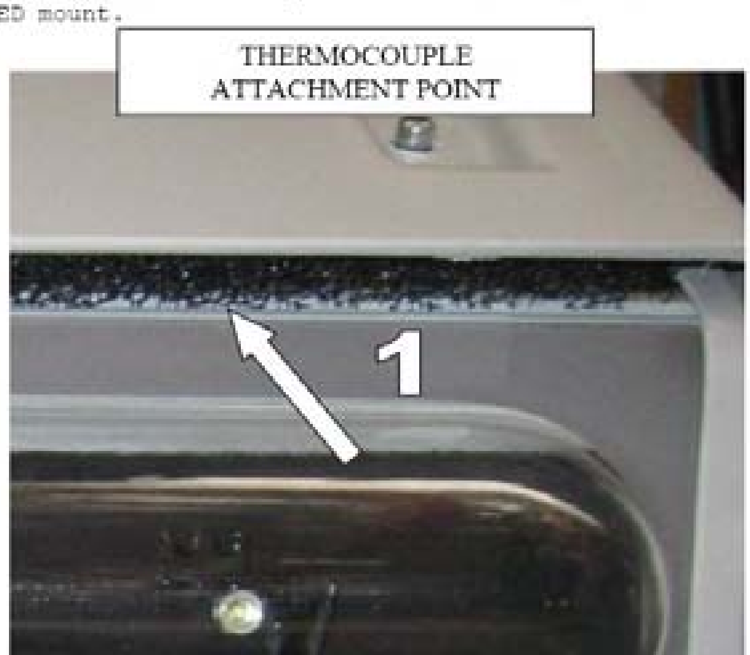
CIE Chromaticity Diagram



Temperature Measurements

At thermocouple #1 location (front top): 39.7°C

Thermocouple was placed on warmest protrusion of heat sink from the enclosure, beside the top left LED mount.



PHOTOGRAPHS

LUMINAIRE – FRONT VIEW

LUMINAIRE – FULL VIEW

LUMINAIRE – BOTTOM VIEW

ADDITIONAL NOTES: Stabilization data was recorded for approximately one hour prior to each test on each apparatus to ensure complete stabilization prior to testing. If RDS would like this data supplied, please notify ITL and we will supply the data needed

Total time this unit was energized for all testing is 87.5 hours.