GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light-Emitting Diode (LED) Street Lighting

Host Site: Lija Loop, Portland, Oregon

**Final Report prepared in support of the
U.S. DOE Solid State Lighting
Technology Demonstration GATEWAY Program**

Study Participants:
Pacific Northwest National Laboratory
U.S. Department of Energy
City of Portland
Leotek
Energy Trust of Oregon, Inc.

November 2009

Prepared for the U.S. Department of Energy by
Pacific Northwest National Laboratory

PNNL- 18947

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Pacific Northwest National Laboratory
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Preface

This document is a report of observations and results obtained from a lighting demonstration project conducted under the U.S. Department of Energy (DOE) GATEWAY Demonstration Program. The program supports demonstrations of high-performance solid-state lighting (SSL) products in order to develop empirical data and experience with in-the-field applications of this advanced lighting technology. The DOE GATEWAY Demonstration Program focuses on providing a source of independent, third-party data for use in decision-making by lighting users and professionals; this data should be considered in combination with other information relevant to the particular site and application under examination. Each GATEWAY Demonstration compares one SSL product against the incumbent technology used in that location. Depending on available information and circumstances, the SSL product may also be compared to alternate lighting technologies. Though products demonstrated in the GATEWAY program have been prescreened and tested to verify their actual performance, DOE does not endorse any commercial product or in any way guarantee that users will achieve the same results through use of these products.

Executive Summary

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a residential street lighting application, under the U.S. Department of Energy GATEWAY Solid-State Lighting Technology Demonstration Program. In this project, eight 100W (nominal) high-pressure sodium cobra head fixtures were replaced with a like number of LED street light luminaires manufactured by Leotek, Inc.

The Leotek product achieved an estimated payback in the Lija Loop installation of about 20 years for replacement scenarios and a much shorter 7.6 years for new installations. Much of the associated energy savings (55%) supporting these payback periods, however, were achieved by reducing average horizontal photopic illuminance a similar amount (53%).

Examined from a different perspective, the measured performance suggests that the Leotek product is at approximate parity with the HPS cobra head in terms of average delivered photopic illumination for a given power consumption. HPS comprises the second most efficacious street lighting technology available, exceeded only by low pressure sodium (LPS). LPS technology is not considered suitable for most street lighting applications due to its monochromatic spectral output and poor color rendering ability; therefore, this LED product is performing at an efficiency level comparable to its primary competition in this application.[1]

In its roadway lighting design calculations, the City of Portland uses end-of-life lamp lumens together with an appropriate luminaire maintenance factor. The selected sample (Model No. SL-150W1M3-FX) is at present only just meeting the minimum illumination levels (greater than or equal to an average horizontal illuminance of 0.2 fc) required by City of Portland lighting standards when the required light loss factors are applied, leaving no room for error or contingency. The model selected for Lija Loop may therefore be slightly undersized, at least in terms of using it elsewhere in the city for similar applications. Installing the next higher-output model (the SL-175 or its current equivalent) would be a more conservative choice although it would incur slightly higher power consumption and corresponding costs, along with a corresponding increase in the simple payback period. The higher output unit has been neither tested nor priced in this study.

In terms of user acceptance, ten out of eleven respondents in the resident survey either noticed no difference or thought the lighting quality was improved following the LED substitution. The resident responses to the survey were positive overall.

As of publication, these luminaires have operated for approximately one year without incident. Illumination levels on Lija Loop will be periodically measured and documented over the near term to contribute to the growing body of field experience with LED products.

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[1] Though some amount of energy savings could also be achieved by reducing wattage and corresponding illumination of the HPS system, the savings would be less because HPS efficacy drops as lamp wattage is reduced.

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1.0 Introduction

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a residential street lighting application conducted by Pacific Northwest National Laboratory (PNNL) in Portland, Oregon, September-December 2008. The project was supported under the U.S. Department of Energy (DOE) Solid-State Lighting GATEWAY Demonstration Program. Other participants in the demonstration project included Energy Trust of Oregon, Inc. (ETO), Leotek Inc., the Bonneville Power Administration (BPA) and Pacificorp, and the City of Portland. PNNL conducted the measurements and analysis of the results. PNNL manages a number of related demonstrations for DOE and represents their perspective in the conduct of the work.

DOE supports such demonstration projects to develop real-world experience and data with SSL products in general illumination applications. DOE's approach is to carefully match applications with suitable products and form teams to carry out the needed project work. Other project reports and related information are available via DOE's SSL website at www.ssl.energy.gov/demos.

Leotek manufactures an LED street lighting product and approached PNNL and the City with a proposal to investigate LED street lighting on a Portland neighborhood street. ETO also expressed an interest in participation in the project, in keeping with its mission of encouraging investment in efficient technologies and renewable resources in Oregon, as did Pacificorp and BPA.

The location selected was NE Lija Loop, a small roughly circular street containing approximately 30 homes located near the Columbia River in NE Portland. NE Lija Loop was selected because the eight street lights around the loop are owned and operated by the City, and because its geographic location effectively isolates it from other lighting sources.

In addition to power savings, advantages of the LED luminaires include the improved uniformity of illuminance, broad spectrum and high color rendering index [CRI], along with the much greater lifetime claimed by the manufacturer.

The luminaires were purchased by ETO and installed by the City during October 2008.

2.0 Methodology

2.1 Site Description

Lija Loop is located in the NE section of Portland, OR. The road consists of a closed loop only accessible from NE Gertz Road. Houses are located on both the inside and outside of the loop as shown in Figure 2.1.1. The luminaires are mounted 30' above finished grade (AFG). A total of eight street lights provide illumination for Lija Loop, with the typical spacing between the luminaires ranging between 125' to 150' (see Figure 2.2).

Figure 2.1. Lija Loop (Aerial View)

Figure 2.2. Original 100W HPS Luminaires

Preliminary modeling of the loop was conducted to help size the replacement luminaires. Street layout, pole height and spacing were all considered in originally estimating the luminaire output needed to match IESNA guidelines for minimum recommended illumination for residential street applications. Following installation, the City provided their own street lighting standards (see Appendix D) for the evaluation and those became the focus of all subsequent comparisons.

2.2 Typical Luminaires

Portland uses the 100–watt high-pressure sodium (HPS) GE Lighting Systems M-250A2 POWR/DOOR® cobra head luminaire, with type III medium distribution and flat lens (classified as IES Full Cutoff). Typical 100W HPS lamps have 9500 initial lumens, a CCT of 2100 K, and a CRI of 22. The City uses magnetic-regulator (Mag-Reg) type HPS ballasts with a power draw of 120W, and the Lija Loop fixtures each have an added internal capacitor to bring the power factor to 1.0 (see Figure 2.3). With a fixture efficiency of 71%, the overall luminaire efficacy of the GE product is 56 LPW.

2.3 New Luminaires

The Leotek Model No. SL-150W1M3-FX with a Type III medium distribution was selected as the replacement luminaire. Laboratory test results for a slightly lower power unit (SL-125W1M3-FX, measured consumption of 37 watts, see Figure 2.4) were used to characterize the efficacy, color temperature, and power factor of the subject luminaire. Both units employ the same LED chips (in different quantities) and the same power supply. The apparent input power of the installed luminaire was measured at 54VA, translating to a real power level of about 53W using the lab-tested power factor value of 0.987. The luminaire produced about 3780 lumens, yielding an overall luminaire efficacy of 71 lumens per watt (LPW). The correlated color temperature (CCT) of the luminaire was 5210 K (x = 0.3394, y = 0.3467) with a CRI of 68.

Figure 2.3. HPS Cobra Head Fixture with Ballast Tray Removed to Expose the Capacitor (Cylinder)

Figure 2.4. Tested Leotek Luminaire

Luminaires should be carefully selected to efficiently illuminate the street while minimizing glare and wasted or obtrusive light. In support of the ENERGY STAR® program for SSL, DOE has developed a new metric to evaluate the performance of area and roadway luminaires independent of the context of a specific project. Fitted Target Efficacy (FTE) differs from luminaire efficacy by distinguishing between useful lumens and those that might cause glare, wasted light, or light trespass. FTE draws on two basic assumptions in evaluating luminaires: that a rectangular distribution pattern minimizes overlap and spillover for most roadway and area lighting applications, and that the area covered by a luminaire can be defined as the area illuminated to IES-recommended uniformity ratios. A more thorough discussion of FTE is included in Appendix F.

Figure 2.5 compares the GE Type III cobra head and the Leotek LED product. Both luminaires cover a rectangle extending 2.5-mounting heights to either side and 2.0-mounting heights forward, and both produce a substantial amount of backlight, but the Leotek product generally distributes its light over a larger area. As a result, even though the Leotek product has a higher FTE, it would be expected to direct a larger proportion of its light beyond the street in this application.

In the Lija Loop installation the illumination of yards and sidewalks was appreciated in the overall comments received from residents (see Section 4.0). This would not necessarily be the case in all neighborhoods, however, as it potentially creates issues with light trespass.

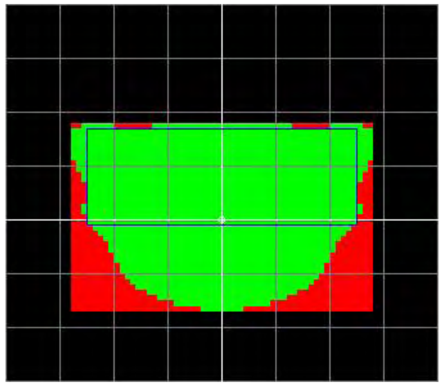
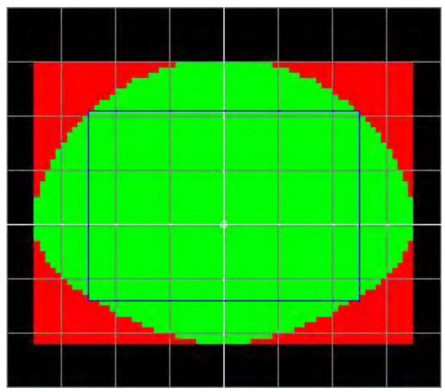
Product	Uniform Pool & Rectangular Target	FTE (lm/W)
GE Type III Medium Full Cutoff Flat Glass Lens 150W HPS Cobrahead M2AC15S***GMC3* GE177285.IES		38
Leotek Type III Medium SL-125W1M3-FX ITL61163.IES		49

Figure 2.5. Fitted Target Efficacies for the HPS and LED Streetlight Products

2.4 Installation

Prior to their replacement, the existing cobra heads were cleaned, relamped and operated for two weeks before baseline illumination and power measurements were taken. Following this period the HPS luminaires were replaced with the LED luminaires (Figure 2.6); power and illumination measurements were repeated. Figure 2.7 shows both the LED and HPS luminaires.

The eight LED luminaires were installed in a total of 4 hours (30 minutes per luminaire) with no notable issues encountered.

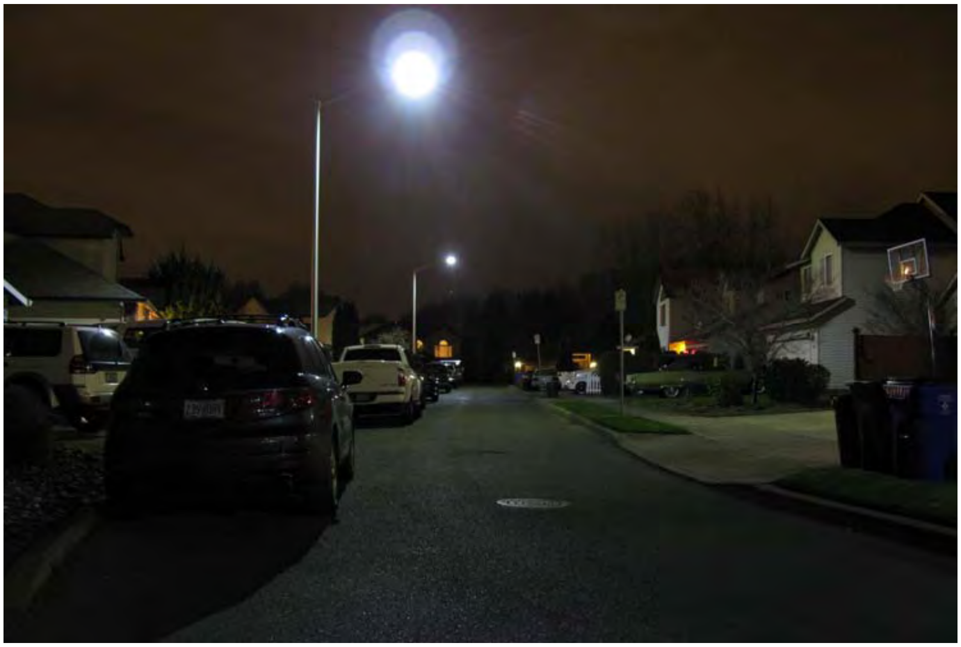


Figure 2.6. Lija Loop LED Installation

Figure 2.7. Visual Comparison between LED and HPS at Entrance to Lija Loop

2.5 Power and Energy

Power measurements for both the HPS and LED luminaires were taken at the same point in the circuit, upstream of the ballast/power supply at the base of each pole (Table 2.1). Each luminaire (either HPS or LED) is controlled via a photocell integral to the luminaire. Operating hours were assumed to average 12 hours per day because of the photocell (turning on the light during twilight and turning off after dusk). Table 2.1 lists the power measurements for Lija Loop and the calculated energy consumption of the two lighting systems.

Table 2.1. Power Measurements and Energy Calculation

Qty	Source Type	Luminaire Power (W)	Total Power (W)	Hours	Energy (kWh)	Reduction
8	HPS	120	960	4380	4205	N/A
8	LED	53	426	4380	1866	55%

2.6 Illuminance

Illuminance for the HPS installation was measured after 9:00 pm on 10.16.08 along an approximately 150' x 20' area marked out in thirty 10' x 10' measurement grids comprising 48 measurement points (Figure 2.8). The temperature was 62°F and the weather conditions were dry, clear, and just past full moon. A direct view of the moon was mostly blocked by nearby houses and trees, and most porch lights were on in the neighborhood.

Illuminance was measured for the LED installation along the same 10' x 10' measurement grid, on 11.6.08 after 8:00 pm. The temperature was 57°F with rainy conditions and wet street surfaces; most leaves had fallen off of the surrounding trees. No moon was present and porch lights were mostly on. Project analysts concluded the change in background conditions relative to those observed during HPS illumination measurements had no significant effect on the overall illumination measurements. The values obtained for both systems are listed in Table 2.2.

Table 2.2. Lija Loop Illuminance Values

	HPS Values	LED Values
Max	2.2 fc	0.5 fc
Min	0.2 fc	0.1 fc
Average	0.8 fc	0.3 fc
Max/Min	9.8	5.4
Avg/Min	3.4	2.8
Std. Dev	0.6 fc	0.1 fc
Coefficient of Variation	0.8	0.5

The maximum illuminance of the HPS system was nearly four-and-a-half times that of the LED system, yielding a higher average and a higher (worse) uniformity ratio for the HPS system.

The table indicates that the LED system produced minimum and average illuminance values roughly half (53%) of those produced by the HPS system (see Figure 2.7 below). In addition, the "hot spots" corresponding to the notably higher maximum illuminance values of the HPS system are clearly visible in the figures. The actual measured values are included in Appendix C. Note that at no point under either luminaire type was a "zero" value measured; the measured minimum in both cases was 0.1 fc.

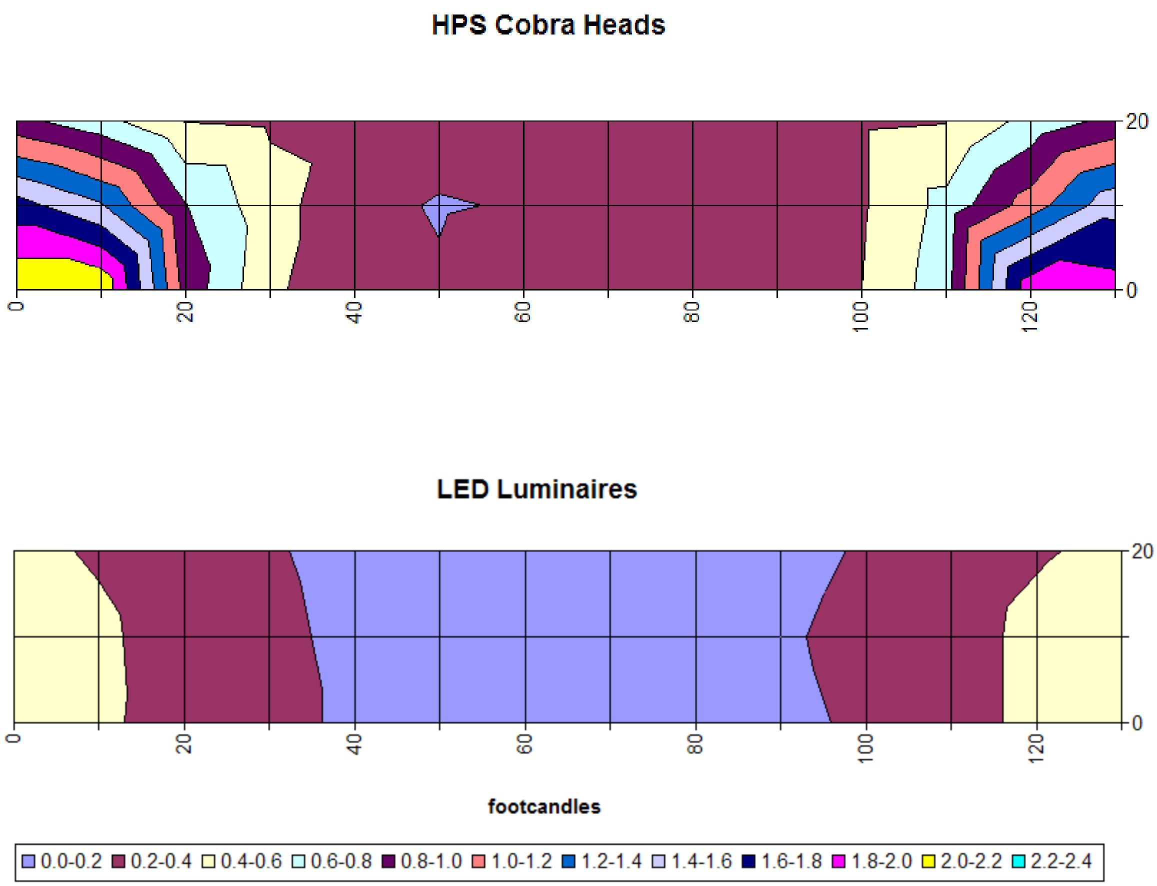


Figure 2.8. Comparison of HPS and LED Illumination Grid on Lija Loop. Each cell is 10 feet by 10 feet with measurements taken at each corner point. Luminaires are located at points "0" and "130." Parked cars at upper left prevented measurement in both cases so these values are simulated from symmetrical points measured on the right luminaire; see Appendix C.

Table 2.2 lists the Coefficient of Variation (CV) for each set of measured illuminance values; the CV is the ratio of the standard deviation to the mean and serves to de-emphasize extreme values that occur only in a few locations. The higher CV of the HPS measurements (0.8 vs. 0.5) is another indication of higher variation (i.e., less uniformity) compared to the LED system.

The City of Portland's lighting standards were established in the early 1980s (see Appendix D). Lija Loop falls under Class 6 (local service) per Portland's Street Lighting Standards, meaning that the average maintained illuminance should be equal to or greater than 0.2 fc on the horizontal surface. Portland requires that design calculations use end-of-life lamp lumens (Lamp Lumen Depreciation) and the appropriate luminaire maintenance factor (Luminaire Dirt Depreciation). LED end of life is typically defined as when light output reaches 70% of the initial value (L70). As the average illuminance measured under the LED installation was 0.3 fc, the LED system meets

Portland's requirements [0.3 x 0.70 (end-of-life output) x 0.90 (Luminaire Dirt Depreciation) = 0.2 fc average]. The City has no requirements for uniformity of illuminance.

3.0 Economics

3.1 Maintenance and Energy Schedules

The City of Portland operates streetlights falling under two rate schedules: "Option B" fixtures are those for which the City pays a monthly combined maintenance and power fee to the utility, PGE. "Option C" fixtures are those for which the City pays only a monthly power fee; the City does its own maintenance on these lights. ("Option A" fixtures would be owned, operated, and maintained by a third party; there are no Option A fixtures within city limits.) Table 3.1 shows the rate schedule for four different streetlight wattages, for both Option B and Option C types. The maintenance charge is calculated to be the difference between the two options shown; the corresponding costs of maintenance under the Option C lights maintained by the City are assumed to be similar.

Table 3.1. Rate Schedule for Portland HPS Streetlights

		Cost per Fixture ($)				
HPS Wattage	**Option**	**Monthly Rate**	**Maintenance Charge**	**Total Annual Maintenance**	**Total Annual Energy**	**Total Annual Costs**
100	B	$6.50	$2.70	$32.40	$45.60	$78.00
	C	$3.80	---	*	*	*
150	B	$8.19	$2.71	$32.52	$65.76	$98.28
	C	$5.48	---	*	*	*
250	B	$11.76	$2.73	$32.76	$108.36	$141.12
	C	$9.03	---	*	*	*
400	B	$17.16	$2.74	$32.88	$173.04	$205.92
	C	$14.42	---	*	*	*

*Assumed to be the same as value in cell immediately above, although the City is incurring maintenance costs separately (i.e., are not paid to the utility).

Calculating the dollar values of either the maintenance or energy savings resulting from the switch to LED luminaires is at present only a theoretical exercise, since Portland would have to negotiate a new rate schedule for the LEDs with the local utility to realize these savings (at least in the case of Option B lights which include a maintenance fee to the utility). The utility benefits from reduced maintenance whether or not it passes the savings to users via a reduced fee, however. Applying the 55% energy savings calculated in Table 2.1 to the 100W annual energy cost shown above ($45.60) yields an annual energy savings estimate of $25.08.

Leotek, like many other LED manufacturers, claims a 50,000 hour lifetime on their products based on estimated lumen depreciation rates provided by the chip manufacturer (Nichia, in this case). Such a lifetime claim is based on a number of assumptions and statistical extrapolations of LED test data, and assumes that the luminaire components (e.g., electronics, housing, etc.) will not fail before lumen output levels no longer meet the needs of the application. Because LED outdoor lighting products are still relatively new in the marketplace, actual field data to verify these manufacturer claims are lacking. For example, a 50,000 hour life corresponds to about 5.5 years at 24/7 operation—longer than any of the current generation of products has been in existence, hence the need to rely on statistical extrapolation of the limited data available to date. GATEWAY will continue to monitor this and other sites in order to contribute to the growing body of field experience.

Despite the lack of field data for LED fixtures, the long-term performance of some fixture components is well understood. For example, photocells require periodic cleaning and, with traditional fixtures, are typically changed during group relamping (e.g., once every five years). Even though photocells have a longer expected life than the lamp, their material cost (<$10) is only a small fraction of the total cost of getting to the site and replacing them. Luminaire optics also require periodic cleaning (typically performed during relamping), and the extended relamping cycles for LED products will not necessarily diminish their need for cleaning. In the absence of actual field data, a monthly maintenance fee savings of $1.20 was assumed for purposes of this evaluation (meaning the fee drops from $2.70 to $1.50 per month for a 100W replacement luminaire), based on the combination of eliminating the 5-year lamp replacement and extending the time between visits. Ultimately, the actual savings benefit will be determined by the utility based on empirical field experience.

3.2 Payback

A price quote provided by a local distributor for the Leotek luminaires was $449.00 per unit. Installation time for both the HPS cobra head and the LED unit appears to be similar; installation cost, therefore, is assumed as similar and is estimated at about $213 per pole for a new installation.[2] For a retrofit scenario, where conventional 100W HPS fixtures in good operating condition are swapped for LED products, the cost also includes removal of the existing fixture and is estimated at $346.[2] Simple payback for a retrofit scenario calculates as:

($449 + $346) / ($25.08 + $14.40/yr) = 20.1 years

In the case of new construction, where only the incremental cost for the LED product ($449-$150 = $299) [2] is considered and the installation cost drops out due to equivalency between the two options, simple payback falls to:

($299)/($25.08 + $14.40/yr) = 7.6 years

Again, realizing this payback would require the City to renegotiate the lighting energy and maintenance rate schedules offered by the local provider.

[2] Estimates for labor cost of retrofitting a cobra head ($346) or new installation ($213), and capital cost of new cobra head ($150) provided by Tod Rosinbum, City of Portland Office of Transportation.

4.0 User Feedback

The GATEWAY program considers user feedback on the qualitative aspects of LED lighting to be an essential component of the overall evaluation. Products that fail to maintain the quality of illumination produced by the incumbent technology are likely to encounter significant resistance to their use and are, therefore, not likely to be adopted on a wide scale regardless of the unit energy savings they offer. In addition, quantitative analysis of the measurements to the exclusion of qualitative feedback does not capture the full effect of the substitution; it disregards other aspects impacting human perception, such as color rendition, glare, and ability to detect objects.

4.1 Local Residents Survey

PNNL and the City jointly developed and implemented a mail-in resident survey for use during the first week in December 2008. Residents were asked to respond to several relevant aspects of lighting quality and to provide any additional comments they had on the new street lighting. All questions were carefully worded so as to minimize the introduction of bias into the responses.

Thirty questionnaire packages were hand-distributed among the resident households along Lija Loop. Each package contained a cover letter, the questionnaire, and a self-addressed, stamped envelope. Of those, 11 questionnaires were completed and returned, yielding a 36% response rate.

Overall responses to the LED luminaires were generally positive, though two respondents cited brightness or glare issues as detractions from the overall quality of light. None of these issues were strong enough to prevent the respective responder from recommending the lights be used elsewhere. One other respondent thought the lights were too dim, suggesting perhaps it was a function of the high color temperature ("too blue"), and strongly recommended they not be used elsewhere. This was the only overall negative response received.

Of positive comments, one respondent noted the greater coverage of the LED lighting relative to the previous HPS. Others noted improved visibility or other qualities, citing other locations that needed such improvement. One went as far as to comment that the lighting made him "enjoy living on Lija Loop."

The questions, summary responses, and comments received (verbatim) are listed below.

Lija Loop Resident Survey Conducted December, 2008

1. Before receiving this survey, were you aware that the street lights on Lija Loop had been recently changed?

Responses	Number	Percentage
Yes	9	81.8%
No	2	18.2%

2. Compared to the standard street lighting on Gertz Road, how would you characterize the lighting on Lija Loop?

Responses	Number	Percentage
extremely different	8	72.7%
somewhat different	2	18.2%
not different	0	
no opinion	1	9.1%

3. The quality of street lighting on Lija Loop ________ my ability to see the street and objects that are on it.

Responses	Number	Percentage
greatly enhances	7	63.6%
enhances	2	18.2%
has no effect on	1	9.1%
inhibits	1	9.1%
greatly inhibits	0	

4. The lighting on Lija Loop creates ________ glare than other street lights.

Responses	Number	Percentage
much less	4	36.4%
somewhat less	3	27.3%
no noticeable difference in	3	27.3%
somewhat more	1	9.1%
much more	0	

5. The lighting on Lija Loop creates ________ shadows/dark areas on the ground than other street lights.

Responses	Number	Percentage
many fewer	6	54.5%
somewhat fewer	2	18.2%
no noticeable difference in	2	18.2%
somewhat more	0	
many more	1	9.1%

6. The lighting level on Lija Loop is _________.

Responses	Number	Percentage
too dim	1	9.1%
somewhat dim	1	9.1%
just right	8	72.7%
somewhat bright	1	9.1%
too bright	0	

7. The quality of the lighting on Lija Loop makes it seem ________ to drive under.

Responses	Number	Percentage
very safe	3	23.7%
safe	6	54.5%
neither safe nor unsafe	1	9.1%
unsafe	1	9.1%
very unsafe	0	

8. As a pedestrian, I feel ________ under the lighting on Lija Loop.

Responses	Number	Percentage
very safe	2	18.2%
safe	6	54.5%
neither safe nor unsafe	1	9.1%
unsafe	1	9.1%
very unsafe	1	9.1%

9. I _______ recommend use of this type of lighting elsewhere.

Responses	Number	Percentage
would definitely	6	54.5%
would	2	18.2%
may or may not	2	18.2%
would not	0	
would definitely not	1	9.1%

10. Additional comments about the street lighting on Lija Loop.

- *"We didn't notice any difference."*
- *"Noticeably brighter. We had to modify "black out" curtains to decrease street light shining in bedroom (street facing) window. However, I do appreciate the change/modification in lights. (seems similar to LED light in color & brightness. I would request/recommend the 'brightness' to be turned down 1-2 levels.)"*
- *"It appears to light a much larger area"*
- *"It's bright w/o being overly bright. I like the color compared to the prior, orange/red ones. (Halide & Sodium I presume)"*

- *"Bring our 'old' lights back, please!! Maybe if the bulb wasn't so blue in coloring, it just doesn't cast the light as effectively as the ones on Gertz, though it is better with glare."*
- *"Excellent quality, makes me enjoy living on Lija Loop"*
- *"Highly needed on Gertz Rd, Vancouver Way, and most importantly MLK north of Columbia!!! For a very long time, Gertz Rd off of MLK was not visible. Thank you for your time and support."*
- *"Yeah!"*

11. Year of birth

Responses	Number	Percentage
1932 or earlier		
1933-1942		
1943-1947	**1**	9.1%
1948-1952	**1**	9.1%
1953-1957	**1**	9.1%
1958-1962	**1**	9.1%
1963-1967	**2**	18.2%
1968-1972	**1**	9.1%
1973-1977	**1**	9.1%
1978-1982	**2**	18.2%
1983-1989		
no indication	**1**	9.1%

12. Gender

Responses	Number	Percentage
Male	2	18.2%
Female	8	72.7%
No Indication	1	9.1%

5.0 Discussion

In this study the Leotek product has achieved an estimated payback, 7.6 years for new installations, which could be within the range of consideration for other potential users. However, the measured energy savings (55%) supporting this payback were achieved by reducing average illuminance levels by a similar amount (53%). On the basis of output from the complete luminaire, the LED luminaire does in fact produce only about half the light output (~3000 lumens) as the traditional HPS cobra head (~6700 lumens), though the LED product is still able to meet the applicable Portland lighting specification.

It is not uncommon to find actual applications being overlighted by a traditional product with respect to site illumination requirements. One reason for this is the omnidirectional output of the lamp, a significant portion of which must be reflected/redirected through fixture optics towards the target surfaces. Some of the light output is absorbed by fixture components, while some ends up redirected in unwanted directions. A significant portion may exit at high angles, for example, where it is not providing useful illumination and may cause glare and light trespass, skyglow, etc. A typical result of relatively non-uniform distribution is a visible "hot spot," or overlighting of the area directly beneath the luminaire and rapidly decreasing illumination levels outside of that area.

As is common practice elsewhere, the City of Portland lighting requirements focus on average illuminance of the roadway. Averages can be deceiving, as they tend to mask extremes of non-uniformity. The average illuminance between a point lighted to 10 footcandles, for example, and an adjacent point measuring 0 footcandles, is 5 footcandles. The same result would be obtained if the two readings were 8 and 2 footcandles, 6 and 4 footcandles, or 5 and 5 footcandles. Yet the suitability of any of these combinations for a given space varies greatly.

Compared with omnidirectional sources, LED products are able to offer a higher level of control due to the inherent directionality of LED light output and the small size of the originating source, which translate into a reduced need for secondary optics to control distribution and resulting uniformity. More effective use of each lumen produced means that fewer lumens are needed to satisfy the application from the outset. A further benefit is the ability to more precisely "dial in" the illumination levels from the luminaire to just those needed to meet the applicable site specification, minimizing over-lighting and its attendant energy use.

The Leotek product takes advantage of all of these capabilities on Lija Loop. The measured energy savings are due to a combination of higher luminaire efficacy (71 lumens/watt vs. 58 lumens/watt for the HPS), and the reduced illumination levels reported in Table 2.2. Despite the reduced output, the Leotek product still meets the City of Portland's lighting specification, though it should be pointed out that this portion of the energy savings will vary in a given location by the relative amount of overlighting (with respect to meeting the site specification) in that location. Should the traditional HPS luminaire exactly meet Portland's specification in another location, for example, this portion of the energy savings would be zero.

The selected LED sample, Model No. SL-150W1M3-FX, is at present only just meeting the minimum illumination levels (0.2 fc) required by City of Portland lighting standards when the required light loss factors are applied, leaving no room for error or contingency. The model selected for Lija Loop may hence be slightly undersized, at least in terms of considering its use elsewhere. Installing the next higher-output model (the SL-175) would be a more conservative choice although slightly higher power consumption and corresponding costs would accompany the substitution, along with a corresponding increase in the estimated simple payback period. The higher output unit has been neither tested nor priced in this study.

In terms of user perceptions of illumination quality, ten out of eleven respondents in the resident survey either noticed no difference or thought the lighting quality was improved following the LED substitution. The resident responses to the survey were positive overall.

As part of a larger ongoing evaluation of LED product installations, GATEWAY will be periodically revisiting the Lija Loop installation to monitor illumination levels, and may post future updates as needed. GATEWAY plans to compile lumen maintenance results from multiple products across multiple installations after a few years of actual field operation.

Finally, underlying the estimated payback period is the assumption that there is no difference between installation labor for the LED and conventional cobra head units (which was the case here), and that the LED product will achieve its projected lifetime. Limited historical field experience exists for LED outdoor lighting products at this writing; consequently, their expected lifetime remains only a projection. As of publication, these luminaires have operated for approximately one year without incident.

Appendix A

Lamp, Ballast and Meter Information

Appendix A

Lamp, Ballast and Meter Information

Lamp Information

Below are median values derived from data on 36 100W HPS lamps from 6 different manufacturers:

Ballast: S54
Initial Lumens: 9500
Mean Lumens: 8000
Life: 24,000 hours
Correlated Color Temperature: 2100 K
CRI: 22

Sample Ballast Information:

Circuit Type: Regulated Lag
Power Factor (min): 90%
Regulation
Line Volts: ±10%
Line Watts: ±6%
Input Watts: 120W

Illuminance Meter Information:

Minolta Chroma Meter CL-100
Measuring Range: 5.1 lx (0.47 fc) – 32,700 lx (3037.93 fc); display blinks for measured value under range, “EO” appears on display for measured value over range
Accuracy Illuminance: ±2% of reading ±1 digit

Power Meter: Fluke 434[3]

Watt, VA, VAR

Measurement range:	1.0 to 20.00 MVA
Accuracy:	±1% ± counts

kWh, kVAh, kVARh

Measurement range:	00.00 to 200.0 GVAh
Accuracy:	± 1.5% ± 10 counts

Power Factor/ Cos Φ / DPF

Measurement range:	0 to 1
Accuracy:	± 0.03

[3] All power meter information obtained from http://www.myflukestore.com/p1504/fluke_434.php?p_tab=specs.

Appendix B

Luminaire Photometric Testing Results

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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*

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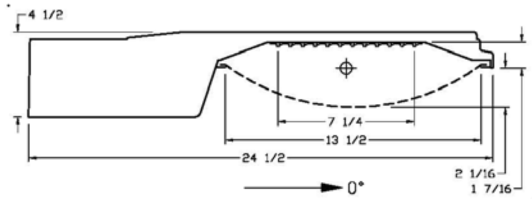
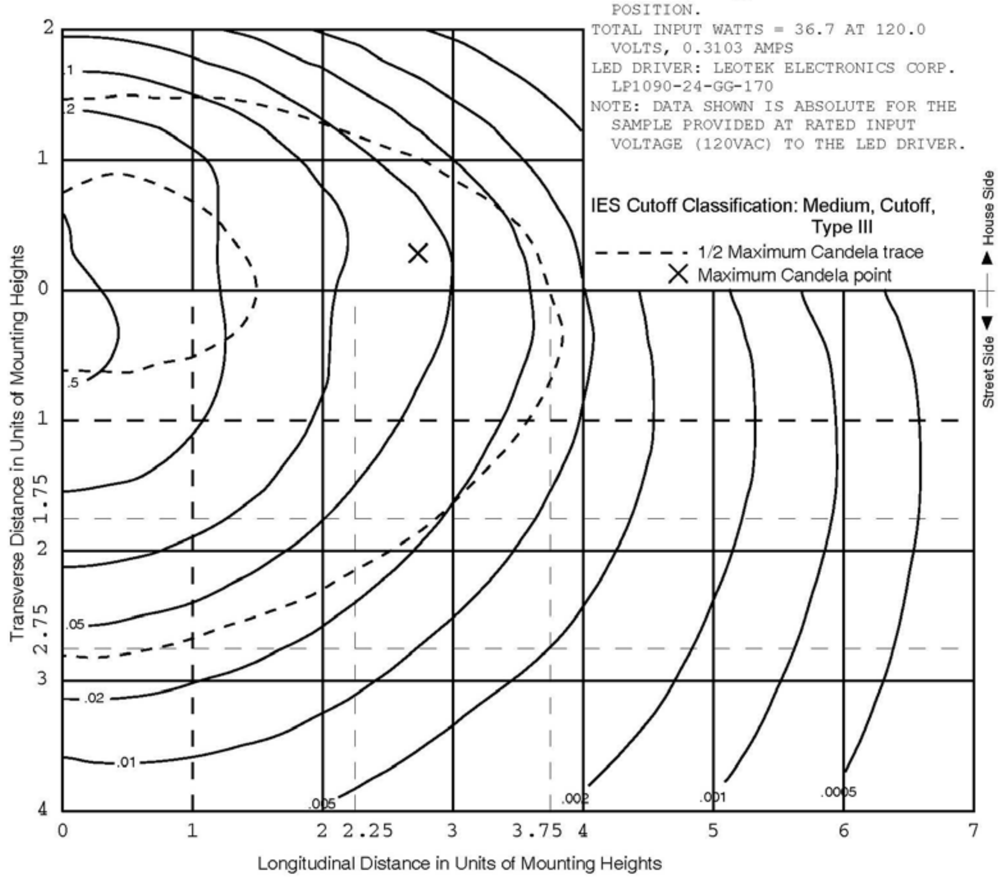
ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION

Values based on 25 foot mounting height.

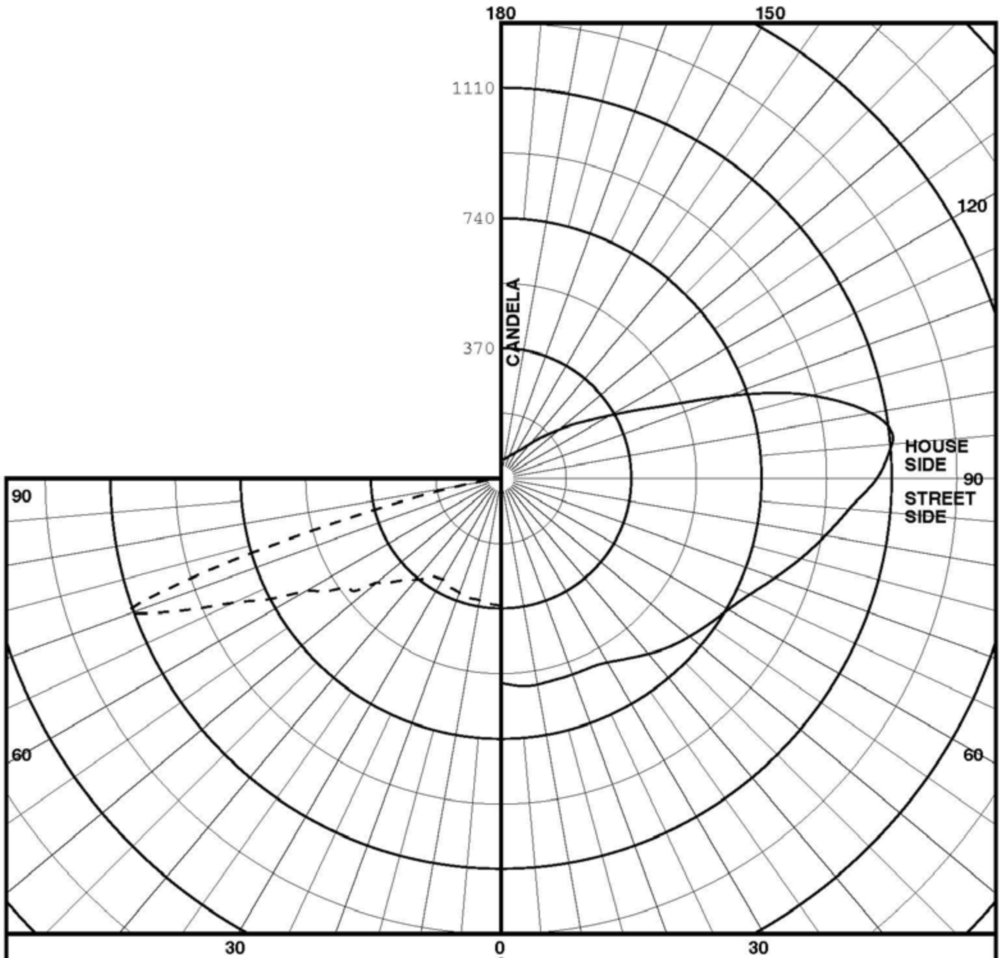


CATALOG NUMBER: CALIPER 08-110
LUMINAIRE: CAST METAL HOUSING WITH FINNED TOP SECTION, ONE WHITE CIRCUIT BOARD WITH 36 LEDS, 12 CLEAR MOLDED PLASTIC INTERIOR LENSES ATTACHED TO CIRCUIT BOARD EACH WITH 9 OPTICS, ONLY 36 OPTICS OF INTERIOR LENSES HAS A CORRESPONDING LED, MOLDED GRAY PLASTIC REFLECTOR, CLEAR MOLDED PLASTIC EXTERIOR SAG LENS, FABRICATED SPECULAR METAL LENS FRAME.
LAMP: THIRTY-SIX WHITE LIGHT EMITTING DIODES (LEDS), VERTICAL BASE-UP POSITION.
TOTAL INPUT WATTS = 36.7 AT 120.0 VOLTS, 0.3103 AMPS
LED DRIVER: LEOTEK ELECTRONICS CORP. LP1090-24-GG-170
NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT VOLTAGE (120VAC) TO THE LED DRIVER.



THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES. FIELD PERFORMANCE MAY DIFFER FROM LABORATORY PERFORMANCE.

MAXIMUM PLANE AND MAXIMUM CONE PLOTS OF CANDELA

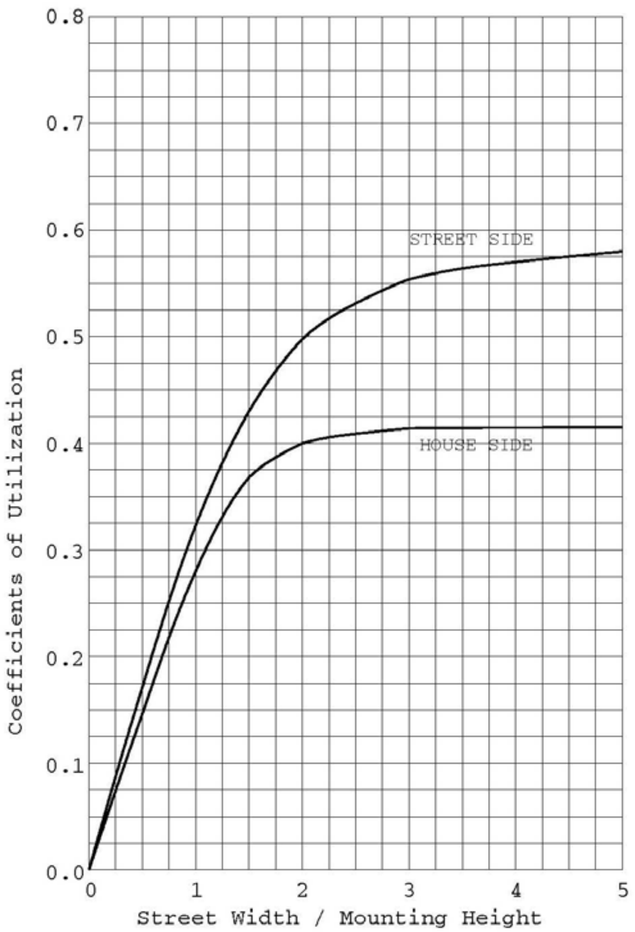


VERTICAL PLANE THROUGH MAXIMUM CANDELA
70.0 (Degrees Vertical)

CONE THROUGH MAXIMUM CANDELA
96.0 (Degrees Horizontal) = 1120

THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES. FIELD PERFORMANCE MAY DIFFER FROM LABORATORY PERFORMANCE.

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.

THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES. FIELD PERFORMANCE MAY DIFFER FROM LABORATORY PERFORMANCE.

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

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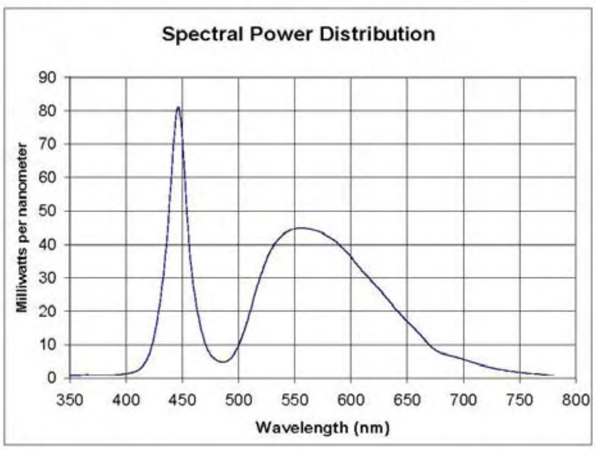
CATALOG NUMBER: CALIPER 08-110

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.

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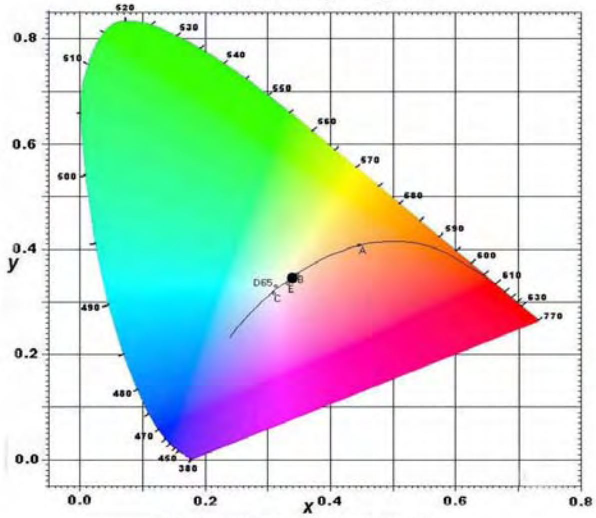
CATALOG NUMBER: CALIPER 08-110

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

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.

Appendix C

Detailed Illuminance Data

Appendix C
Detailed Illuminance Data

Table C.1 below provides the measured illuminance values (in footcandles, fc) for both products across the measured grid. Vehicles were parked along one side of one section of the street and precluded the taking of readings in those respective locations (shown as grayed cells in the table). The corresponding values shown in the table were substituted from readings in the same relative locations to the pole, taken at the adjacent pole.

Table C.1 - Difference between HPS and LED Illuminance Values

	HPS	HPS	HPS	LED	LED	LED	Diff	Diff	Diff
10	2.2	1.7	0.9	0.5	0.5	0.4	77%	71%	56%
20	2.2	1.4	0.7	0.4	0.4	0.4	82%	71%	43%
30	0.9	0.8	0.4	0.3	0.3	0.3	67%	63%	25%
40	0.4	0.5	0.4	0.2	0.2	0.2	50%	60%	50%
50	0.3	0.3	0.3	0.2	0.2	0.2	33%	33%	33%
60	0.2	0.2	0.3	0.2	0.1	0.1	0%	50%	67%
70	0.3	0.2	0.2	0.1	0.1	0.1	67%	50%	50%
80	0.3	0.2	0.2	0.1	0.1	0.1	67%	50%	50%
90	0.3	0.2	0.3	0.1	0.1	0.1	67%	50%	67%
100	0.3	0.3	0.3	0.2	0.2	0.2	33%	33%	33%
110	0.4	0.4	0.4	0.2	0.2	0.2	50%	50%	50%
120	0.7	0.7	0.4	0.3	0.3	0.3	57%	57%	25%
130	1.9	1.1	0.7	0.5	0.5	0.4	74%	55%	43%

Appendix D

Portland Street Lighting Standards

STREET LIGHTING STANDARDS

Mayor:	**Francie Ivancie**
Commissioner: Public Works	**Mike Lindberg,**
Commissioner:	**Margaret Strachan**
Commissioner:	**Charles Jordan**
Commissioner:	**Mildred Schwab**

Adopted by City Council
Ordinance No. 149210
February 28, 1980
Revised by Ordinance No. 156728
November 1, 1984

CITY OF PORTLAND
STREET LIGHTING STANDARDS

Class	Portland Street Classification	Horizontal Illumination E_h			Luminance L				Glare		
		$E_{h(ave)}$ fc	Ave / Min	Max / Min	L_{ave} FL	Ave / Min (Overall)	Max / Min (Overall)	Max / Min (Longitudinal)	GM	TI	L_V
1	Regional Trafficway	≥ 1.2	≤ 3	≤ 9	≥ 0.30	≤ 2.5	≤ 5	≤ 2.5	≥ 6	≤ 20	$\leq .05$
2	Major Traffic Major Transit	≥ 1.0	≤ 3	≤ 9	≥ 0.24	≤ 2.5	≤ 5	≤ 2.5	≥ 6	≤ 20	$\leq .04$
3	District Collector	≥ 0.7	≤ 3	≤ 9	≥ 0.18	≤ 2.5	≤ 5	≤ 2.5	≥ 6	≤ 20	$\leq .03$
4	Neighborhood Collector – Major Transit	≥ 0.7	≤ 3	≤ 9	≥ 0.18	≤ 2.5	≤ 5	≤ 2.5	≥ 6	≤ 20	$\leq .03$
5	Neighborhood Collector – Minor Transit	≥ 0.5	≤ 3	≤ 9	≥ 0.12	≤ 2.5	≤ 5	≤ 2.5	≥ 6	≤ 20	$\leq .02$
6	Local Service	≥ 0.2			≥ 0.06	≤ 5	≤ 10	None	≥ 4	≤ 25	$\leq .05$
7	Intersections				$L_{ave} \geq 1.5 L_{ave(r)}$ Unif. $\frac{L_{ave(I)}}{L_{min(I)}} \leq 2.5$				≥ 7	≤ 10	$\leq .05$

Horizontal Illumination, E_h:

a. The value of average horizontal illumination, $E_{h(ave)}$, is measured in footcandles (fc) and calculated as the average over the area of the traffic lanes including the center median and bike lanes, if any. The area for $E_{h(ave)}$ does not include parking lanes, sidewalks, berm, or other areas outside of the vehicular traffic lanes. A parking lane will be assigned 7 ft of width.

b. For design calculations, the end-of-life lamp lumens will be used together with an appropriate luminaire maintenance factor.

c. $E'_{h(ave)}$: The $E'_{h(ave)}$ is for areas out to 15 ft to each side of the outside traffic lane.

d. and shall be lighted to a ≥ 0.2 fc(ave) if such areas are used for parking or pedestrian traffic. No ratios are specified for the side areas.

e. Ave/Min values of horizontal illumination are related to twin-beam luminaires at 30-40 foot mounting heights.

Luminance, L:

a. L_{ave}, measured in footflamberts (fL), is the average luminance within the traffic lanes from a transverse line 100 ft ahead to about 400 ft ahead of the observation point. The lateral boundaries shall include the area of the traffic lanes. At least 20 points shall be used to calculate L_{ave} with at least 5 points along the centerline of the outside lane.

   The individual luminance points shall be calculated or measured from a point 4.5 ft above the roadway located approximately in the center of the outside lane and at a longitudinal point along the centerline spaced to include the maximum longitudinal variations in road luminance.

   For 2-way traffic roadways, the luminances shall be determined for each direction of traffic if the luminance pattern is asymmetric.

b. Field measurements will be made with a suitable telephotometer using an acceptance aperture with a 2 arc minute vertical angle. At least 20 points will be measured on the roadway within the prescribed area at approximately equal angular increments.

c. The L_{ave}/L_{min} ratios shall be calculated for each observer location and shall consider all of the individual luminances within the area. The ratio of L_{ave}/L_{min} in shall be met for all observer locations.

d. The L_{max}/L_{min} ratios shall be calculated overall and along the centerline of the outside lane for each direction of traffic.

Glare:

Glare will be evaluated by two criteria: (1) discomfort glare and (b) disability glare.

a. Discomfort Glare

The discomfort from glare is described by a Glare Control Mark, GM, which expresses on an ordinal scale the subjective appraisal of the degree of discomfort experienced. The value of GM is associated to different glare sensations as follows:

GM-1 "Unbearable"
GM-2 "Disturbing"
GM-5 "Just admissible"
GM-7 "Satisfactory restriction"
GM-9 "Unnoticeable"

The wordings are not intended to indicate an absolute level of glare. They are listed here as used in the international Commission on illumination (CIE) experiments.
The subjective appraisal of the glare and the associated value of the Glare Control Mark depend on the photometric and geometric characteristics of the lighting installation.

b. Disability Glare

The method for evaluation of disability glare is based on the Holladay formula. According to the formula, the effect of glare is quantified by an equivalent uniform luminance, which describes the effect of the stray light in the eye: lowering the contrast. The relative threshold increment, TI, is expressed as the difference between the threshold under glare condition and its value without glare, expressed in percent of the value without glare.

The veiling luminance, L_v, represents the illumination at the eye due to glare sources and is the equivalent uniform luminance, in footlamberts, superimposed over the entire visual field.

c. Recommendations on Glare

The recommendations concerning the restriction of glare in road lighting installations have been given in terms of GM and T1. These values should be considered as minimum requirements. If higher values for G and lower values for TI are economically feasible, preference should be given to such an improvement of the glare restrictions.

Field measurements of glare should be made using a telephotometer located at the luminance observation location. The photometer should use a 6 arc minute aperture (approx. 2-inch circle at 100 ft) and should have a mount that can give vertical and horizontal angles with respect to a reference line of sight. All sources within the normal field of view of a driver that are greater than about 20 times the average road luminance should be measured for maximum luminance within a 6' cone angle. The approximate field of view will be ± 30° horizontal, + 20° vertical to - 5° vertical. The location and magnitude of each source should be recorded. If the sources subtend a solid angle greater than 0.0002 steradians (2 ft^2 at 100 ft), separate measurements should be made in each incremental solid angle.

Intersections:

a. The area used to determine Lave will be that roadway area within the traveled lanes extending from the centroid of the intersection along each lane to a transverse line 10 ft beyond the point of entry.

b. $L_{ave(i)}$ is the average luminance in the intersection, $L_{ave(r)}$ is the average luminance of the intersecting road with the highest value, and $L_{min(i)}$ is the minimum luminance in the intersection.

Appendix E

Luminaire Classification System (LCS) and BUG Ratings

Appendix E

Luminaire Classification System (LCS) and BUG Ratings

Table 1. GE Full Cutoff

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	656.5	6.9	9.8
FM (30-60)	2002.3	21.1	29.9
FH (60-80)	1177.4	12.4	17.6
FVH(80-90)	16.7	0.2	0.2
BL (0-30)	689.3	7.3	10.3
BM (30-60)	1597.4	16.8	23.9
BH (60-80)	548.7	5.8	8.2
BVH(80-90)	7.5	0.1	0.1
UL (90-100)	0.0	0.0	0.0
UH (100-180)	0.0	0.0	0.0
Total	6695.8	70.6	100.0
BUG Rating	**B2-U1-G2**		

Notes:

1. 100W HPS .IES file not available. BUG rating performed for 150W HPS (16,000 lumens) and scaled to a 100W HPS (9,500 lumens) lamp.

Table 2. Leotek

Lum. Classification System (LCS)

LCS Zone	Lumens	%Lamp	%Lum
FL (0-30)	181.8	7.0	7.0
FM (30-60)	688.6	26.3	26.3
FH (60-80)	625.9	23.9	23.9
FVH (80-90)	24.6	0.9	0.9
BL (0-30)	146.2	5.6	5.6
BM (30-60)	597.2	22.8	22.9
BH (60-80)	341.3	13.1	13.1
BVH(80-90)	5.3	0.2	0.2
UL (90-100)	1.5	0.1	0.1
UH (100-180)	1.2	0.0	0.0
Total	2613.6	99.9	100.0
BUG Rating	**B1-U1-G1**		

Notes:

1. Based on absolute lumens emitted in a zone

Table 2 - Backlight Rating

	Secondary Solid Angle	B0	B1	B2	B3	B4	B5
Backlight/ Trespass	BH	110	500	1000	2500	5000	>5000
	BM	220	1000	2500	5000	8500	>8500
	BL	110	500	1000	2500	5000	>5000

Table 3 - Backlight Rating

	Secondary Solid Angle	U0	U1	U2	U3	U4	U5
Uplight / Skyglow	UH	0	10	100	500	1000	>1000
	UL	0	10	100	500	1000	>1000
	FVH	10	75	150	>150		
	BVH	10	75	150	>150		

Table 4 - Glare Rating for Asymmetrical Luminaires (Type I, Type II, Type III, Type IV)

	Secondary Solid Angle	G0	G1	G2	G3	G4	G5
Glare / Offensive Light	FVH	10	250	375	500	750	>750
	FVH	10	250	375	500	750	>750
	FH	660	1800	5000	7500	12000	>12000
	BH	110	500	1000	2500	5000	>5000

Table 5 - Glare Rating for Symmetrical Luminaires (Type V, Type V Square)

	Secondary Solid Angle	G0	G1	G2	G3	G4	G5
Glare / Offensive Light	FVH	10	250	375	500	750	>750
	FVH	10	250	375	500	750	>750
	FH	660	1800	5000	7500	12000	>12000
	BH	660	1800	5000	7500	12000	>12000

Appendix F

FTE Overview

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Overview of Fitted Target Efficacy (FTE) for Outdoor Pole-Mounted Area and Roadway Luminaires
US Department of Energy, ENERGY STAR for SSL Luminaires
June 30, 2009

DOE developed a new metric, Fitted Target Efficacy (FTE), to quantify outdoor pole-mounted luminaire performance for ENERGY STAR qualification purposes. Other existing project-independent metrics do not adequately measure the efficacy with which outdoor pole-mounted luminaires will deliver light to intended target areas.

Two key assumptions underlie the FTE metric. First, relatively rectangular distribution patterns cover most areas more efficiently (with less unnecessary overlap) than rounded distributions (see **Figure 1** below). Second, a luminaire's approximate area of coverage can be defined as the area illuminated to IES-recommended uniformity ratios.

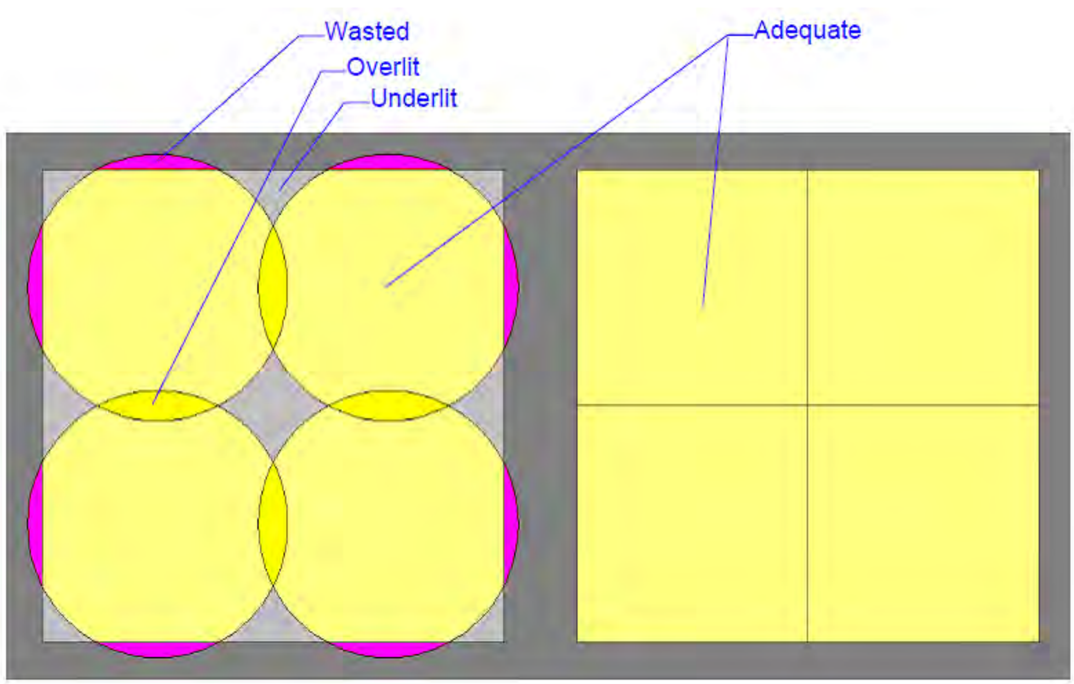

Figure 1. Simplified comparison of circular and rectangular (square) distributions of equal area

In the FTE approach, the target (or task) is defined as the rectangle enclosing the uniform "pool" of light produced by the unique intensity distribution of each luminaire. This uniformly covered portion of the target is itself defined as the area meeting IES-recommended uniformity ratios.

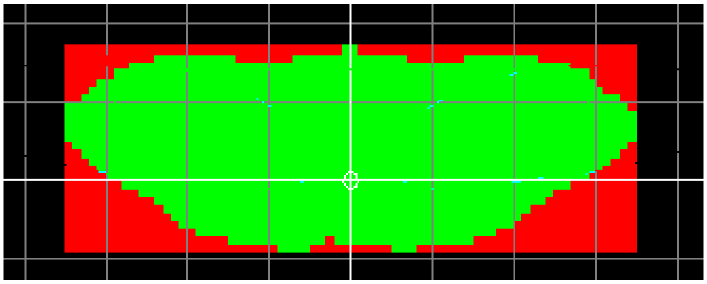

Figure 2. Uniform Pool within Rectangular Target

In **Figure 2** above, a luminaire represented by a white circle is surrounded by the uniform pool of light (green area). Luminous flux landing outside the uniform pool (red and black areas) is discarded. Flux landing inside the uniform pool is summed and then scaled down by the percent of the rectangular target area covered by the uniform pool (green area divided by the sum of green and red areas), thus discounting a portion of non-rectangular distributions that tends to result in wasted or obtrusive light. *For example, note that a tell-tale trait of uncontrolled backlight is non-rectangularity*. FTE is then calculated as the remaining flux (lumens) divided by luminaire input power (watts). The equation can be summarized as:

$$\text{FTE} = \frac{\text{(flux in uniform pool) (percentage of rectangular target covered by uniform pool)}}{\text{(luminaire input power)}}$$

The result is a measure of efficacy that has been tailored (or fitted) to the distribution, independent of any specific project. By using uniformity and rectangularity of distribution as the criteria for useful luminous flux, the same method of calculation can be applied to luminaires of all IES types (Types I through V), and no project-specific geometries or criteria are required.

DOE evaluated hundreds of HID luminaire photometric files to establish ENERGY STAR minimum FTE requirements. Minimum FTEs for SSL luminaires in each category were established to achieve at least 20% energy savings compared to top performing incumbent HID products.