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Demonstration Assessment of Light-Emitting Diode (LED) Area Lights for a Commercial Garage

Host Site: Providence Portland Medical Center Garage, 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
Energy Trust of Oregon
Providence Portland Medical Center
Lighting Sciences Group (LSG)

November 2008

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Richland, Washington 99352

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) SSL 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 program seeks to demonstrate SSL products in applications that save energy, are cost effective, and maintain or improve light levels in the tested lighting application. 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. Although 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 U.S. Department of Energy GATEWAY Demonstration project studied the applicability of light-emitting diode (LED) luminaires for commercial parking garage applications. High-pressure sodium (HPS) area luminaires were replaced with new LED area luminaires. The project was supported under the U.S. Department of Energy (DOE) Solid-State Lighting Program. Other participants in the demonstration project included Providence Portland Medical Center in Portland, Oregon, the Energy Trust of Oregon, and Lighting Sciences Group (LSG) Inc. Pacific Northwest National Laboratory (PNNL) conducted the measurements and analysis of the results. PNNL manages GATEWAY demonstrations for DOE and represents their perspective in the conduct of the work.

Quantitative and qualitative measurements of light and electrical power were taken at the site for both HPS and LED light sources. Garage users' responses to the new light sources were gauged with a survey.

Two versions of the LSG LED luminaires were used in this demonstration: an existing version (Version 1), which had been available on the market since 2007, and a newer version (Version 2), recently introduced, which has 30% more light output and uses about 8% less power. Six Version 1 luminaires were installed in the below-ground parking Level A, replacing six existing 150W HPS lamps spread out over two rows of parking spaces. Illuminance measurements were taken at floor level on an approximately 60-ft x 40-ft grid to measure the light output of these LED luminaires. Power measurements of the 6 LED luminaires were conducted, and it was determined that they drew an average of 82 W per fixture (versus 191 W for each of the HPS luminaire). Version 2 of the LSG luminaire was installed in Level B of the parking garage. Illuminance measurements were not made of this second luminaire on site due to higher traffic conditions; however, power and photometric measurements of this luminaire were made off-site by an independent laboratory.

Maximum and minimum light levels were measured for the HPS and LED Version 1 luminaires and projected for the Version 2 luminaires. Maximum light levels in foot-candles (fc) were 23.51 fc, 20.54 fc, and 26.7 fc respectively, and minimum light levels were 1.49 fc, 1.45 fc, and 1.88 fc. These results indicate very similar minimum light levels produced by Version 1 of the LED luminaires and HPS, and possibly slightly higher minimum light levels with Version 2 of the LED luminaires. All results were above the IES recommended level of 1 fc. User perceptions of the LED luminaires on Level B of the parking garage were collected via a written survey form given to maintenance and security personnel. More than half felt the LED luminaires provided more light than the HPS sources and a majority expressed a preference for the new fixtures when viewing the relamped area through a security camera. Respondents commented that the LED luminaires were less glary, created less shadows, had a positive impact on visibility, and improved the overall appearance of the area.

PNNL conducted an economic analysis and found that the Version 1 lamp produced annual energy savings of 955 kWh and annual energy cost savings of $62 per lamp at electricity rates of 6.5 cents per kWh (local rate), and $105.03 at 11 cents per kWh (national average rate). PNNL found that the Version 2 lamp produced annual energy savings of 991 kWh and energy cost savings of $64 per lamp at electricity rates of 6.5 cents per kWh and $109 at 11 cents per kWh. PNNL also calculated simple payback and found that Version 1 showed paybacks of 6.5 yrs at $0.065/kWh and 4.1 yrs at $0.11/kWh while Version 2 showed paybacks of 6.3 yrs at $0.065/kWh and 3.9 yrs at $0.11/kWh.

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1.0 Introduction

This U.S. Department of Energy GATEWAY Demonstration project studied the applicability of light-emitting diode (LED) luminaires for commercial parking garage applications. High-pressure sodium (HPS) area luminaires were replaced with new light-emitting diode (LED) area luminaires. The project was supported under the U.S. Department of Energy (DOE) Solid State Lighting Program. Other participants in the demonstration project included Providence Portland Medical Center in Portland, Oregon, the Energy Trust of Oregon (ETO), and Lighting Sciences Group (LSG) Inc. Pacific Northwest National Laboratory (PNNL) conducted the measurements and analysis of the results. PNNL manages GATEWAY demonstrations for DOE and represents DOE's perspective in the conduct of the work.

1.1 Background

Parking lots and garages can be challenging environments to light. The lighting must accommodate both vehicular and pedestrian traffic, endure harsh operating environments, and take into account public safety considerations as well as light trespass issues. At the same time, all of these objectives must be met in the most economical way possible. Specific issues that parking lot lighting must address include the following:

- Vibration from vehicle traffic can create a harsh operating environment for light sources.
- Most parking garage lights operate 24 hours-a-day.
- Public safety concerns may favor white light and a high color rendering index (CRI) despite higher cost.
- Failed lamps can create safety hazards if not replaced.

Many commercial garages use area luminaires for general illumination, typically with high-pressure sodium (HPS), metal halide (MH), or linear fluorescent lamps. HPS lamps are used because of their low cost, high efficacy, and long life. MH or fluorescent sources typically have shorter lives but produce a whiter light.

A number of solid-state lighting-based (SSL-based) luminaires (products using a LED light source) are currently being introduced into the market. Well-designed SSL-based fixtures have the potential to provide:

- greater control of light distribution
- better lighting color quality
- longer life
- energy savings when compared to some traditional light sources.

Commercial applications for LEDs that can take advantage of these factors include indoor and outdoor area luminaires. Parking garage lighting is an excellent application for LED lighting for several reasons:

- LED sources have the potential for longer life, better color rendition, and lower energy use than HPS.
- Area lighting can take advantage of the inherently directional nature of light emitted from LEDs, minimizing light loss within the fixture.
- LED sources are not affected by vibration, compared to some traditional light sources.
- LEDs can be easily adapted to control systems such as motion sensors and photoelectric cells to further reduce electricity consumption, where applicable.
- LEDs function well in cold temperature environments.
- LED luminaires can be more resistant to breakage and vandalism, depending on their design and construction.

1.2 Project Objectives

The objective of the demonstration was to compare HPS and LED-based luminaires in a commercial parking garage. Performance was evaluated in three areas: energy usage, lighting, and economics, as detailed below:

- energy usage - luminaire wattage, estimated annual kWh usage
- lighting performance - illuminance, uniformity, correlated color temperature (CCT, in Kelvin), user satisfaction
- economic performance – simple payback for substitution in new installation or replacement scenarios, accounting for light source lifespan, maintenance costs, and electrical costs.

1.3 Overview of the Report

Chapter 2 describes the project methodology. Chapter 3 is a discussion of the results of the study. Chapter 4 presents the conclusions. Appendices A though F contain information on the luminaires, measurement data, and calculation details and assumptions.

2.0 Methodology

The Providence Portland Medical Center (PPMC) GATEWAY Demonstration Project was a joint project of DOE, Energy Trust of Oregon (ETO), Lighting Sciences Group Corporation (LSG – via its local distributor, Extra Effort Consulting), and PPMC's Physical Plant Department. The project was coordinated by PNNL. A description of the evaluation and methods used is provided below.

2.1 Demonstration Site

In early 2008, ETO's Commercial Efficiency Program contacted DOE regarding the viability and availability of commercially available LED lighting technologies and expressed interest in working with DOE on demonstrations of solid-state lighting. Based on the PPMC's expressed interest in incorporating LED lighting into their projects, ETO, along with the PPMC Physical Plant Department, approached DOE and offered the PPMC Portland garage as a potential demonstration location (see Figure 2.1). The Providence facility is evaluating a number of energy-efficient lighting options to replace its stock of aging HPS area lighting fixtures, and the use of LED luminaires was viewed as a straightforward option for this application.

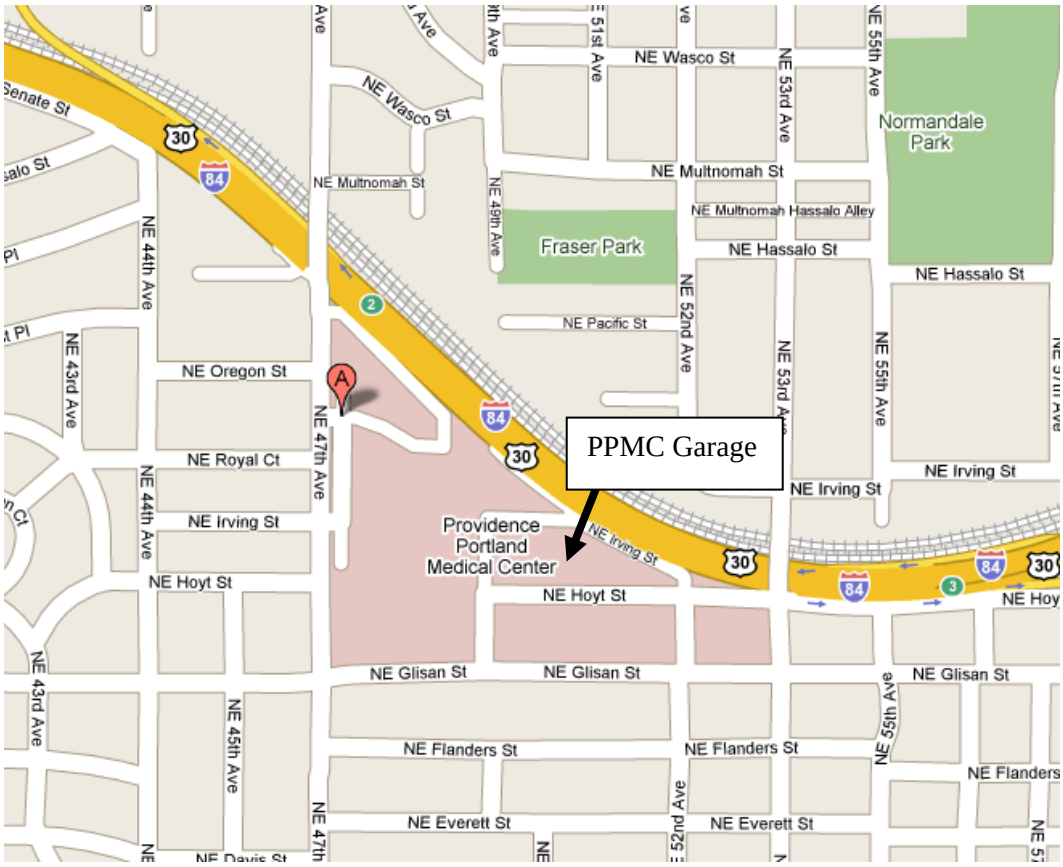

Figure 2.1. Location of Providence Portland Medical Center, in Southeast Portland, Oregon. Arrow shows garage location. (Source: Google Maps)

PPMC is part of Providence Health & Services in Oregon, a not-for-profit network of hospitals, health plans, physicians, clinics, and affiliated health services. The NE Portland location is a large campus occupying about five city blocks by five city blocks (Figure 2.1). The parking garage is a six-story structure located on the northeast side of the campus with approximately 50,000 square feet of parking area. The garage is lit with about 400 HPS luminaires that operate 24 hours per day.[1] The PPMC garage is pictured in Figure 2.2 and Figure 2.3.

Figure 2.2. Exterior of the PPMC Garage, Portland, Oregon

2.2 Products Tested

The product selected for demonstration at the site is Lighting Science Group's pyramid-shaped "Low Bay" LED indoor area luminaire (30 degrees base angle). DOE tested one version of LSG's "Low Bay" product to verify its performance prior to accepting it into the demonstration program. The luminaires used in the demonstration are a mix of an existing version (Version 1), which had been available on the market since 2007, and a newer version (Version 2), recently introduced, which has 30% more light output (4700 rated lumens vs. 3600 rated lumens) and uses about 8% less power (78 watts rated power vs. 85 watts rated power).

[1] PPMC's Electrician noted that a number of luminaires on the outside perimeter of the parking levels have been retrofitted with photo sensors, so these luminaires would not be operating at 24 hours per day.

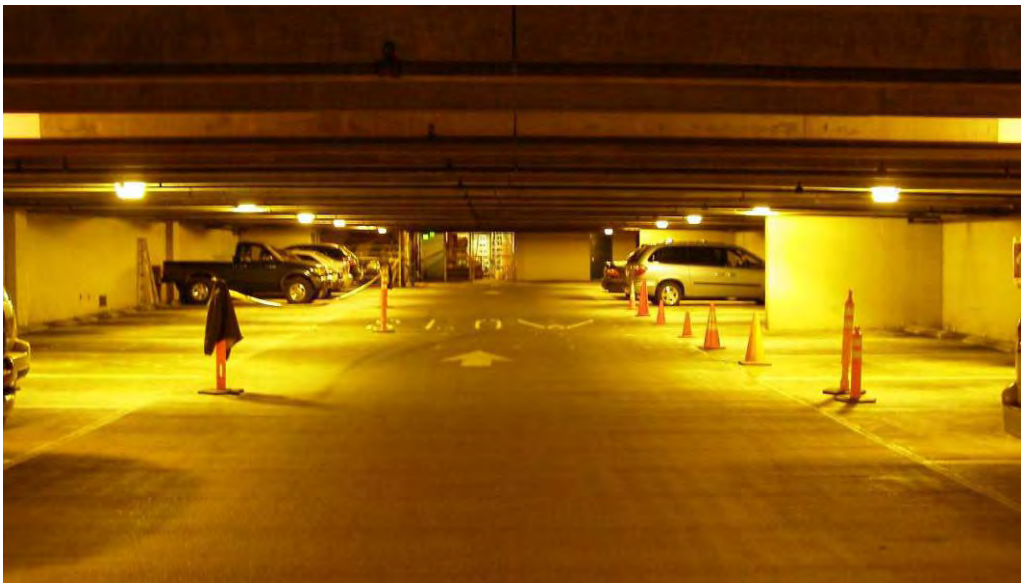

Figure 2.3. Interior of the PPMC Garage (Level A), with HPS fixtures, Portland Oregon

In the PPMC demonstration, the LED luminaires replaced existing HPS luminaires, which are at least 15 years old and were manufactured by Crouse-Hinds Lighting (Cat # LW/VLC15 120/277 Style # 7240D94G14, using GE LUCALOX 150W HPS lamps). These round-shaped luminaires are approximately 16 inches in outside diameter, and 10 inches in height. Each luminaire is pendant mounted to the roof of the garage via a short pole and conduit. The lamps are vertically oriented with the ballast located in its own compartment above the reflector, lamp, and cover assembly. The integral lenses of the luminaires in the garage appeared to be acrylic in various conditions (from dirty to cracked). The lens "bowl" provides dust sealing for the luminaires and the reflectors. The reflectors are painted metal. More information about the HPS lamps and ballasts can be found in Appendix A. Figure 2.4 shows a typical HPS parking garage luminaire similar to the Crouse-Hinds luminaires used at the PPMC parking garage.

Figure 2.4. Typical HPS Parking Garage Luminaire
Source: www.buylightfixtures.com

The HPS luminaires on Level A were cleaned and re-lamped with new HPS lamps about a week prior to being replaced by the LED fixtures. Because lamps on Level A operate 24 hours per day, when the illuminance measurements were taken a week later, the new HPS lamps had operated well over the 100 hours needed for normal "burn-in" of discharge lamps. Ballasts were not replaced for purposes of these measurements. Figure 2.6 shows the installed HPS luminaires.

Figure 2.5. Crouse-Hinds HPS Luminaires at the PPMC Garage.
(Note: X's on pavement show locations of illuminance measurement points)

The LSG Low Bay LED luminaire used in this project is a pyramid-shaped fixture 14 inches wide by 14 inches long, and about 8 inches in height, containing 108 LEDs per fixture (27 per side). The fixture is designed for area lighting in warehouses, stockrooms, parking garages, gyms, and other spaces. The Low Bay is available from the manufacturer in pendant, surface, and tilt installation mounting options for both new construction and retrofit applications (Figure 2.6).

Figure 2.6. Lighting Sciences Group's Pyramid Low Bay LED Fixture
Source: LSG Corp.

2.3 Measurements

Following development of a field measurement plan, PNNL conducted a preliminary site visit to the Providence garage to document the existing conditions. No potential issues were identified during this visit. The installation field visit and grid set-up for the luminaire measurements were combined and

occurred on the same day. Initially, the installation location was the garage's below-ground parking level (Level A). This was considered to be an ideal location, as there would be no ambient light to interfere with illumination measurements or to affect users' perception of the new luminaires. A section of the garage away from the entrance and exit was selected as the test location. This section also had the advantage of being the nurses' parking area and was, therefore, potentially useful in obtaining qualitative feedback from garage users (Figure 2.7).

Six of the Low Bay LED luminaires were installed in the designated section of Level A and measurements were taken of both the existing luminaires and of the installed LED replacements. After the installation, LSG made available a number of higher output Low Bay LED luminaires. In addition, the security staff requested that the test luminaires be moved to another location on the ground floor observable by installed security cameras. The installed LED luminaires were moved from the original position on Level A to Level B, near the entrance to the garage to accommodate the security staff request. These LEDs were installed along with the newer Version 2 LED fixtures. Because the new location is a high traffic location, additional measurements were not taken.

In the original Level A location, illuminance measurements were taken on an approximately 50-ft by 30-ft grid, encompassing six luminaires and two rows of parking spaces. The distance between the luminaires is approximately 22 feet over the parking spaces and about 24 feet across the rows. Ideally, parking garage luminaires should be spaced equally for lighting uniformity; however, actual luminaire spacing is usually by the variable distances between concrete ceiling beams. The grid spacing was approximately 4 ft over the entire measurement area.

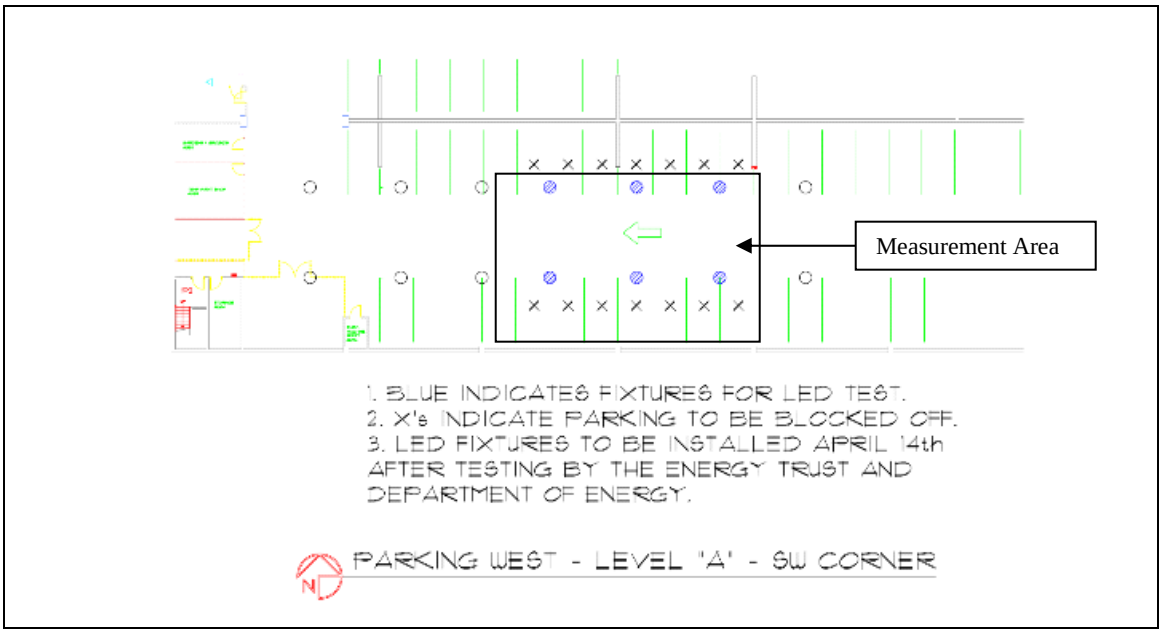

Figure 2.7. Drawing of Installation Area on Level A (not to scale)

The luminaires were located approximately 90 inches above the concrete floor of the garage, on 1.5-ft mounting poles. The light level measurements were taken with a Canon/Minolta illuminance meter at a uniform height of 2 inches above ground. Temperature measurements were measured with a portable

thermometer. As the parking level was below ground, the temperature remained constant throughout the measuring period at about 63°F. Table 2.1 contains the details of the measurement areas. Appendix B contains a listing of equipment used, and Appendix C contains the detailed measured data and measurement areas.

Other measurements taken in the garage at Level A were CCT and power usage.[1] Power data were measured on site for the six HPS luminaires, as well as the six Version 1 LED luminaires. (Power usage for the Version 2 LED luminaire was measured at an independent testing laboratory.) Because all six luminaires were on one circuit, the power drawn on that circuit could be measured and an average per-lamp usage calculated both with the HPS lights installed and then with the LED fixtures installed. All pre- and post-retrofit measurements were taken within an eight-hour period because the Medical Center maintenance staff was able to install the new LED luminaires on the same day that PNNL took measurements. No corrections were required for ambient light, as the location was underground. Photometric results from independent laboratories for both the HPS and LED luminaires are included in Appendix D.

Table 2.1. Measurement Details for Providence Portland Medical Center Garage

Location	Approximate Grid Area	Approximate Grid Spacing	Measurement Height
Across Parking Spaces	60 ft x 30 ft	4 ft	2 inches above floor
Across Parking Lane	40ft x 20 ft	4ft	2 inches above floor

[1] The CCT values of two LSG Version 1 LED luminaires were measured on site at garage Level A. These two luminaires were in the center of the measurement grid and were at least 40 feet away from the nearest HPS luminaires.

3.0 Project Results and Discussion

3.1 Electrical Demand and Energy Savings

The HPS luminaires consumed an average of 191 watts each (lamp plus ballast). As a result, the estimated annual power consumption for each luminaire, assuming 8760 hours of operation annually, is 1674 kWh. Version 1 of the LSG LED luminaire consumed an average of 82 watts per luminaire. Over the same annual operating hours, the estimated annual power consumption for each of the LED luminaires is 719 kWh. Version 2 of the LSG LED luminaire is rated at 78 watts and its estimated annual power consumption at 8760 hours of operation is 683 kWh. Table 3.1 contains a summary of the electrical demand and energy savings of the luminaires.

Table 3.1. Electrical Demand and Energy Savings

	Lamp Watts	Hrs/day Use	Annual kWh	Annual kWh Savings	Percent Energy Savings
LSG Low Bay LED luminaire V1*	82*	24	719	955	57%
LSG Low Bay LED luminaire V2**	78**	24	683	991	59%
Crouse-Hinds HPS luminaire*	191*	24	1674		

Notes: * Measured; ** Rated

3.2 Lighting Performance

PNNL conducted illuminance testing on site in the garage at Level A, taking measurements for the six HPS fixtures and of the six Version 1 LED luminaires at ground level at each 4-ft point along the 30-ft by 50-ft measurement grid described in Section 2. No illuminance measurements were taken on site for the Version 2 LED luminaire; however, for evaluation purposes, this luminaire version was projected to produce 30% higher illuminance levels.[1]

The average illuminance levels for each luminaire spacing, and for the entire test area, were calculated and converted to foot-candles for ease of use. These average illuminance levels, along with the maximum and minimum measured values, were then used to calculate the average- and maximum-to-minimum uniformity ratios.

Overall, Version 1 of the LSG LED luminaires provided similar, if not somewhat lower measured minimum illuminance levels (across parking spaces) compared to the HPS luminaires they replaced. Version 2 of the LED luminaire, with its higher light output, is projected to provide slightly higher minimum illuminance level than the HPS luminaires. Note that all three luminaires provided higher minimum illuminance levels than the minimum level recommended by the Illuminating Engineering

[1] Note that this is only a projection based on Version 2's laboratory reported performance. Actual illuminance levels will depend on many factors.

Society of North America (IESNA) of 1 fc on the horizontal surface. Table 3.2 contains a summary comparison of the illuminance levels.

Table 3.2. Illuminance Level Comparison – across Parking Spaces

	Existing HPS Fixture	LSG Low Bay V.1	LSG Low Bay V.2 (Projected)
Max Light Level (fc)	23.51	20.54	26.70
Min Light Level (fc)	1.49	1.45	1.88
Average (fc)	7.35	4.05	5.26
Average to Min	4.94	2.79	2.79
Max to Min	15.81	14.17	14.17

Note: "average" is average of all points measured across the parking spaces, not maximum and minimum points only.

Both versions of the LSG LED luminaires provide lower average light levels than the installed HPS fixtures (about 45% less for the older version and about 28% less projected for the newer version), but the newer version of the LSG luminaire is projected to provide higher maximum and minimum illuminance levels. Lower averages do not necessarily mean that the garage will be dimmer with the new fixtures. Version 1 of the LED luminaires maintained minimum light levels across the parking spaces with slightly increased overall uniformity compared to the HPS (as indicated by the lower max to min uniformity ratios), thus providing slightly more even light distribution.[1] The new version of the LED luminaire is expected to provide slightly higher minimum illuminances than the HPS, with the same even distribution.

Some HPS luminaires typically over-light the area directly beneath the luminaires (creating "hot spots") in order to maintain minimum levels further away.[2] This can result in very noticeable variation in light levels in the illuminated area (this is indicated by a high max to min ratio). A more uniform light distribution is indicated by a lower uniformity ratio. The LED luminaires in this case are expected to provide a slightly better uniformity ratio, but the difference between the HPS and LED uniformity is slight and more than likely not easily discernible. Figure 3.1 and Figure 3.3 show the installed LSG Low Bay luminaires on PPMC Parking Garage Level A.

[1] Independent photometric testing results are available for all three luminaires. The Version 1 LED luminaire (drawing 82 W) produced 3,600 lumens of light. The Version 2 LED luminaire (drawing 78 W) produced over 4,967 lumens of light, 30% more light output than Version 1 (an efficacy of 63 lumens/watt). In comparison the HPS lamp produced 9800 lumens, almost twice as much light output (for an efficacy of 53.7 lumens/watt).

[2] In practice, lighting installations such as parking garages are designed to achieve specific "maintained" illuminance levels, based on the mean lumen output of the lighting system. For HPS lamps, "mean lumens" is typically understood as light output at 50% of rated life. As a result, a lighting installation with new lamps will be initially "over lit."

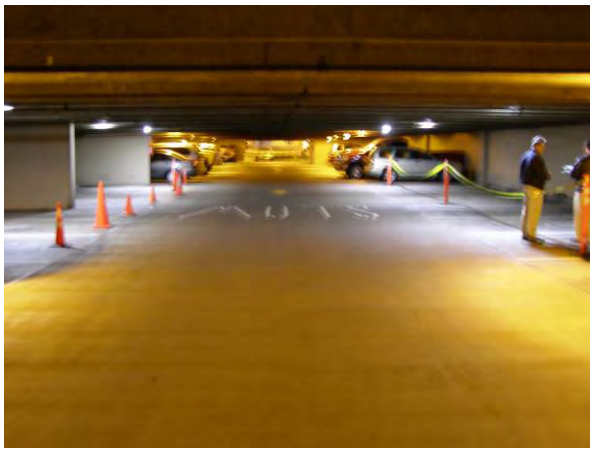

Figure 3.1. Installed LSG Low Bay LED Luminaires on PPMC Parking Garage Level A

No vertical illuminance measurements were taken for either HPS or LED luminaires. However, according to the PPMC Electrician, Version 2 of the LSG LED luminaire provided noticeably more vertical illuminance (more light on the walls or better lateral dispersion) than the Version 1 LED luminaires that were installed on Level A. The color appearance of parked cars was also improved, as illustrated in Figure 3.2.

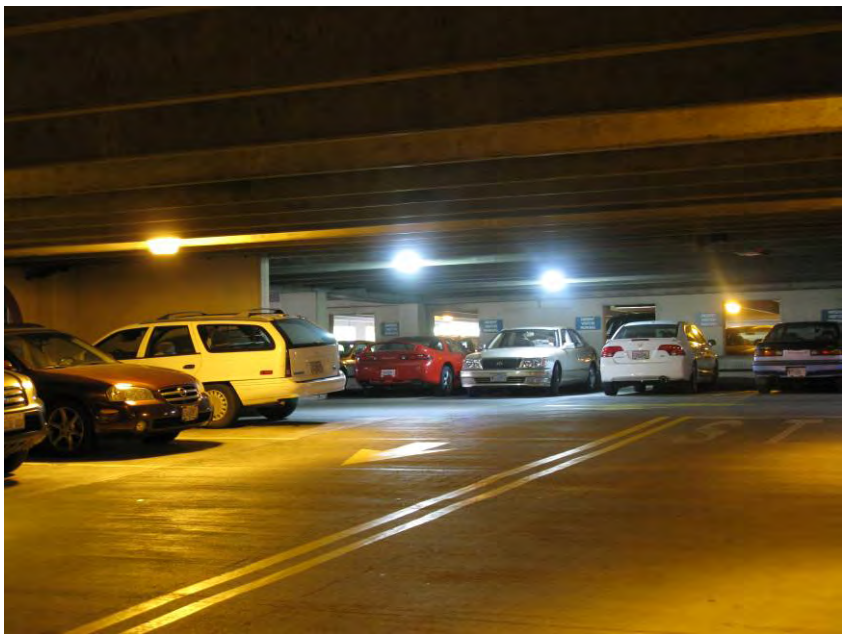

Figure 3.2. LED Luminaires at PPMC Parking Garage Entrance (Level B)

The CCT of two LSG LED luminaires was measured on site at garage Level A. These two LED luminaires were in the center of the grid and were at least 40 feet away from the nearest HPS luminaires.

The CCT measurements for these two luminaires were 5285 K and 5423 K, which is close to the 5600 K CCT claimed by the manufacturer. These CCT measurements indicate a much whiter light than the 2051 K and 2177 K measured for two HPS luminaires that had been installed at the same grid locations. The difference in color between the white light of the LED luminaires and the yellow light of the HPS luminaires is quite noticeable in Figures 3.1 and 3.2.

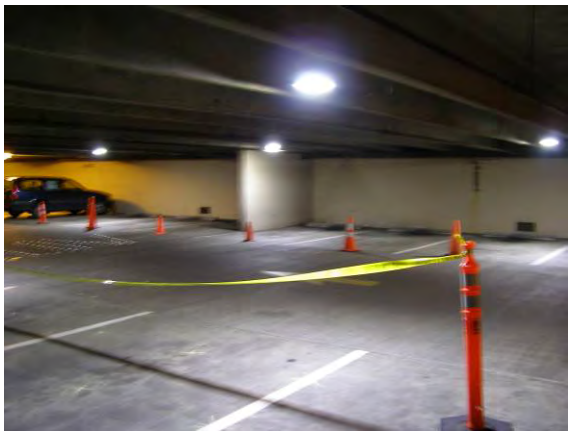

Figure 3.3. Installed LSG Low Bay LED Luminaires on PPMC Parking Garage Level A

Figure 3.4. Installed LSG Luminaire on PPMC Parking Garage Level B

3.3 Lamp Lifetime

Unlike conventional light sources, LEDs typically don't "burn out" and fail suddenly, but rather produce diminished light output over time.[1] HPS lamps also dim gradually over time before eventually failing completely. According to LSG Corporation, the LED luminaires used in this study have a life expectancy of 50,000 hours, meaning at 50,000 hours of use they will still be producing 70% of their initial light output (as measured at 25°C ambient temperature). High operating temperatures can reduce LED light output and shorten their operating life; conversely, cooler operating conditions may extend the life of the diodes.[2]

Note, however, that the long-term performance of LED luminaires is still largely untested. For example, a claimed product life of 50,000 hours translates to nearly six years of continuous operation. IESNA has only recently published an official test method for lumen depreciation testing (LM-80, released in September 2008). Consequently, no independent data is available to corroborate the manufacturer's lifetime estimates.

3.4 User Acceptance

The PPMC Electric Department managed the customer opinion survey for this assessment. Given the difficulty of surveying public users of the garrage, the user survey was conducted only with maintenance and security personnel. Also, once the fixtures were moved to Level B, it was not possible to expand the survey to include the Medical Center nurses who use Level A parking, as originally planned. Two groups of security and maintenance personnel were surveyed: the first group was the night shift staff that routinely walk or drive through the area where the new luminaires were installed (6 total respondents); the second group was the night staff that viewed the area illuminated by the new luminaires on security monitors via installed security cameras in the garage (3 total respondents). A copy of the survey form is presented in Appendix E.

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[1] Under normal operating conditions, the diodes themselves do not suffer from catastrophic failure such as an incandescent filament may experience. Rather, the LEDs simply produce less light. However, other components of an LED luminaire, such as the power supply, can still suffer from a catastrophic failure.

[2] The rated life of the HPS lamp used in this study is 24,000 hours. At 24,000 hours, the HPS lamp would be expected to provide 75%-85% of initial lumens. A LED luminaire, if the manufacturer's predictions are correct and ambient conditions average below 25°C, could still be providing a high percentage of its initial lumens at 24,000 hours. It should also be noted that these LED luminaires contain no replaceable parts. Replacement means the replacement of the full assembly, as opposed to the HPS luminaire, where the lamp, ballast, and lens can be individually replaced (at higher maintenance costs).

Figure 3.5. Installed LED Luminaire at PPMC Garage (Level B), with Security Camera in Background

The first question asked of both groups was if they had noticed the change in garage lighting. A "no" answer to this question meant skipping most of the remaining questions. Six respondents out of ten in the first group, and three out of six of the second group reported noticing the new lighting. The results below are, therefore, limited to these nine respondents, a number sufficient to note any developing trends but insufficient to perform any statistical extrapolation to a larger population.

Four of the nine respondents that expressed any preference felt that the new lights were at least as good as the old lights. Two of the three that observed the relamped area via the security video system expressed a preference for the new lights. Over half of the respondents thought that the LED luminaires provided somewhat more light than the incumbent HPS luminaires. Some of respondents also thought that the LED luminaires were less "glary" and created less shadow. There were also comments suggesting that the new light sources had a more positive impact on overall visibility and helped to improve the appearance of the illuminated area.

3.5 Economic Analysis

Economic performance was evaluated primarily by calculating the simple paybacks for the LED sources versus the HPS sources. To calculate simple payback, current energy and materials costs were used to calculate annual maintenance cost and energy cost. For these calculations, the LSG "quantity pricing" was used at $470 per unit for both versions of the Low Bay LED luminaire. The average price for a new HPS luminaire was assumed to be $275.[1]

To estimate annual and lifetime energy cost, two average electricity rates were used: a commercial rate local to northeast Portland by Portland General Electric (6.5 cents per kWh – Rate Schedule 89) and an average national rate (11 cents per kWh). Under these rates, the LSG LED luminaires yielded annual energy savings of about $62 to $109 per unit when compared to the existing HPS luminaires, based on 24 hours of use per day.[2] Table 3.3 below contains the cost calculations.

[1] The average was obtained through a survey of online merchants such as www.buylightfixtures.com, and Contractor Lighting & Supply (http://www.contractorlighting.com).
[2] Details on the calculations can be found in Appendix F: Payback Calculations.

Table 3.3. Operating Costs and Annual Energy Savings Estimates for LED Luminaires

	Lamp Watts	Hrs/day Use	Annual kWh	Annual kWh Savings	Annual Savings @ 6.5c/kWh	Annual Savings @ 11c/kWh
LSG Low Bay LED luminaire V1	82*	24	719	955	$ 62.06	$ 105.03
LSG Low Bay LED luminaire V2	78**	24	683	991	$ 64.40	$ 108.98
Crouse-Hinds HPS luminaire	191*	24	1674			

Notes: * Measured; ** Rated

Notes: See Appendix F for further details.

Because of the manufacturer's long claimed life (50,000 hrs), the LED modules were assumed to have zero lamp replacement cost over the course of their useful life (about 5.7 years if operated 24 hrs/day). Some maintenance will be required to periodically clean off dust and cobwebs; however, as this would require the same amount of maintenance time regardless of the luminaire type used, it was not figured into the calculations.

Three payback scenarios were calculated: a retrofit 24 hr/day scenario, a retrofit 12 hr/day scenario, and a new construction 24 hr/day scenario.

The first retrofit scenario is based on 24 hours per day of luminaire operation. The retrofit scenario assumes an operational HPS luminaire is already in place and is being replaced by the LED fixture; therefore, the full cost of the LED luminaire ($470) is figured into the payback calculation. The simple payback periods for the LED modules in the retrofit, 24 hr/day usage is between 3.9 and 6.5 years. Table 3.4 shows the cost calculations and payback results.

Table 3.4. Operating Costs and Payback Estimates for LED Low-Bay Luminaire Retrofits – 24-hrs/day Usage

	Estimated Unit Cost	Lamp Watts	Hrs/day Use	Annual kWh	Est. replace lamp costs/year (inc. maint.)	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1*	$ 470	82*	24	719		$ 46.75	$ 79.11	6.5	4.1
LSG Low Bay LED luminaire V2**	$ 470	78**	24	683		$ 44.41	$ 75.16	6.3	3.9
HPS luminaire*	$ 275	191*	24	1674	10.5	$ 119.32	$ 194.66		

Notes: * Measured; ** Rated

Notes: See Appendix F for assumptions.

The second retrofit scenario is based on 12 hours per day of operation and shows that the payback times will lengthen considerably with shorter daily operating hours (Table 3.5)

Table 3.5. Operating Costs and Payback Estimates for LED Low-Bay Luminaire Retrofits – 12 hrs/day Usage

	Estimated Unit Cost	Lamp Watts	Hrs/day Use	Annual kWh	Est. replace lamp costs/year (inc. maint.)	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1*	$ 470	82*	12	360		$ 23.37	$ 39.56		
LSG Low Bay LED luminaire V2**	$ 470	78**	12	342		$ 22.21	$ 37.58	11.0	7.2
HPS luminaire*	$ 275	191*	12	837	10.5	$ 64.92	$ 102.58	11.3	7.5

Notes: * Measured; ** Rated

Notes: See Appendix F for assumptions.

The third scenario is a new construction scenario, where it is assumed that the builder could install either kind of luminaire. Therefore, only the differential cost of the LED luminaire versus the HPS luminaire is taken into account, thus the unit cost used in the calculation of payback is $470 - $275 = $195. Based on this cost, the payback is between 1.6 and 2.7 years (Table 3.6).

Table 3.6. Operating Costs and Payback Estimates for LED Low-Bay Luminaires in New Construction – 24-hrs/day Usage

	Estimated Unit Cost	Lamp Watts	Hrs/day Use	Annual kWh	Est. replace lamp costs/year (inc. maint.)	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1*	$ 470	82*	12	360		$ 23.37	$ 39.56		
LSG Low Bay LED luminaire V2**	$ 470	78**	12	342		$ 22.21	$ 37.58	4.6	3.0
HPS luminaire*	$ 275	191*	12	837	10.5	$ 64.92	$ 102.58	4.7	3.1

Notes: * Measured; ** Rated

Notes: See Appendix F for assumptions.

4.0 Conclusions

In this GATEWAY Demonstration project conducted at Providence Portland Medical Center between April and September 2008, it was determined that the LSG LED area luminaires have the potential to offer significant energy savings over the HPS area luminaires currently in use at the PPMC parking garage. The project also demonstrated how swiftly one manufacturer was able to take advantage of advances in LED technologies within a short time period.

Of the two LED replacement luminaires used in this demonstration, the newer version can provide a higher minimum light level and a more uniform light distribution than the incumbent HPS luminaire. Specifically, the new version of the LSG Low Bay LED luminaire has the potential to improve the minimum light level up to 25% over the HPS luminaires currently used in the PPMC garage (1.88 fc versus 1.49 fc), while providing slightly better light uniformity (2.79 average to minimum ratio versus 4.94 for the HPS luminaire).

Economic analyses were performed and payback costs ranged from 1.6 to 11.3 years, depending on hours of operation per day and whether the luminaire was used in a retrofit or new construction situation. The shortest payback was with the LED luminaire operating 24 hrs/day in the new construction scenario with electricity rates at 11c/kWh (1.6 years). The new LED luminaires could save up to $109 per fixture annually in electricity cost savings, assuming 11c/kWh electricity rates.

The LED luminaires also provided a much whiter light than the HPS lamps; the average CCT for two LED fixtures measured on site was 5354 K versus 2114 K average for the two HPS lamps. The LED luminaires' light output and general lighting performance were commented upon by maintenance and security personnel through a survey. A number of the surveyed security and maintenance staff thought the LED-based fixtures improved the visibility in the garage, compared to the HPS luminaires, and a number indicated their preference for both the visibility and color of the new light source.

From an economic perspective, acceptance of these LED replacement fixtures may be limited by their initial purchase cost. Despite the significant reduction in annual energy consumption and maintenance costs that they can offer in this project, the high upfront cost of these LED products (and of LED products in general) can be a significant barrier to their adoption. Even with the improvements in light output seen in the newer version (at the same cost), the payback period for the LED luminaires used in this study remains slightly longer than its expected lifetime at the lowest electricity rate (6.3 years projected payback versus 5.7 years estimated lifetime). With the expected improvements in efficacy and a reduction in the cost of LED devices, the payback of any LED luminaire installation can improve. Utility incentive programs could also help bring the price down to a more attractive level for users in the near term.

Appendix A

Demonstration Site

Appendix A

Demonstration Site and Luminaire Data

Providence Portland Medical Center (PPMC) is part of Providence Health & Services in Oregon, a not-for-profit network of hospitals, health plans, physicians, clinics, and affiliated health services. The northeast Portland location is a large campus occupying about five city blocks by five city blocks (Figure A1). The garage is lit with about 400 HPS luminaires; most operate 24 hours per day. PPMC's electrician noted that a number of luminaires on the outside perimeter of the parking levels have been retrofitted with photo sensors, so these luminaires would not be operating at 24 hours per day. The Providence facility is evaluating a number of energy-efficient lighting options to replace its stock of aging HPS area lights.

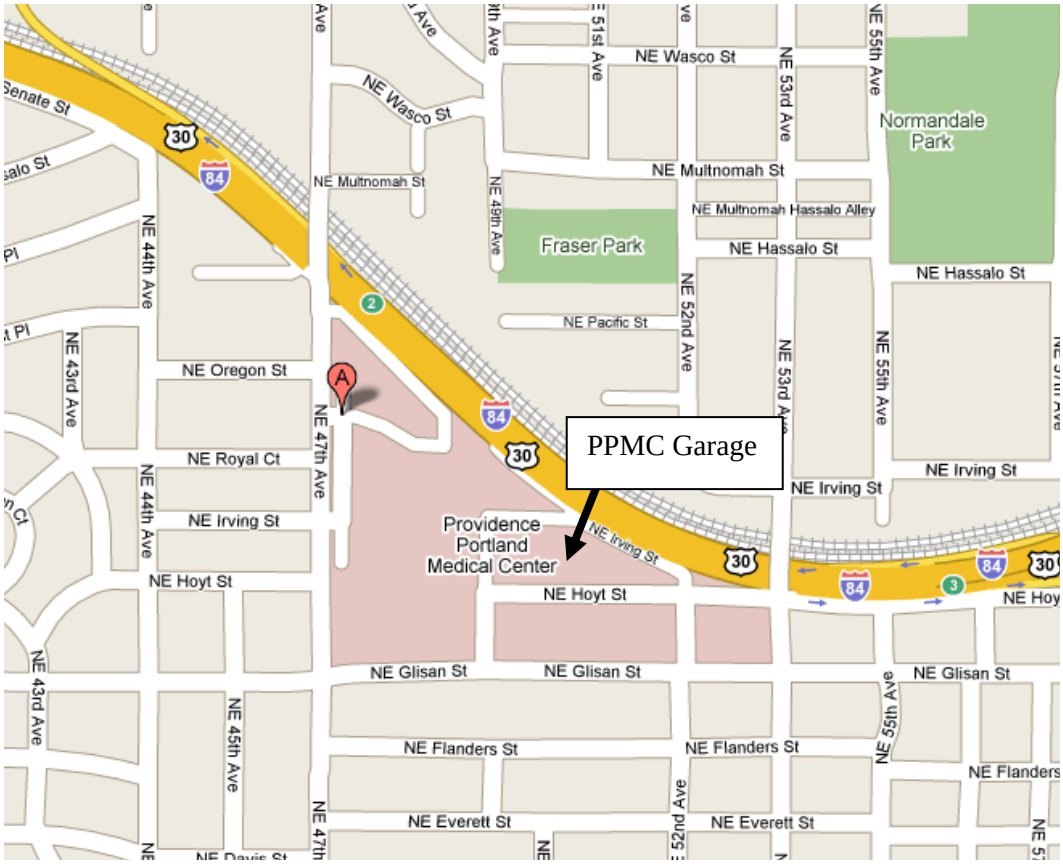


Figure A1. Location of Providence Portland Medical Center, in Southeast Portland, Oregon. Arrow shows garage location.

Garage Specific Data:

- Approximate garage area: 50,000 square feet
- Number of parking levels: 6
- Approximate number of parking spaces: 900
- Parking space width: 9 feet
- Parking space length: 15 feet
- Width of traffic lane: 24 feet
- Garage operating hours: 24 hours/day, 7 days/week, 365 days/year
- Approximate number of luminaires: 410

Luminaire Specific Data:

Crouse-Hinds Lighting

- Cat # LW/VLC15 120/277
- Style # 7240D94G14HPS Parking garage luminaire
- White interior & metal reflector, prismatic truncated cone lens
- GE Magnetic Ballast
- GE 150W HPS lamp, Cat# LU150/55
- Fixture input: 120 VAC / 183 W / 1.7 A / 0.90 PF

Lighting Science Group

- Low Bay PSU/Luminaire
- 14" x 14” x 4-1/16"
- 9 ¼ " x 9 ¼” x 4 1/6” Pyramid shape Acrylic clear lens.
- 108 Cool white LEDs
- Lighting Science ballast
- 220 TO 277V 60Hz Electronic
- 78 W or 85 W

Appendix B

Measuring Equipment

Appendix B

Measuring Equipment

Date: April 13, 2008

Time: 9:45 AM – 4:30 PM

Temperature: 63 Degrees F

Conditions: Covered indoors conditions

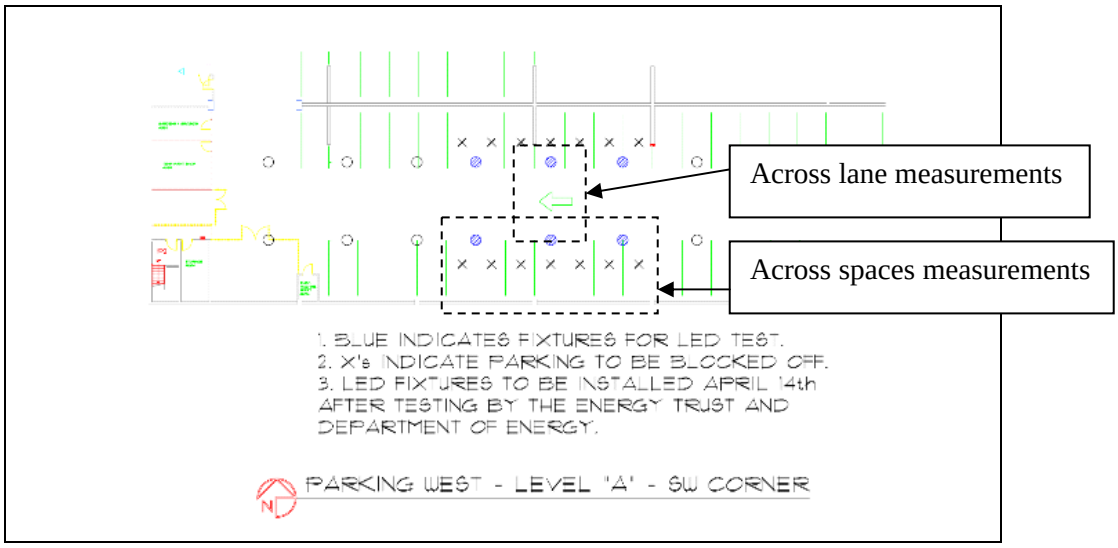
Illuminance Meter	Minolta Illuminance Meter, Model T-1
Chroma Meter	Konica Minolta Chroma Meter, Model CL-200
Power Meter	N/A
Temperature Meter	Indoor thermometer

Appendix C

Measurement Data

Appendix C

Measurement Data



PPMC HPS Data, Across Spaces

21.4	104.0	200.0	253.0
18.1	66.8	172.0	180.0
16.3	31.3	47.7	80.9
16.6	29.7	55.7	64.8
16.0	32.5	69.4	107.0
19.1	52.8	170.0	186.0
20.2	70.8	172.0	202.0
18.2	53.0	170.0	175.0
16.0	32.0	63.0	105.0
16.1	30.5	50.1	76.6
16.0	29.0	59.1	61.9
20.8	50.1	176.0	199.0
16.3	88.8	191.0	249.0

Calculated Values

Average	79.1	7.4
Max	253.0	23.5
Min	16.0	1.49
Ave to min	4.94	4.94
Max to min	15.81	15.81

PPMC LEDs Data, Across Spaces

20.8	44.2	122.0	214.0
18.7	34.7	76.1	124.0
17.8	22.7	36.9	52.1
16.5	20.9	29.6	44.2
16.7	19.7	32.5	38.6
15.9	18.3	36.6	41.4
16.1	26.8	69.2	99.5
16.4	29.3	88.8	175.0
15.9	27.8	57.7	112.0
15.6	20.1	31.9	47.1
15.8	19.3	31.6	40.7
17.1	18.4	35.2	36.9
18.6	21.3	39.9	49.5
20.5	31.7	80.3	123.0
22.8	40.7	121.0	221.0

Calculated Values

Average	43.55	4.05
Max	221.00	20.54
Min	15.60	1.45
Ave to min	2.8	2.8
Max to min	14.2	14.2

Appendix D

Test Data (from Independent Laboratories)

LIGHT LABORATORY INC.
1539 W. Orange Grove Ave.
Building B
Orange, CA 92868
Tel. 877 888-6780 / Fax. 714 288-1481
www.lightlaboratory.com

IES SUSTAINING MEMBER

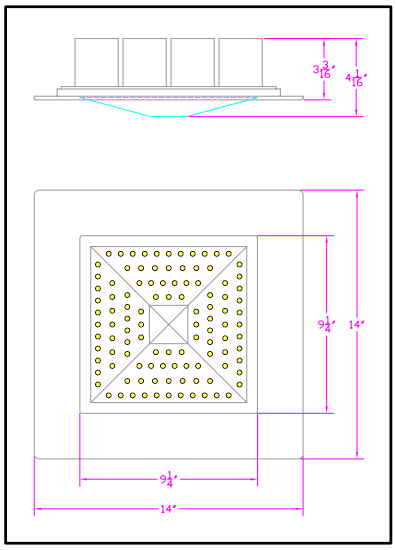
IES INDOOR REPORT
PHOTOMETRIC FILENAME : LLI030804E.IES

DESCRIPTION INFORMATION (From Photometric File)

IESNA:LM-63-2002
[TEST] LLI 0308-04E
[TESTLAB] LIGHT LABORATORY INC.
[ISSUEDATE] 3/17/2008
[MANUFAC] LIGHTING SCIENCE GROUP.
[LUMCAT] LOW BAY PSU/LAMPS-FIXTURE
[LUMINAIRE] 14" SQ. X 4-1/16" H. LOW BAY LUMINAIRE.
[MORE] 9-1/4" SQ. X 7/8" H. PYRAMID SHAPE ACRYLIC CLEAR LENS.
[MORE] 108 COOL WHITE LEDS
[BALLASTCAT] LIGHTING SCIENCE BALLAST
[BALLAST] 220 TO 277V 60Hz ELECTRONIC
[LAMPPOSITION] 0,0
[LAMPCAT] COOL WHITE LED
[OTHER] INDICATING THE CANDELA VALUES ARE ABSOLUTE AND
[MORE] SHOULD NOT BE FACTORED FOR DIFFERENT LAMP RATINGS.
[_INPUT] 220VAC, 78.31W

CHARACTERISTICS

Total Rated Lamp Lumens	N.A. (absolute photometry)
Total Luminaire Efficiency	N.A.
CIE Type	Direct
Spacing Criteria (0-180)	1.38
Spacing Criteria (90-270)	1.38
Spacing Criteria (Diagonal)	1.52
Basic Luminous Shape	Rectangular w/Sides
Luminous Length (0-180)	0.77 ft
Luminous Width (90-270)	0.77 ft
Luminous Height	0.07 ft



LUMINANCE DATA (cd/sq.m)

Angle In Degrees	Average 0-Deg	Average 45-Deg	Average 90-Deg
45	24355	23398	24355
55	23924	22957	23952
65	24217	21000	24396
75	25934	21439	25985
85	27366	31720	27466

IES INDOOR REPORT
PHOTOMETRIC FILENAME : LLI030804E.IES

CANDELA TABULATION

	0	5	15	25	35	45	55	65	75	85
0	1297	1297	1297	1297	1297	1297	1297	1297	1297	1297
1	1296	1298	1297	1298	1299	1299	1299	1298	1297	1299
3	1298	1299	1298	1298	1298	1298	1298	1297	1298	1298
5	1296	1298	1298	1297	1297	1298	1297	1297	1297	1297
7	1295	1295	1295	1294	1293	1294	1293	1295	1296	1295
9	1292	1292	1293	1291	1291	1291	1291	1291	1292	1291
11	1287	1285	1287	1285	1286	1284	1284	1284	1285	1284
13	1277	1277	1279	1279	1281	1278	1280	1279	1279	1276
15	1268	1269	1271	1272	1273	1271	1272	1271	1272	1269
17	1258	1260	1262	1264	1265	1265	1263	1263	1262	1262
19.5	1249	1250	1249	1252	1252	1252	1251	1251	1250	1251
22.5	1239	1239	1236	1239	1240	1243	1242	1240	1237	1238
25.5	1224	1223	1224	1226	1225	1226	1223	1223	1223	1223
29	1193	1193	1200	1205	1202	1200	1200	1204	1203	1194
33	1163	1162	1165	1163	1163	1167	1163	1167	1169	1163
37.5	1132	1129	1125	1120	1124	1121	1126	1123	1126	1129
42.5	1075	1075	1072	1072	1073	1072	1069	1068	1067	1076
47.5	1004	1003	997	994	995	997	995	999	995	1003
55	859	856	856	860	857	865	858	857	860	861
65	679	669	657	649	638	630	637	650	656	675
75	501	492	490	470	466	459	468	471	498	490
85	274	282	314	348	377	386	379	352	315	284
90	203	204	210	225	240	245	245	237	227	212
95	74	75	72	57	33	21	49	69	97	107
105	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0

Vert. Angles	**Horizontal Angles**
	90
0	1297
1	1297
3	1298
5	1296
7	1295
9	1291
11	1285
13	1277
15	1269
17	1261
19.5	1251
22.5	1240
25.5	1222
29	1194
33	1161
37.5	1128
42.5	1073
47.5	1006
55	860
65	684
75	502
85	275
90	209
95	104

CANDELA TABULATION - (Cont.)

105	0
180	0

IES INDOOR REPORT
PHOTOMETRIC FILENAME : LLI030804E.IES

ZONAL LUMEN SUMMARY

Zone	Lumens	%Lamp	%Fixt
0-30	984.38	N.A.	19.8
0-40	1577.4	N.A.	31.8
0-60	2960.33	N.A.	59.6
0-90	4852.94	N.A.	97.7
90-120	114.49	N.A.	2.3
90-130	114.49	N.A.	2.3
90-150	114.49	N.A.	2.3
90-180	114.49	N.A.	2.3
0-180	4967.44	N.A.	100

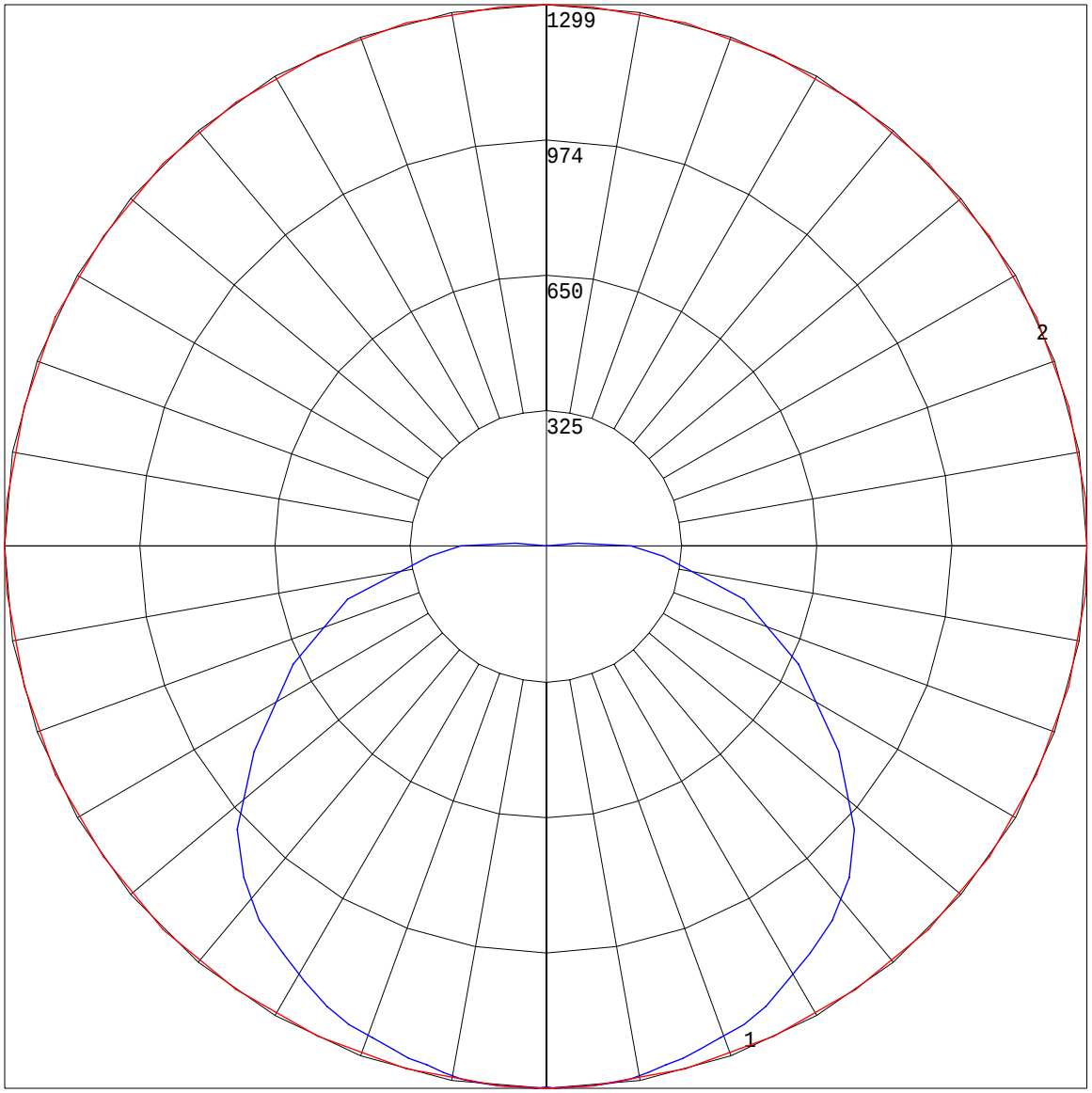
Total Luminaire Efficiency = N.A.%

ZONAL LUMEN SUMMARY

Zone	Lumens
0-10	100.2
10-20	359.64
20-30	524.55
30-40	593.02
40-50	787.91
50-60	595.02
60-70	716.45
70-80	581.77
80-90	594.4
90-100	79.8
100-110	34.69
110-120	0
120-130	0
130-140	0
140-150	0
150-160	0
160-170	0
170-180	0

IES INDOOR REPORT
PHOTOMETRIC FILENAME : LLI030804E.IES

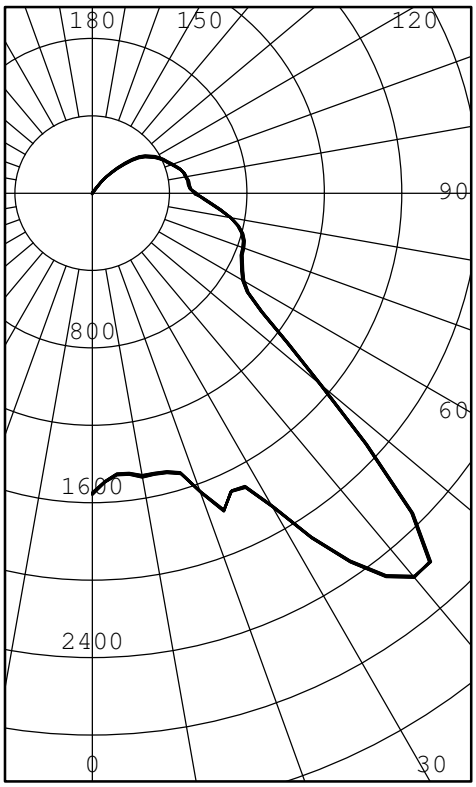
POLAR GRAPH



Maximum Candela = 1299 Located At Horizontal Angle = 5, Vertical Angle = 3
1 - Vertical Plane Through Horizontal Angles (5 - 185) (Through Max. Cd.) : BLUE
2 - Horizontal Cone Through Vertical Angle (3) (Through Max. Cd.) : RED

CERTIFIED TEST REPORT No. 24038

CALIPER # TD 08-90 - GONIOPHOTOMETER TEST - USED HPS PARKING GARAGE LUMINAIRE WHITE INTERIOR & PRISMATIC TRUNCATED PLASTIC CONE OPERATING ON MAGNETIC BALLAST NEW SEASONED GE 150 W HPS LAMP,CAT# LU150/55. LUMINAIRE LUMEN OUTPUT = 9835 LMS. FIXTURE INPUT 120 VAC / 183 WATTS / 1.7 AMPS / .90 PF / BALLAST CASE TEMP 97 F



INTENSITY(CANDLEPOWER) SUMMARY

ANGLE	MEAN CP	LMS.	ANGLE	MEAN CP	LMS.
0	1553		90	532	
5	1460	143	95	504	552
10	1486		100	494	
15	1493	431	105	473	498
20	1646		110	438	
25	1700	805	115	409	405
30	1873		120	375	
35	2324	1448	125	334	296
40	2589		130	269	
45	2336	1708	135	185	146
50	1543		140	110	
55	1069	1006	145	39	31
60	902		150	1	
65	853	850	155	0	0
70	831		160	0	
75	803	838	165	0	0
80	727		170	0	
85	618	678	175	0	0
90	532		180	0	

ZONAL LUMENS AND PERCENTAGES

ZONE	LUMENS	% LAMP	%LUMINAIRE
0-30	1379	14.02	14.02
0-40	2826	28.74	28.74
0-60	5540	56.33	56.34
0-90	7907	80.40	80.40
40-90	5080	51.65	51.66
60-90	2366	24.06	24.06
90-180	1927	19.60	19.60
0-180	9834	100.00	100.00

** EFFICACY: 53.7 LUMENS/WATT **

LUMINANCE SUMMARY - CD./SQ.M.

ANGLE	MEAN CD/SQ M
45	23686
55	11228
65	9598
75	10048
85	9026

CERTIFIED BY:

DATE:
JUL 30, 2008

PREPARED FOR:
RDS
MORGANTOWN, WV

TESTED IN ACCORDANCE WITH IES PROCEDURES.

LIGHTING SCIENCES, INC.
7826 E. EVANS RD.
SCOTTSDALE, AZ, USA 85260

CERTIFIED TEST REPORT No. 24038

CALIPER # TD 08-90 - GONIOPHOTOMETER TEST - USED HPS PARKING GARAGE LUMINAIRE WHITE INTERIOR & PRISMATIC TRUNCATED PLASTIC CONE OPERATING ON MAGNETIC BALLAST NEW SEASONED GE 150 W HPS LAMP,CAT# LU150/55. LUMINAIRE LUMEN OUTPUT = 9835 LMS. FIXTURE INPUT 120 VAC / 183 WATTS / 1.7 AMPS / .90 PF / BALLAST CASE TEMP 97 F

INTENSITY(CANDLEPOWER) DATA

ANGLE	INTENSITY(CANDLEPOWER)	LUMENS
0	1553	
5	1460	143
10	1486	
15	1493	431
20	1646	
25	1700	805
30	1873	
35	2324	1448
40	2589	
45	2336	1708
50	1543	
55	1069	1006
60	902	
65	853	850
70	831	
75	803	838
80	727	
85	618	678
90	532	
95	504	552
100	494	
105	473	498
110	438	
115	409	405
120	375	
125	334	296
130	269	
135	185	146
140	110	
145	39	31
150	1	
155	0	0
160	0	
165	0	0
170	0	
175	0	0
180	0	

Appendix E

Survey of Users' Perceptions of LED Lighting

Appendix E

Survey of Users' Perception of LED Lighting

Subject: Test Lighting Questionnaire

An alternative type of light fixture was recently installed by the PPMC Garage Entrance (Level B) and on Level A. The U.S. Department of Energy is interested in your opinions of the alternative light and has constructed a brief questionnaire to obtain your feedback.

1. Did you notice that new lights were installed?

Yes --1
No **(SKIP TO Q12)** 2

(ASK Q2-Q11 ONLY IF YES IN Q1)

2. Do you feel that the new light fixtures have improved or not improved overall visibility in the area where they are installed?

Strongly improved	--1
Somewhat improved	--2
Somewhat not improved	--3
Strongly not improved	--4
No change/about the same	--5
DK/NA	--6

3. Do you feel that the new fixtures have made it easier or more difficult to see faces?

Much easier	--1
Somewhat easier	--2
Somewhat more difficult	--3
Much more difficult	--4
No change/about the same	--5
DK/NA	--6

4. Do you feel that the new fixtures create less glare or more glare?

Much less glare	--1
Somewhat less glare	--2
Somewhat more glare	--3
Much more glare	--4
About the same as old lights	--5
DK/NA	--6

5. Do you feel that the new fixtures provide the right amount of light, or are they too bright or too dim?

Right amount of light	--1
Much too bright	--2
Somewhat too bright	--3
Somewhat too dim	--4
Much too dim	--5
DK/NA	--6

6. Do you feel that the new light fixtures create fewer or more shadows?

Many fewer	--1
Somewhat fewer	--2
Somewhat more	--3
Many more	--4
No change/about the same	--5
DK/NA	--6

7. Do you feel the new light fixtures have improved or not improved the overall appearance of the building and site?

Strongly improved	--1
Somewhat improved	--2
Somewhat not improved	--3
Strongly not improved	--4
No change/about the same	--5
DK/NA	--6

8. Do you feel the new light fixtures have improved or not improved the overall safety of the building and site?

Strongly improved	--1
Somewhat improved	--2
Somewhat not improved	--3
Strongly not improved	--4
No change/about the same	--5
DK/NA	--6

9. When all things are considered, do you prefer the new light fixtures that were installed or do you prefer the old light fixtures they replaced?

Strongly prefer new fixtures	--1
Somewhat prefer new fixtures	--2
Somewhat prefer old fixtures	--3
Strongly prefer old fixtures	--4
DK/NA	--5

10. In a few words of your own, why do you prefer the light fixtures you selected in the last question? (Skip if no preference.)

a. New fixtures

_____

b. Old fixtures

_____

Appendix F

Payback Calculations and Assumptions

Appendix F

Payback Calculations and Assumptions

Assumptions:
HPS luminaire cost: $275 (average)
HPS replacement lamp cost: $35 (www.grainger.com)
HPS lamp lifetime: 24,000 hrs
LED luminaire cost: $470
LED luminaire lifetime: 50,000 hrs

A. Retrofit Case, 24 hours operation:

	Estimated Unit Cost	Annual kWh	Cost of Electricity	Cost of Electricity	Energy Cost/Year @ 6.5c/kWh	Energy Cost/Year @ 11c/kWh	Annual Savings @ 6.5c/kWh	Annual Savings @ 11c/kWh	Est. replace lamp costs/year	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1*	$ 470	719	0.065	0.11	$ 46.75	$ 79.11	$ 62.06	$ 105.03		$ 46.75	$ 79.11	6.5	4.1
LSG Low Bay LED luminaire V2**	$ 470	683	0.065	0.11	$ 44.41	$ 75.16	$ 64.40	$ 108.98		$ 44.41	$ 75.16	6.3	3.9
Crouse-Hinds HPS luminaire*	$ 275	1674	0.065	0.11	$ 108.81	$ 184.14			10.5	$ 119.32	$ 194.66		

Notes: * Measured; ** Rated

B. Retrofit Case, 12 hours operation:

	Estimated Unit Cost	Annual kWh	Cost of Electricity	Cost of Electricity	Energy Cost/Year @ 6.5c/kWh	Energy Cost/Year @ 11c/kWh	Annual Savings @ 6.5c/kWh	Annual Savings @ 11c/kWh	Est. replace lamp costs/year	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1*	$ 470	360	0.065	0.11	$ 23.37	$ 39.56	$ 31.03	$ 52.52		$ 23.37	$ 39.56		
LSG Low Bay LED luminaire V2**	$ 470	342	0.065	0.11	$ 22.21	$ 37.58	$ 32.20	$ 54.49		$ 22.21	$ 37.58	11.0	7.2
Crouse-Hinds HPS luminaire*	$ 275	837	0.065	0.11	$ 54.41	$ 92.07			10.5	$ 64.92	$ 102.58	11.3	7.5

Notes: * Measured; ** Rated

C. New Construction Case, 24 hours operation:

	Estimated Unit Cost	Annual kWh	Cost of Electricity	Cost of Electricity	Energy Cost/Year @ 6.5c/kWh	Energy Cost/Year @ 11c/kWh	Annual Savings @ 6.5c/kWh	Annual Savings @ 11c/kWh	Est. replace lamp costs/year	Annual Operating Costs @ 6.5c/kWh (elec + rep)	Annual Operating Costs @ 11c/kWh (elec + rep)	LEDs Payback @ 6.5c/kWh (Years)	LEDs Payback @ 11c/kWh (Years)
LSG Low Bay LED luminaire V1	$ 470	719	0.065	0.11	$ 46.75	$ 79.11	$ 62.06	$ 105.03		$ 46.75	$ 79.11		
LSG Low Bay LED luminaire V2	$ 470	683	0.065	0.11	$ 44.41	$ 75.16	$ 64.40	$ 108.98		$ 44.41	$ 75.16	2.6	1.6
Crouse-Hinds HPS luminaire	$ 275	1674	0.065	0.11	$ 108.81	$ 184.14			10.5	$ 119.32	$ 194.66	2.7	1.7

Notes: * Measured; ** Rated

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