GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light Emitting Diode (LED) Walkway Lighting

Host Site: Federal Aviation Administration William J. Hughes Technical Center, Atlantic City, New Jersey

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
Federal Aviation Administration
Beta LED, Inc.

March 2008

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

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Electronic copies of the report are also available from the DOE Solid State Lighting website at http://www.netl.doe.gov/ssl/techdemos.htm.

This document was printed on recycled paper.
(9/2003)

PNNL- 17407

Demonstration Assessment of Light Emitting Diode (LED) Walkway Lighting at the Federal Aviation Administration William J. Hughes Technical Center, in Atlantic City, New Jersey

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
Federal Aviation Administration
Beta LED, Inc.

B.R. Kinzey
M.A. Myer

March 2008

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830
Pacific Northwest National Laboratory
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) 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 documents the results of a collaborative project to demonstrate a specific solid state lighting (SSL) general illumination product in an outdoor area walkway application. In the project, six light-emitting diode (LED) luminaires were installed to replace six existing high pressure sodium (HPS) luminaires mounted on 14-foot poles on a set of exterior walkways and stairs, situated between a pair of buildings and a parking lot located at the Federal Aviation Administration (FAA) William J. Hughes Technical Center in Atlantic City, New Jersey. Installation of the SSL product occurred in December, 2007. The effort was a U.S. Department of Energy (DOE) SSL Technology Gateway Demonstration that involved a teaming agreement between DOE, FAA and Ruud Lighting (and their wholly owned division, Beta LED) with measurement and analysis conducted by Pacific Northwest National Laboratory (PNNL).

The focus of the DOE Gateway Demonstrations is to identify new SSL products that achieve three goals: 1) save energy relative to the incumbent technology; 2) match or better the existing illumination and visibility produced by the incumbent technology; and 3) offer economic value to users.[1] Once products are identified, the Gateway activity strives to find suitable applications where those products can be installed and their attributes demonstrated. Products are independently tested to verify their performance prior to being accepted into the Gateway Program, and applications are carefully selected to ensure a good match with the attributes of the given product. Pre- and post-installation power and illumination measurements are taken and used in calculations of energy savings and related economic payback. Finally, "users" or personnel impacted by the new lights are provided questionnaires to gauge their perceptions and feedback. All of this information is provided for the product and application discussed herein.

In this project, the SSL product demonstrated energy savings of more than 25% while maintaining illuminance levels and improving illuminance uniformity, compared to new high pressure sodium (HPS) lamps installed in the existing luminaires at the site. As a new technology, LED luminaires cost more to initially purchase than the traditional, commodity-grade HPS light sources. Many factors contribute to the economic performance of LED luminaires in any given installation, so a range of payback scenarios must be typically considered rather than a single value.

Further, the Beta LED product used in this project is modular, consisting of a series of "light bars" that each contain 20 LEDs. Adding (or subtracting) light bars from a given fixture increases (or decreases) both light output and final cost. The fixtures selected for this application used a 3-bar configuration (for a total of 60 LEDs) to produce illuminance levels similar to the existing HPS luminaires. However, computer simulation has determined that 2-bar (40 LED) luminaires would also easily provide the IESNA recommended minimum level of illumination needed for this particular

[1] It should be stressed that the focus of the Gateway Demonstrations is **not** to evaluate all possible investment decisions for the site and identify the "best" among them. Rather, the demonstrations provide a single data point related to the particular product tested; due diligence on the part of the host site is subsequently required to evaluate this information against other possible alternatives and their attendant financial and other benefits.

walkway application (minimum average of 0.5 fc), while going to the lower wattage luminaire would significantly reduce the payback ranges discussed below.

Table ES.1 below summarizes the energy savings for this demonstration project.

Table ES.1. Existing Lighting Data and Results from LED Replacement Luminaires

	Existing 70W* HPS	New 3-bar Luminaire	Optional 2-bar Luminaire
Average illumination levels	3.54 fc	3.63 fc	2.42 fc
Max/Min Ratio**	6.04:1	2.68:1	2.68:1
Energy consumption per luminaire***	425 kWh/yr	311 kWh/yr	210 kWh/yr
Energy savings per luminaire	N/A	114 kWh/yr **26.8%**	215 kWh/yr **50.6%**

* Nominal wattage.
** Measurement of lighting uniformity; lower ratios indicate more uniformly lit area.
*** Energy consumption for the HPS system is based on manufacturer-rated power levels for lamps and ballasts, multiplied by 4380 hours per year. Energy consumption for the 3-bar LED unit is based on laboratory power measurements multiplied by 4380 hours per year. Energy consumption for the 2-bar unit is based on manufacturer-rated power levels multiplied by 4380 hours per year.

The amount of light (or average illuminance) provided by the new 3-bar SSL luminaires was very similar (~3.5 fc) to that provided by the original HPS installation, while illuminance uniformity improved (as indicated by the significantly reduced max/min ratio). Increased uniformity translates into less contrast between shadows and bright spots and improved overall visibility. Thus, the SSL installation both saves energy and improves the lighting quality in this demonstration.

Tables ES.2 and ES.3 display the results of an economic analysis using 2-bar and 3-bar LED luminaires across a range of scenarios. The scenarios vary two important aspects of the situation: whether or not maintenance savings are included in the estimates and whether or not the original HPS fixtures are due for replacement. Payback ranges vary widely depending on how these factors are treated.

The FAA pays for a site-wide maintenance contract that includes lighting as only one component covered under the contract. As a result, FAA is not directly billed for the labor cost of lamp or ballast replacement, because it is rolled into a larger contract fee. While some maintenance savings is assured from not having to relamp and reballast the existing fixtures, the actual amount cannot be realized without a renegotiation of the existing maintenance contract. Results therefore include estimates with and without an estimated maintenance savings.

The second factor, whether or not the original fixtures are to be replaced, means the LEDs are being compared against both a new HPS installation as well as a “do nothing” alternative. Given the existing HPS fixtures are 30+ years old it is likely they will be replaced with something sooner or later, yet they are still operational so both of these scenarios are relevant. Table ES.2 shows the results for the case where the existing luminaires will be retained if not replaced by the LED product. In Table ES.2, Net Savings is the Life Cycle Cost (LCC) of the Alternative Case (replacing HPS luminaires with LED luminaires) subtracted from the LCC of the Base Case (the do-nothing or don’t replace the HPS luminaires case). In Table ES.3, the original luminaires are to be replaced with either a new HPS or a

new LED product. In Table ES.3, Net Savings is the Life Cycle Cost (LCC) of the Alternative Case (replace the HPS lamps with SSL) subtracted from the LCC of the Base Case (replace HPS with new HPS). The results in Table ES.3 would be relevant to a new installation, where a building owner is determining whether to install LED technology or HPS technology.

Table ES.2. Results of Economic Analysis for Non-Replacement Scenario

Base Case	Alternative Case	Net Savings*	Savings to Investment Ratio (SIR)	Adjusted Internal Rate of Return (AIRR)	Simple Payback (Years)†	Discounted Payback (Years)†
HPS, existing fixture, energy only (no maintenance)	3-bar SSL	($804)	0.14	-5.57%		
HPS, existing fixture, including maintenance	3-bar SSL	($68)	0.93	2.66%	18	
HPS, existing fixture, energy only (no maintenance)	2-bar SSL	($478)	0.39	-1.17%		
HPS, existing fixture, including maintenance	2-bar SSL	$258	1.33	4.29%	13	16
* Net Savings is the Life Cycle Cost (LCC) of the Alternative Case subtracted from the LCC of the Base Case. †A blank space indicates that payback is not achieved within the design lifetime of the LED (23 years or 100,000 hrs).						

Table ES.3. Results of Economic Analysis for Luminaire Replacement Scenario

Base Case	Alternative Case	Net Savings*	Savings to Investment Ratio (SIR)	Adjusted Internal Rate of Return (AIRR)	Simple Payback (Years)†	Discounted Payback (Years)†
HPS, replace fixture, energy only (no maintenance)	3-bar SSL	($224)	0.36	-1.45%		
HPS, replace fixture, including maintenance	3-bar SSL	$513	2.46	7.14%	7	7
HPS, replace fixture, energy only (no maintenance)	2-bar SSL	$103	1.51	4.87%	10	12
HPS, replace fixture, including maintenance	2-bar SSL	$839	5.16	10.67%	3	3
* Net Savings is the Life Cycle Cost (LCC) of the Alternative Case subtracted from the LCC of the Base Case. †A blank space indicates that payback is not achieved within the design lifetime of the LED (23 years or 100,000 hrs).						

FAA Ordinance 1600.9B and Executive Order 12902 direct the agency to use a 10-year payback guideline in evaluating energy efficiency equipment procurements. **Incorporating both maintenance**

savings and the replacement cost of a new HPS luminaire therefore yields favorable payback results for either the 2-bar or 3-bar LED alternatives. In addition, if simple rather than discounted payback is used, the 2-bar LED is cost effective against a new HPS luminaire even ignoring the value of maintenance savings. There may be further savings not accounted for in these values as well, for example, resulting from improved lighting quality of the white light compared to the much narrower-spectrum yellow light of the HPS.

In sum, both the original lighting and the replacement 3-bar LED luminaires, which were sized to match the original levels of illumination, provide significantly more light than the IESNA recommended minimum for exterior walkway applications (0.5 fc average). Such "over-lighting" directly translates into higher costs than necessary, both in terms of energy used and in fixture capital costs. For this reason, a 2-bar LED luminaire should be considered for installation at the site. However, either the 2-bar or the 3-bar luminaires can potentially meet the 10-year payback criterion, depending on what they are being compared against.

In the future, the dramatic pace of improvement underway in both LED chip performance and price can be expected to continue reducing the premium on LED-based products. Both of these factors will lead to further reductions in the payback periods achieved from LED retrofits.

Contents

Figures

Tables

1.0 Introduction

This report describes the process and results of a demonstration of solid state lighting (SSL) technology in an exterior walkway application. The project was supported under the U.S. Department of Energy (DOE) Solid State Lighting Program. Other participants in the demonstration project included the Federal Aviation Administration (FAA), William J. Hughes Technical Center (Tech Center) in Atlantic City, New Jersey, and Beta LED (a division of Ruud Lighting). Pacific Northwest National Laboratory conducted the measurements and analysis of the results. PNNL manages these demonstrations for DOE and represents their perspective in the conduct of the work.

DOE is presently supporting a number of such demonstration projects to develop real world experience and data with SSL products in general illumination applications. Other project reports and related information are available via DOE's SSL website at www.netl.doe.gov/ssl/.

DOE first issued an Invitation to Participate in March 2007 to solicit market-ready SSL products for demonstration. In parallel, DOE contacted a number of Federal and private agencies to identify parties potentially interested in participating in the demonstrations, either as host sites or through related motivations such as interests in promoting energy efficiency. DOE's approach is to carefully match applications with suitable products and form teams to carry out the needed project work.

FAA submitted a number of potential applications for consideration, including multiple opportunities within the Tech Center. The Tech Center serves as a training and research center for FAA and is one location where new technologies, equipment, and even materials like tarmac are tested prior to being rolled out to the entire agency. As the facility receives a relatively large number of visitors and thereby external visibility, an exterior walkway application was selected as a suitable opportunity for the available LED product.

The product selected for demonstration at the site is the Ruud Beta LED "The Edge" Area Light. Ruud Lighting submitted a proposal in response to the March 2007 solicitation that proposed the entire "The Edge" family of products. Two models of The Edge products were tested in July 2007 prior to their acceptance into the demonstration program to verify their performance; the area luminaire (8-bar) exhibited a total luminous flux of 9800 lumens at a luminaire efficacy of 52 lm/W, making them the highest performing products submitted to the program at that time.[2]

[2] This initial qualification of the product family was achieved using an earlier version than was ultimately demonstrated in December of 2007. The model that was demonstrated contained a subsequent generation of LED chip that offered an even higher efficacy of 57 lm/W.

2.0 Methodology

PNNL conducted a preliminary site visit to the FAA to document the existing conditions at that location. Sites are not always ideal for demonstrations; other nearby luminaires may adversely affect the planned illumination measurements, or limited access to the site/equipment may restrict project activities, etc. A walkway leading from a parking lot to the main entrance of Building 300 was selected to serve as the demonstration area. Preliminary illumination measurements were taken and subsequently compared against modeling results for the SSL product to ensure it would sufficiently satisfy the site requirements.

2.1 Site Description

The chosen area is a high-volume walkway running from Parking Lot B to Building 300; it includes three short sets of stairs with a number of other staircases in the general area. The walkway is also adjacent to another building, Building 316, which serves to further increase the volume of foot traffic past the demonstration luminaires. A total of six luminaires illuminate the walkway. Four of the luminaires (L3, L4, L5, and L6) are located on a flat section of walkway and two luminaires (L1 and L2) are located on a higher section of walkway leading to a round plaza. This section is adjacent to the first section via a staircase of five stairs. All of the luminaires are mounted on 14-foot poles. A seventh fixture is located nearby but was not included in the demonstration. This seventh luminaire is obscured by foliage from an adjacent tree much of the year (see arrows in Figure 1.1). Image 1 was taken from a GIS satellite; yellow dots in the photo indicate the location of the six luminaires in the demonstration. Image 2 was taken at night during the initial site visit.

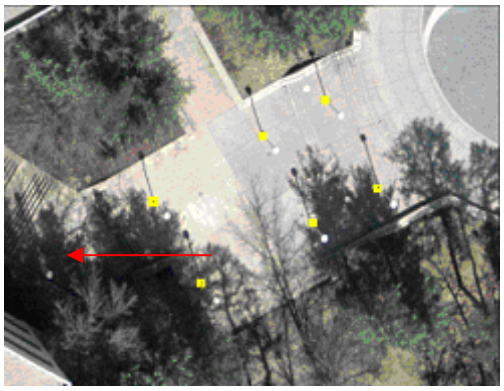


Image 1

Image 2

Figure 2.1. Aerial and Color Views of Original HPS Luminaires

Recessed step lights are also installed within the plaza (see Image 3 in Figure 2.2), which appear to use metal halide (MH) lamps, though they were not working properly at the time of demonstration. The round plaza adjacent to the demo walkway contains similar step lights, and only a few of those were working properly. Floodlights are also mounted to some of the walkway poles just outside of the round plaza (see Image 4 in Figure 2.2). The floodlights use HPS lamps and provide illumination where the step lights do not. Due to the grade changes between the plaza and the demonstration walkway (about

4 feet) the light from the HPS floodlights spills over onto the walkway. Supply voltage to all luminaire types is 277 volts.

Image 3

Image 4

Figure 2.2. Nearby Walkway Area Lights that Were not Replaced. Image 3 shows Recessed Step Lights, most of which were not working. Image 4 shows flood lights that were mounted to nearby poles to provide stair lighting in place of the non-functioning recessed step lights; these flood lights provided some light to the test area which was included in the ambient light measurements.

2.2 Existing Luminaires

The existing on-site luminaires are 30 years old or more and were manufactured by Sterner Lighting (catalog # M-99435). Luminaire dimensions are approximately 10" tall x 23" outside diameter. Each luminaire is mounted to its pole via a collar with three tenons. Lamps are vertically oriented with the ballast located inside the pole near the luminaire. The ballasts used by the luminaires are the HX-HPF type made by Advance Transformer Company (catalog # 74P7933-011-P [or N, for "normal" power factor correction]). The original lamps installed were 70W HPS manufactured by Osram/Sylvania (ANSI Code LU70/Eco), with rated CCT of 1900 and a CRI of 22. More information about the lamps and ballasts can be found in Appendix A.

The integral lens of the luminaire appeared to be tempered glass in good condition (not cracked or discolored). The lens managed to sufficiently seal the luminaire over the life of the luminaire so that the internal reflectors appeared to be in good condition as well.

The luminaires to be replaced with the LED product were first cleaned with a wet rag and re-lamped with fresh HPS lamps on November 16, 2007. As lamps at the site operate a minimum of 12 hours per night during this time of year, by the time the illuminance measurements were taken on December 5, 2007, the lamps had operated well over the 100 hours used for normal "burn-in" of discharge lamps. Ballasts were not replaced for purposes of these measurements.

2.3 New Luminaires

The new luminaires were manufactured by RUUD Lighting's Beta LED division.[3] The nominal dimensions of the luminaire are 18" wide x 14" long x 2" tall. The luminaire was mounted to the pole via two tenons, replacing the entire collared subassembly used for the previous HPS. For aesthetics, the luminaires were oriented so that the axis of the tenons were parallel to the walkway. The major axis of the walkway extends from the building to the parking lot and the arrangement of the luminaires reinforces this axis. The luminaire distribution is Type V (symmetric).

The LEDs and drivers were manufactured by Cree and Advanced Transformer, respectively. The LEDs are Model XRE, generation Q5 chips.

2.4 Installation

Figure 2.3 provides comparative side-by-side images of the two luminaire types. Image 5 and Image 7 in Figure 2.3 are of the original HPS luminaires and Image 6 and Image 8 are the replacement LED luminaires. One of the original HPS fixtures is also visible in the background of Image 6.

The layout of the fixtures and corresponding measurements for the original HPS lamps are shown in Figure 2.4.

[3] Beta LED model number BLD-ARE-T5-DA-042-LED-A-UL-WH.

Image 5

Image 6

Image 7

Image 8

Figure 2.3. Images 5 and 6 show the Six Study Luminaires with the original HPS Lighting and After Replacement with the LED Luminaires. Images 7 and 8 show details of the HPS and LED Luminaires.

2.5 Power and Energy

The nominal wattage of the HPS lamps is 70 watts. The ballast manufacturer's specification sheet lists a power consumption of 97 watts at 277V. (This sheet and is included in Appendix A.) Real power consumption of the lamp and ballast may vary slightly over the course of their lifetimes but this analysis uses a new lamp and assumes a new ballast as the reference baseline. (In our demonstration the lamps were actually replaced, ballasts were not.)

The 3-bar LED luminaire draws 71 watts, according to power measurement taken under steady state operating conditions in an independent testing laboratory.

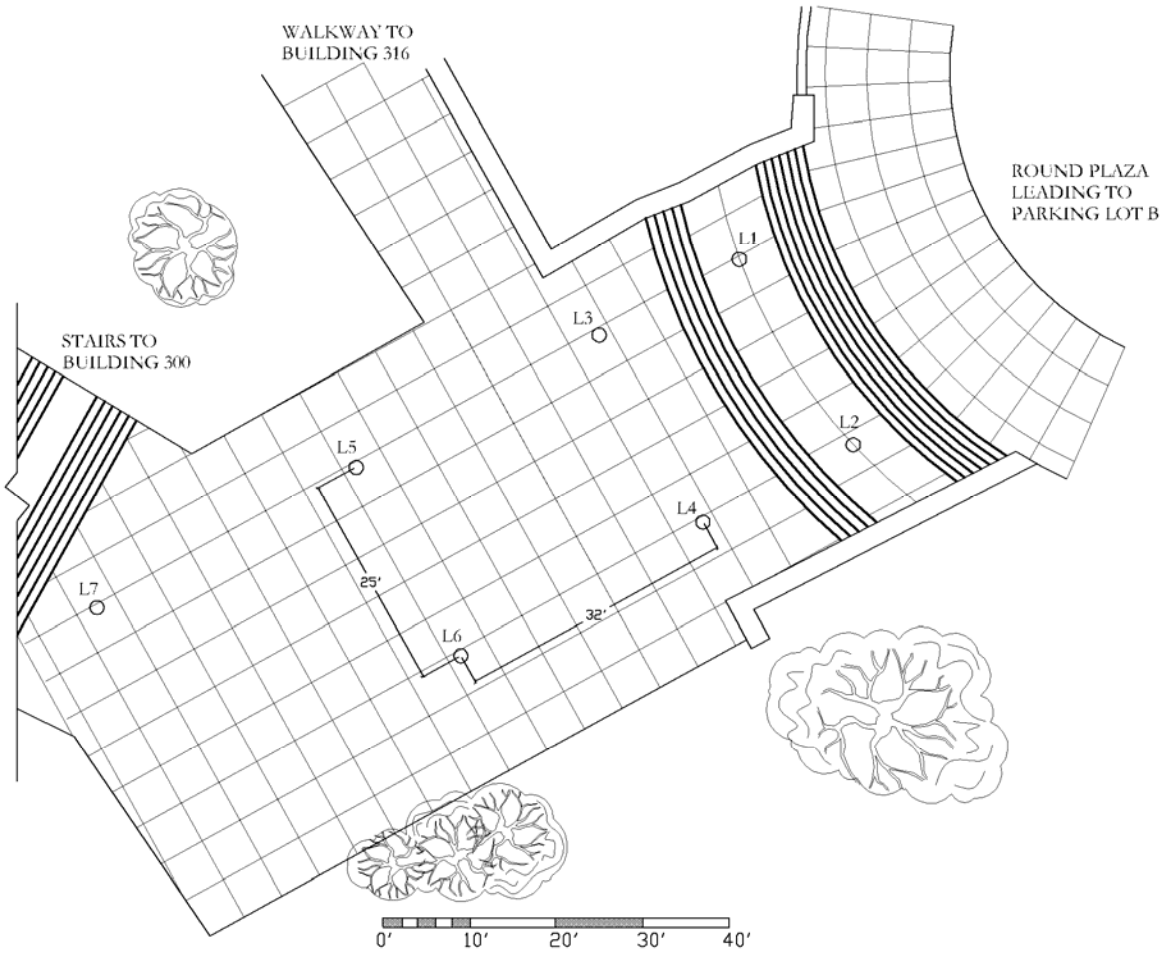


Figure 2.4. Luminaire Layout

Table 2.1 lists the yearly energy consumption of both the existing and new luminaires assuming 12 hours per day of operation or 4380 hours per year. The HPS input power is based on manufacturer lamp and ballast ratings. The LED input power is based on laboratory measurements.

Table 2.1. Estimated Yearly Energy Consumption per Luminaire

Luminaire	Input Power	Yearly Operating Hours	Yearly Energy Consumption (kWh)	Annual Cost ($0.103/kWh)
HPS	97W	4380	425	$43.78
LED	71W	4380	311	$32.03

Replacing the existing luminaires with the LED luminaire therefore results in a 27% energy savings, or $11.75 per year per luminaire replaced.

2.6 Illuminance

On Wednesday, December 5, 2007, the HPS luminaires were turned on at 15:00 and the sun set at 16:34 pm. The illuminance measurements began at 17:21 and ended at 17:51. A winter storm had moved into the area earlier that afternoon, so that snow fell prior to and during the illuminance measurements. The sky was overcast; had it been a clear sky, a quarter-sphere moon might have been visible. The temperatures recorded at the start and the end of the illuminance measurements were 33.4° F and 32.1° F, respectively.

Photopic illuminance was measured on a 5' x 5' grid. Coincidentally, the plaza has 5' square concrete tiles so the intersections of these tiles provided convenient points of measurement. Table 2.2 below lists the illuminance readings obtained for the main plaza. Note that these values also include light from ambient sources, which was subsequently removed as explained below. The gray boxes indicate locations where data points do not exist due to obstructions such as a knee-wall (points A9 – D9, and J5-J9) or curves in the stairs (A3 – A6).

Table 2.2. Illuminance Measurements on December 5, 2007, under HPS Luminaires (fc)

	1	2	3	4	5	6	7	8	9
A	4.76	5.25					6.71	4.63	
B	6.26	5.35	6.03	5.46	5.42	**7.57**	5.60	4.96	
C	6.36	6.68	4.02	3.56	4.11	5.20	5.34	3.45	
D	4.47	5.52	5.25	3.25	3.89	5.48	4.83	3.03	2.92
E	2.19	3.27	3.50	3.32	3.13	3.43	3.76	2.68	**1.30**
F	2.53	2.03	2.84	2.47	2.91	3.26	3.22	2.61	***0.55***
G	2.52	1.90	3.30	3.04	3.27	3.28	3.10	2.29	1.65
H	4.17	2.98	4.67	3.53	3.53	4.52	3.14	2.09	2.33
I	3.42	4.53	3.34	3.33	2.60	3.53	3.41	2.36	2.86
J	1.79	1.83	3.16	1.84					

The average illuminance measured across the grid was 3.69 fc. The maximum and minimum illuminances, shown in bold, were 7.57 fc and 1.30 fc, respectively. The illuminance value of 0.55 (bold italics) is perceived to be an anomaly in that the lift used in the installation was left near the plaza and was partly extended over this point, blocking some of the light.

The IESNA recommends a minimum of 0.5 fc for a walkway, measured on the walkway surface.[4] All areas within the grid easily satisfied this criterion.

After the total illuminance was measured, the luminaires on the plaza were turned off so a baseline measurement could be taken to identify the level of ambient light impacting the data points. Ambient light typically includes light emanating from near-by buildings, stars, skyglow, the moon, as well as other lighting on or near the site. In this case, the light from other luminaires nearby significantly impacts these measurements.

There are existing luminaires on the round plaza adjacent to the stairs and demonstration area that are not working properly. In an attempt to provide adequate illumination to the round plaza, HPS

[4] RP-33-99 IESNA Recommended Practice for Lighting for Exterior Environments

floodlights have been mounted to the poles near the parking lot and are pointed into the plaza (see example in Image 4 in Figure 2.2). These flood lights are causing the variability of illuminance measurements of adjacent points (e.g., cells D5 and D6 in Table 2.2) by spilling light into the measurement area. Table 2.3 lists the illuminance values of the site measured on December 5, 2007, without the HPS post tops lights operating, and thus comprises the ambient baseline. These measurements were taken during the period from 18:10 to 18:40.

Table 2.3. Illuminance Measurements on December 5, 2007, Baseline Ambient Light

	1	2	3	4	5	6	7	8	9
A	0.02	0.02					**0.01**	**0.01**	
B	0.04	0.04	0.02	0.02	0.02	0.02	0.03	0.03	
C	0.07	0.02	0.05	0.04	0.04	0.05	0.03	0.04	
D	0.13	0.05	0.07	0.04	0.05	0.05	0.09	0.06	0.07
E	0.17	0.23	0.13	0.15	0.09	0.24	0.13	0.04	0.05
F	0.24	0.40	0.17	0.22	0.16	0.28	0.20	0.20	***0.27***
G	0.39	0.08	0.22	0.25	0.30	**0.41**	0.24	0.25	0.24
H	0.40	0.17	0.27	0.34	0.39	0.26	0.26	0.31	0.34
I	0.18	0.30	0.16	0.31	0.26	0.15	0.15	0.08	0.03
J	0.02	0.02	0.16	0.21					

The average baseline illuminance was 0.15 fc. The maximum and minimum baseline illuminances, shown in bold, were 0.41 fc and 0.01 fc, respectively. The illuminance point under the lift (bold italics) was not affected by the lift for this calculation.

The baseline measurements in Table 2.3 were next subtracted from the measured illuminance to determine the actual amount of light provided by the HPS luminaires, yielding the "corrected" illuminance (Table 2.4).

Table 2.4. Corrected HPS Illuminance Measurements on December 5, 2007

	1	2	3	4	5	6	7	8	9
A	4.74	5.23					6.70	4.62	
B	6.22	5.31	6.01	5.44	5.40	**7.55**	5.57	4.93	
C	6.29	6.66	3.97	3.52	4.07	5.15	5.31	3.41	
D	4.34	5.47	5.18	3.21	3.84	5.43	4.74	2.97	2.85
E	2.02	3.04	3.37	3.17	3.04	3.19	3.63	2.64	**1.25**
F	2.29	1.63	2.67	2.25	2.75	2.98	3.02	2.41	*0.28*
G	2.13	1.82	3.08	2.79	2.97	2.87	2.86	2.04	1.41
H	3.77	2.81	4.40	3.19	3.14	4.26	2.88	1.78	1.99
I	3.24	4.23	3.18	3.02	2.34	3.38	3.26	2.28	2.83
J	1.77	1.81	3.00	1.63					

The average baseline illuminance was 3.54 fc. The maximum and minimum baseline illuminances, shown in bold, were 7.55 fc and 1.25 fc, respectively. Average:Min in the table is 2.83:1, while Max:Min (the ratio of the brightest and least bright points in the measured area) is 6.04:1. As before, in all areas other than the anomaly due to the presence of the lift, the existing lighting easily met the IESNA recommended minimum level.

2.7 Demonstration Technology

On December 6, 2007, the HPS fixtures were replaced with the LED luminaires. The measurement procedures outlined above were repeated that evening for the new installation. (See Table 2.5 for illuminance measurements for the level area encompassing the four luminaires L3-L6 in Figure 2.4.) The illuminance measurements began at 17:18 and ended at 17:37. The temperature measured at the start and the end of the illuminance measurements was 27.5° F and 24.8° F, respectively.

Table 2.5. Illuminance Measurements on December 6, 2007, under LED Luminaires

	1	2	3	4	5	6	7	8	9
A	4.31	4.04					3.80	3.64	
B	3.93	3.54	4.82	**5.15**	5.07	4.78	3.95	3.99	
C	3.51	2.84	4.50	4.92	4.80	4.15	3.48	3.80	
D	3.67	3.06	4.32	4.10	4.07	4.78	3.29	3.83	3.80
E	3.90	3.26	4.25	4.29	4.32	4.58	3.40	3.70	3.49
F	3.24	3.02	3.70	4.35	4.03	4.13	3.04	3.45	3.15
G	3.82	3.16	4.63	4.77	4.61	4.30	3.31	3.32	2.58
H	3.28	2.72	4.35	4.35	4.27	4.23	2.82	2.96	2.62
I	3.17	2.20	3.73	3.73	3.68	3.85	2.49	2.85	2.36
J	2.34	**1.94**	2.71	2.71					

The average illuminance measured was 3.71 fc, with the maximum and minimum illuminances (bold) measured at 5.15 fc and 1.94 fc, respectively. The lift that had obscured a point on the previous night had been moved during the day and was no longer an issue.

The second night experienced an overcast sky, but no falling snow. Baseline measurements were again recorded to account for any environmental factors and are shown in Table 2.6. These measurements were taken between 17:50 and 18:15.

Table 2.6. Illuminance Measurements on December 6, 2007, Baseline Ambient Light

	1	2	3	4	5	6	7	8	9
A	**0.01**	**0.01**					0.07	**0.01**	
B	**0.01**	0.04	0.02	0.06	0.03	0.10	0.03	**0.01**	
C	**0.01**	0.05	**0.01**	0.04	0.02	0.06	0.02	0.02	
D	**0.01**	0.09	0.02	0.30	0.02	0.23	0.02	0.16	**0.01**
E	0.02	0.12	0.03	0.16	0.07	0.03	0.08	0.10	0.08
F	0.09	0.09	0.03	0.14	0.06	0.02	0.07	0.23	0.06
G	0.09	0.02	0.09	0.16	0.24	0.20	0.16	0.08	0.04
H	0.06	0.15	0.14	0.07	0.18	0.12	0.15	0.05	0.03
I	0.03	0.03	0.11	**0.37**	0.26	0.04	0.08	0.04	0.08
J	0.03	0.04	**0.01**	0.02					

The average baseline illuminance was 0.08 fc, with maximum and minimum illuminances (bold) of 0.37 fc and 0.01 fc, respectively.

The baseline measurements were again subtracted from the total measured illuminance to determine the actual amount of light provided by the LED luminaires, or the “corrected” illuminance (Table 2.7).

Table 2.7. Corrected LED Illuminance Measurements on December 6, 2007

	1	2	3	4	5	6	7	8	9
A	4.30	4.03					3.73	3.63	
B	3.92	3.50	4.80	**5.09**	5.04	4.68	3.92	3.98	
C	3.50	2.79	4.49	4.88	4.78	4.09	3.46	3.78	
D	3.66	2.97	4.30	3.80	4.05	4.55	3.27	3.67	3.79
E	3.88	3.14	4.22	4.13	4.25	4.55	3.32	3.60	3.41
F	3.15	2.93	3.67	4.21	3.97	4.11	2.97	3.22	3.09
G	3.73	3.14	4.54	4.61	4.37	4.10	3.15	3.24	2.54
H	3.22	2.57	4.21	4.28	4.09	4.11	2.67	2.91	2.59
I	3.14	2.17	3.62	3.36	3.42	3.81	2.41	2.81	2.28
J	2.31	**1.90**	2.70	2.69					

The average illuminance was 3.63 fc, with maximum and minimum illuminances (bold) of 5.09 fc and 1.90 fc, respectively. As in the case of the original HPS, the LED fixtures easily meet the IESNA minimum recommended walkway lighting level of 0.5 fc at all points measured. Table 2.8 summarizes the key values from the corrected walkway measurements.

Table 2.8. Summary of Corrected Illuminance (fc) on the Main Plaza

	HPS	LED
Average	3.54	3.63
Maximum	7.55	5.09
Minimum	1.25	1.90
Avg: Min	2.83:1	1.91:1
Max:Min	6.04:1	2.68:1

In addition to the four luminaires lighting the main walkway recorded in the above tables, two more luminaires are located between this walkway and the round plaza in the middle of two sets of stairs (indicated by L1 and L2 in Figure 2.4). All of the illuminance measurements above were repeated at eight points along a single line across the center of the landing between the stairs. Similar to the above, Table 2.9 includes the illuminance provided by the HPS luminaires, a baseline measurement with the luminaires turned off, and a resulting "corrected" illuminance.

Table 2.9. Illuminance (fc) on the Stair Landing* December 5, 2007, under HPS Luminaires

Location:	1	2	3	4	5	6	7	8
HPS	5.18	7.98	4.15	3.82	3.82	4.78	9.91	3.19
Baseline	0.23	0.02	0.05	0.06	0.10	0.05	0.04	0.15
Corrected	4.95	7.96	4.10	3.76	3.72	4.73	9.87	3.04
* The L1 and L2 luminaires positions shown in Figure 2.4.								

The second night these illuminance measurements were repeated under the LED luminaires. Table 2.10 lists the corresponding values.

Table 2.10. Illuminance (fc) on the Stair Landing* December 6, 2007, under LED Luminaires

Location:	1	2	3	4	5	6	7	8
LED	3.14	2.62	4.5	5.27	5.19	4.93	3.78	2.96
Baseline	0.10	0.06	0.03	0.03	0.01	0.01	0.00	0.01
Corrected	3.04	2.56	4.47	5.24	5.18	4.92	3.78	2.95
* The L1 and L2 luminaires shown in Figure 2.4.								

As previously noted, the IESNA recommends a minimum illumination of 0.5 fc for walkways, measured at the walkway surface. As the LED product demonstrated is modular, its output can be easily varied by increasing or decreasing the number of LED bars it uses, and the resulting output scales linearly with such modifications. In order to achieve even greater energy savings, the site could substitute 2-bar fixtures for the 3-bar fixtures investigated above and expect to see precisely two-thirds the illumination measurements at all points in the tables above. This change would still easily meet the minimum recommended level of 0.5 fc.

Actual use of 2-bar luminaires was considered for this study but it was decided that any noticeable drop in illumination levels might be perceived negatively, regardless of whether minimum recommended levels were still achieved. The approach therefore taken was to closely match the previous lighting levels and sacrifice some of the potential energy savings. However, use of the 2-bar fixtures should still be considered by the site if an increased energy savings and decreased luminaire cost is of interest. The following economics discussion includes values for both 3-bar and 2-bar luminaires.

3.0 Economics

A range of factors potentially impact the return on investment from lighting upgrades. Some of these are easily quantified and others are not, and the intrinsic value of these may vary from site to site. For example, at this facility, maintenance is covered under a site-wide contract that also covers plumbing, building repair, and all other maintenance. The subcontractor replaces failed lamps on an individual basis when they are reported by the nighttime security staff. Because the cost associated with replacing an individual lamp is buried in this contract it is difficult to assign a precise cost savings associated with reduced lamp replacement from the longer-lived LEDs, even though it is clear such a value exists. Similar maintenance savings at other sites can be a major contributor to the cost-effectiveness of the LED product. Payback values in this report are estimated both with and without an assumed maintenance value. Labor and equipment costs and other assumptions are listed in Appendix D.

The Tech Center purchases electricity at a rate of $0.103 per kWh. As the peak draw from lighting occurs on a different schedule from the peak power draw of the overall site, no demand charge savings are realized from this replacement. The payback calculations therefore simply consist of luminaire initial cost divided by the difference in energy operating costs and a potential maintenance savings.

Table 3.1 lists the data underlying the payback values reported in Table 3.2, for both the 3-bar luminaire that was tested and a possible (but not tested) 2-bar luminaire. Table 3.2 presents estimated simple paybacks for the 3-bar and 2-bar LED luminaires, with and without maintenance cost savings, for two cases: 1) assumes the existing HPS luminaires are not due for replacement (i.e., the "do nothing" case); and 2) assumes the existing HPS luminaires need to be replaced anyway (so includes the costs of purchasing and installing new HPS lamps, ballasts, and fixtures).

Table 3.1. Values Used in Simple Payback Calculations

	Luminaire Power (W)	Yearly Operating Cost*	Annualized Maintenance Cost	Luminaire Initial Cost
HPS	97	$43.78	$39.24†	$150.00
LED 3-bar	72	$32.03	--**	$725.00
LED 2-bar	48	$21.65	--**	$575.00

*Based on 4380 hr/yr operation and $0.103/kWh paid for electricity
†Based on 5.5 year HPS lamp replacement cycle and 10-year ballast replacement cycle
** LED products used in this study are currently anticipated to last 100,000 hours with no maintenance or luminaire replacement required.

Table 3.2. Estimated Simple Payback Values (Years) from Replacing HPS with LED

Scenario:	HPS Not Scheduled for Replacement		HPS Scheduled for Replacement	
	Without Maint.	With Maint.	Without Maint.	With Maint.
LED 3-bar	80	18	49	7
LED 2-bar	35	13	10	3

The table indicates that a 2-bar LED replacement can meet the FAA 10-year payback criterion if (or when) the original HPS luminaires are scheduled for replacement, whether or not maintenance savings are included. A 3-bar LED replacement is cost-effective if maintenance savings are accounted for; however, realization of these savings requires a renegotiation of the existing maintenance contract to exclude exterior lighting. The tabulated values do not take into account any benefit from improved quality of the lighting, as discussed in the following section of the report, and thus may yet be conservative.

4.0 User Feedback

After two weeks of operation of the LED luminaires, employees of Buildings 300 and 316 were provided an anonymous questionnaire via e-mail with which to provide their feedback on impressions of the new lighting. In addition, the nighttime security staff were provided a separate questionnaire to gauge their reception to the new lighting source and its perceived impacts on their ability to carry out their duties. Both surveys are included in Appendix C.

The results from both of these groups below show a marked preference for the new LED lighting. While being a possible concern, the perceived likelihood of a "Hawthorne Effect" on the opinions of the survey respondents, where the novelty of a change may in itself be enough to favorably bias responses on the part of respondents, is considered to be of only marginal impact here. Some metal halide sources are already used in the vicinity of the luminaires so that the introduction of a "white" light source is not new.

4.1 Building Occupants Questionnaire

The questionnaire for occupants of Buildings 300 and 316 was organized into several statements involving topics of interest relative to the previous HPS lighting that the LEDs replaced. Each topic was then rated on a 5-point scale as follows: 1) greatly worsened, 2) somewhat worsened, 3) no change, 4) somewhat improved, and 5) greatly improved.

A total of 82 responses were received; of those, 24 respondents reported not having noticed the new lights and were thus excused from further participation in the questionnaire. The remaining 58 respondents were subsequently supplied the set of statements shown in Table 4.1 below and asked to rate them according to the scale provided. The resulting average ratings for the 58 responses are listed in the table.

Table 4.1. Buildings 300 and 316 Employee Questionnaire Results

Questionnaire Statement	Avg Rating
Overall night-time visibility in the area where the lights are installed	4.35
Ability to navigate the stairs at night	4.23
Ability to recognize faces at night	4.23
The presence of unwanted glare	3.85
Adequacy of the amount of light	4.39
Depth and appearance of shadows	4.08
Overall appearance of the building and site at night	4.34
Overall perception of safety in the area surrounding the lights	4.29
My overall opinion of the lighting in this area is that it has been:	4.46

A rating between "4" and "5" means the new LED lights were ranked, on average, as being between "Somewhat Improved" and "Much Improved" on the corresponding topic relative to the previous HPS lighting they replaced. In the case of "the presence of unwanted glare," the average response was between "no change" and "somewhat improved."

Following the statements, a text box was provided to allow respondents to explain in their own words why they preferred either the old or new luminaires, if they had expressed a preference. Of 58 responding respondents, 27 provided written comments. The statements below are reported verbatim from those comments received. A few of the responses indicate a potential for bias from believing the new lights to be more energy efficient; this association was not conveyed in the questionnaire or in other known communications but may instead reflect a growing general level of familiarity with LEDs and their perceived benefits. In fact, a number of building occupants passing by while the new luminaires were being installed recognized them as being LEDs.

Each bullet below represents a different respondent; comments are listed in the order the responses were received.

- I question the strong glare and the possible safety concern, particularly when leaving the building and going up the stair. The bottom of the stairs are very low and when looking up your eyes are hit by the glare and strong people will lose focus and missing a stair step. This was not an issue with the previous HPS lights. The selection should have considered a better cut-off for the fixture. The energy saving will be great but it cannot be at expense of safety and acceptable life cycle standards.
- I come down those stairs almost every day at 4-5am. I noticed right away how bright it was.
- Cleaner light makes it much easier to see.
- I like the whiteness of the lighting. Although, I have read some led lighting is not all the same in this regard. Visibility seems improved. The lights seemed easy on the eyes, brightness, glare, color, etc.
- Glare might be a problem on the new.
- Higher initial cost, lower life cycle cost. We need more!
- Sideways floodlighting is blinding, harsh, and unnecessary. A globe light with a diffuser would have sufficed. The real hazard is in the parking lots, which sometimes remain unlighted after dark.
- Nicer look. Easier on the eyes. More sophisticated.
- We should do whatever it takes to help improve the use of energy
- I prefer the new fixtures
- The newer lights have a nice white light emitting from them as the older sodium ones were sort of yellow. They just overall give off a better light.
- Just on electricity usage alone this is a great improvement and one we should spread in terms of increased applications, simply because it makes "cents".
- Prefer new because there's enough lighting, less glare.
- Great to know the power is from solar.
- The old lights have an annoying yellow tint. The new ones don't.
- The new ones are White as opposed to the orange hue which makes everything appear more like daylight, rather than all amber.
- Improved appearance, better visibility.
- Not dark when I come to work or go home

- The fixture/lamp that was used before installing the LED fixture was a mature product. It yielded good night time performance in all of the important categories above. The LED fixture is not a mature product. It still has some way to go in its design cycle. Does it have adequate light output (quantity)? Yes, "tons" of light. But what is its horizontal and vertical performance at out site. Was a site specific study done using AGI or Lumen Designer? Were the initial site readings of our old fixtures done with a meter compensated for rods and cones? Hopefully the finalized design will be a successful product, because the potential useful life of this type of light source is phenomenal and prices will go down. [name and contact information also provided]
- The new light seems more like sunlight and appear to be brighter making it easier to see in that area. Looking directly at the lights is difficult due to their intensity.
- Gives off much more light.
- overall improved night-time visibility in that area with the new LED lights.
- I like the whiter lights
- Light seems more evenly spread and is nearer to the blue end of the spectrum than previously. Visibility is good.
- Regarding question 4, I only noticed the glare when I looked directly up at the lights themselves just to see what they looked like. The glare is not a problem in terms of the light that the lights cast down to the surrounding area below. Also, the new lights cast a more natural daylight type of light as compared to the older yellow vapor lights. And you can see/distinguish things in the LED light area better from a distance.
- Softer light - more like actual daylight
- Adequate

4.2 Security Personnel Questionnaire

Ten nighttime security personnel were provided a form to carry around with them during their rounds, for evaluating the performance of the new LED lighting. As the questions were slightly more variable in content than the building occupants questionnaire above, they are only summarized along with their scored responses in Table 4.2 below.

Table 4.2. Nighttime Security Personnel Questionnaire Results

Questionnaire topic:	Avg Score
Ability to distinguish / identify faces or objects	4.7
Ability to detect movement	4.6
Ability to navigate territory on foot	4.6
Ability to perform manual tasks	4.6
Ability to distinguish color	4.3
Ability to read text	4.4
Presence of shadowed areas	4.3
Depth of shadowed areas	4.6
Presence of glare	4.2

In this case, all of the topics above were rated to fall between “somewhat improved” and “much improved.” In addition, the security personnel were given space to provide additional comments; the three responses received are listed below:

- Bravo, excellent. All outdoor base lighting should be changed, if possible.
- Like the whiter light.
- With the new lights it appears that individuals can be identified much easier, along with any packages they might be carrying.

5.0 Discussion

The investigated LED luminaires clearly achieved their goal in terms of technical performance. Significant energy savings are obtained while simultaneously producing qualities of light that are greatly preferred across the board. However, depending on assumptions used, cost effectiveness ranged widely, from a simple payback of 3 years in the most beneficial situation to never paying back at all during their expected lifetime. A large variety of factors contribute to the cost-effectiveness (or lack thereof) of LED luminaires in any given situation.

Illuminance is scalar so, as previously noted, were the FAA interested in more energy savings and a shorter payback, LED luminaires with two light bars rather than three bars could be used at this site. A 2-bar fixture would achieve a minimum illuminance level of 1.27 fc across the area, still easily meeting the minimum illumination guidelines for walkways (0.5 fc) established by IESNA.

While the LED luminaire produced equivalent illumination to the original HPS, the LEDs provided better illuminance uniformity. The ratios of maximum to minimum lighting levels on the walkway are roughly 6.0 for HPS vs. only 2.7 for the LED replacement, or less than half the variation. As illumination requirements are typically governed by the attempt to achieve recommended minimum average levels at all points in an illuminated space, larger max/min ratios translate into greater “hot spots” that are overlit and consequently represent energy waste. Substituting a lower wattage HPS luminaire for the original unit could also save energy, but the inferior uniformity measured for the HPS lighting would result in notably less illumination in the minimum areas. Improved uniformity of the LED luminaires allows a greater overall reduction in illumination levels, reducing the number of hot spots while still ensuring all areas maintain at least the minimum average illuminance levels required.

Light pollution (skywards illumination, light trespass, and glare) was not identified as an issue with either luminaire in this study. Both luminaires meet a definition of full-cutoff, meaning no illumination occurs above the horizontal and the percentage of total lamp lumens in the 80 to 90 degree range is 10% or less. Neither of these luminaires emits more than about 1% of lumens in this zone. Light trespass is also not an issue due to the luminaires being located in the center of a very large site. Comments regarding glare in the feedback were rather similar for both installations, though glare from the HPS flood lights attempting to light the round plaza at the top of the stairs may need to be addressed.

A relevant consideration for FAA is that the existing HPS luminaires are 30+ years old. Including the capital and labor costs for a new HPS luminaire into the payback calculations is well justified since the existing luminaires have probably reached (or nearly reached) their design lifetime.

The economics of an LED lighting retrofit can be expected to continue improving over the near term due to ongoing decreases in the price of the LED luminaires combined with anticipated increases in the price of electricity. FAA may want to consider investigating additional LED retrofits in other applications.

Appendix A – Lamp, Ballast, and Meter Information

Existing Luminaire

Manufacturer: Sterner
Model: Bartlett (assumption by Sterner based on a photograph)

Existing Installed HPS Lamp

Manufacturer: Osram Sylvania
Lamp Catalog # LU70/ECO
Lamp Rated Power: 70W
Lamp Shape: ET23.5
Rated for Open enclosures
Operating Position: Universal
Base: Mogul
OSI Product Code: 65712
Ballast: S62
Initial Lumens: 6300
Mean Lumens: 5500
Rated Life: 24000 hours
Lamp CCT: 1900
Lamp CRI: 22

Existing Ballast

Manufacturer: Advance Transformer
Catalog # 74P7933-011P
ANSI Code: S62
Lamp Type: 70W HPS
Type: Magnetic
Circuit Type: HX-HPF
Voltage: 277
Watts Input: 97
Max. Input Current: 0.7
Fuse (amps): 2
Length: 17.6”
Weight: 8.5”
Shape: Postline
60 Hz
Age: Assumed 20+ years

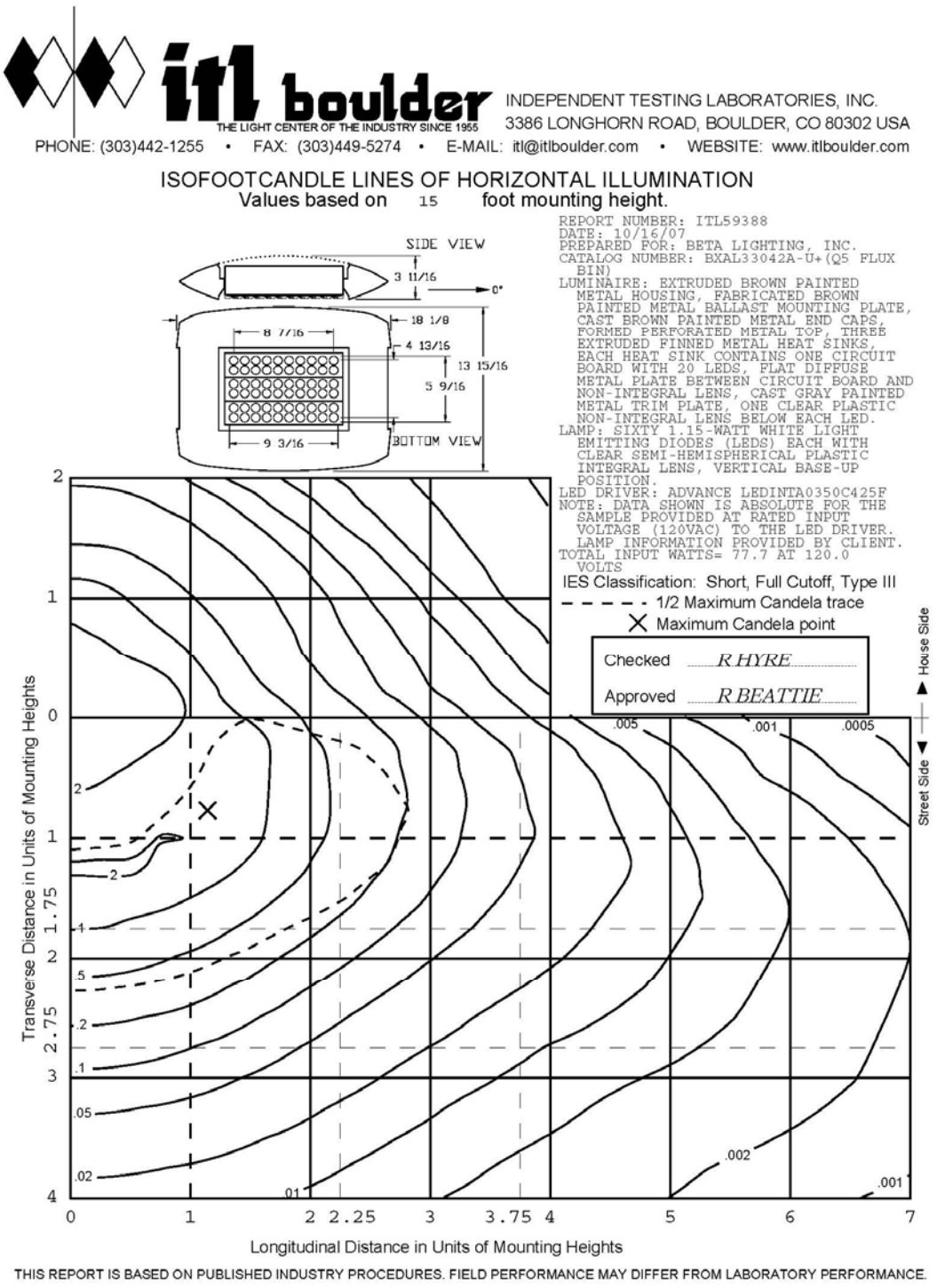
New LED Luminaire

Manufacturer: RUUD/Beta Lighting Inc
Catalog # BLD-ARE-T5-DA-042-LED-A-UL-WH
LEDs: XRE Generation Q5 Chip by Cree
Lumens: 4468
Wattage: 77.7
Rated Life: 100,000 hrs
CCT: 5000
CRI: 75

Meter Information

Manufacturer: PhotoResearch
Type: LiteMate III
Model: 504
Sensitivity Range: 0.01 – 19,990 fc
Measurement Uncertainty: 1.8%
Calibrated: 11/2007

Appendix B – Luminaire Photometric Testing Results[1]

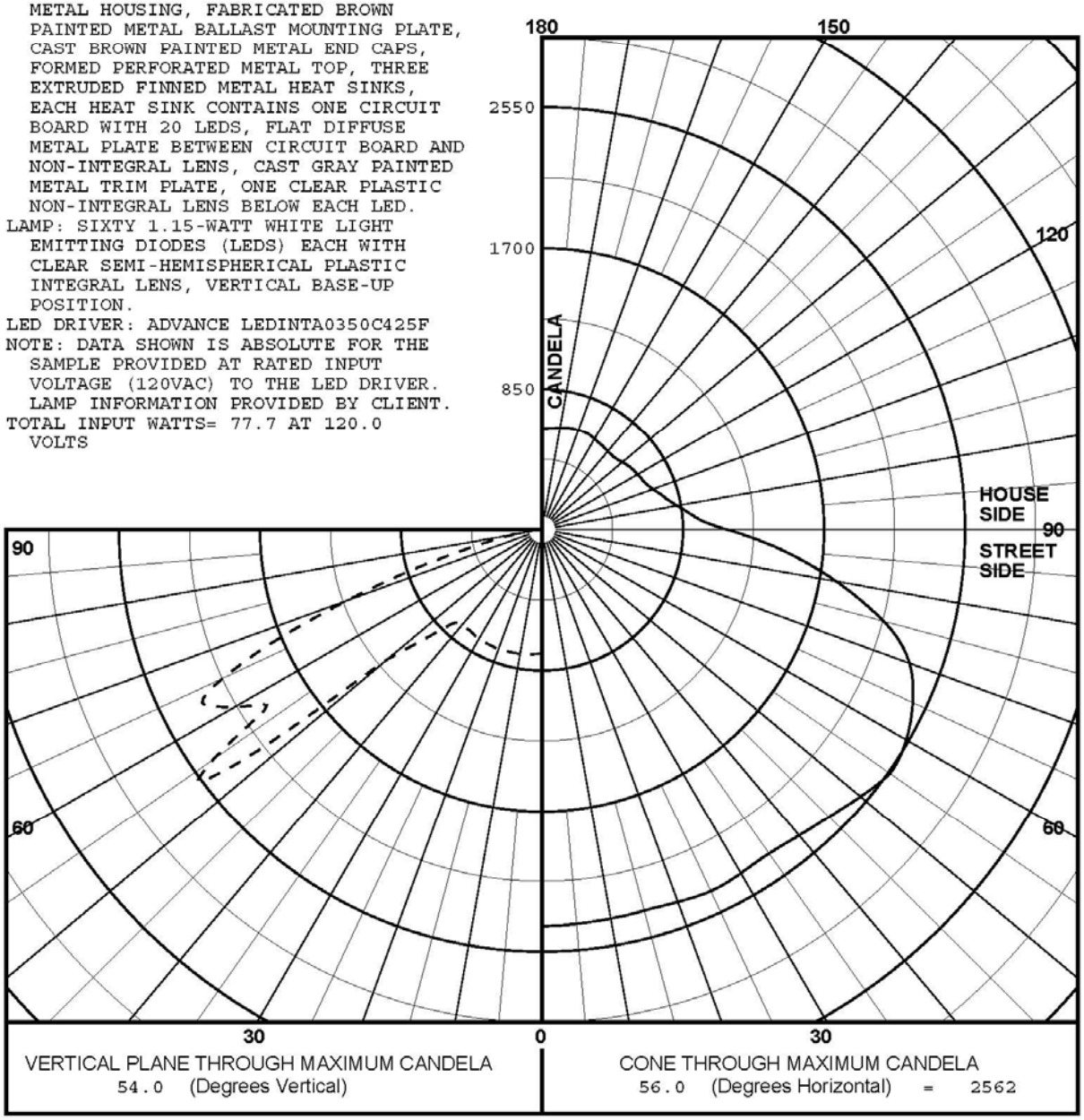


[1] This tested unit was designed for a different application but is the same as the luminaires used at FAA other than the pattern distribution, i.e., this tested unit has Type III rather than Type V distribution. Luminaire design, lumen output, power consumption, and efficacy are otherwise similar.

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

REPORT NUMBER: ITL59388
DATE: 10/16/07
PREPARED FOR: BETA LIGHTING, INC.
CATALOG NUMBER: BXAL33042A-U+(Q5 FLUX BIN)
LUMINAIRE: EXTRUDED BROWN PAINTED METAL HOUSING, FABRICATED BROWN PAINTED METAL BALLAST MOUNTING PLATE, CAST BROWN PAINTED METAL END CAPS, FORMED PERFORATED METAL TOP, THREE EXTRUDED FINNED METAL HEAT SINKS, EACH HEAT SINK CONTAINS ONE CIRCUIT BOARD WITH 20 LEDS, FLAT DIFFUSE METAL PLATE BETWEEN CIRCUIT BOARD AND NON-INTEGRAL LENS, CAST GRAY PAINTED METAL TRIM PLATE, ONE CLEAR PLASTIC NON-INTEGRAL LENS BELOW EACH LED.
LAMP: SIXTY 1.15-WATT WHITE LIGHT EMITTING DIODES (LEDS) EACH WITH CLEAR SEMI-HEMISPHERICAL PLASTIC INTEGRAL LENS, VERTICAL BASE-UP POSITION.
LED DRIVER: ADVANCE LEDINTA0350C425F
NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT VOLTAGE (120VAC) TO THE LED DRIVER. LAMP INFORMATION PROVIDED BY CLIENT.
TOTAL INPUT WATTS= 77.7 AT 120.0 VOLTS

MAXIMUM PLANE AND MAXIMUM CONE PLOTS OF CANDELA

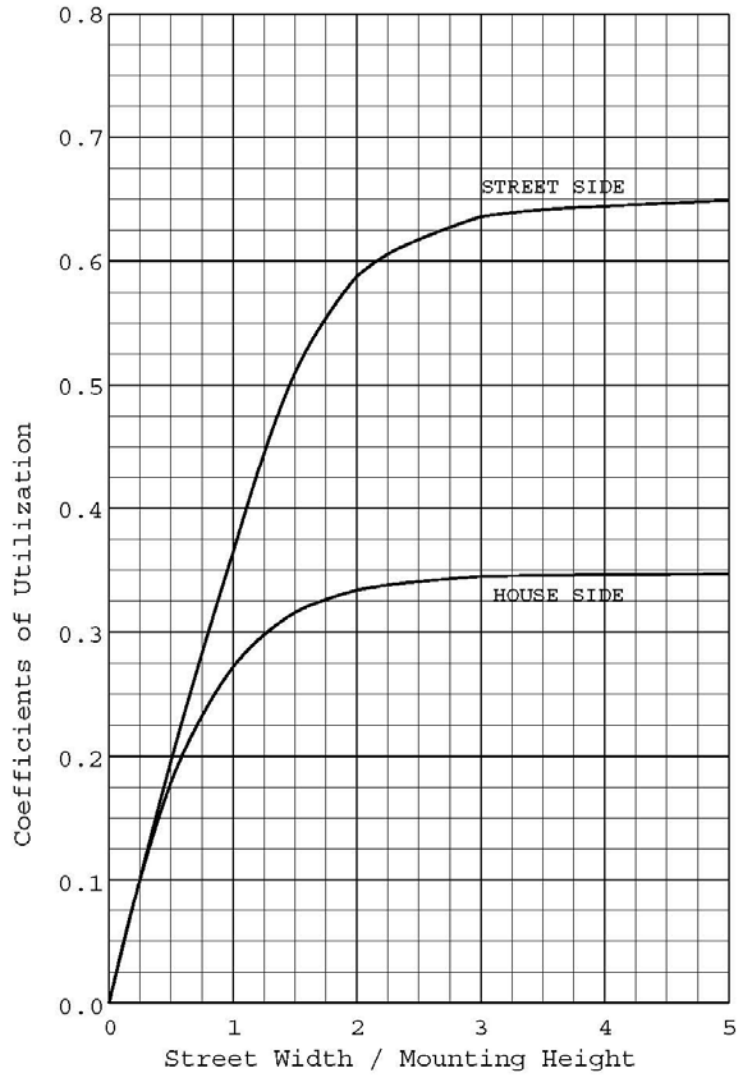


THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES. FIELD PERFORMANCE MAY DIFFER FROM LABORATORY PERFORMANCE.

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

REPORT NUMBER: ITL59388 DATE: 10/16/07
PREPARED FOR: BETA LIGHTING, INC.

COEFFICIENTS OF UTILIZATION AND FLUX DISTRIBUTION



	LUMENS	PERCENT OF FIXTURE
DOWNWARD STREET SIDE	2916	65.3
DOWNWARD HOUSE SIDE	1552	34.7
DOWNWARD TOTAL	4468	100.0
UPWARD STREET SIDE	0	0.0
UPWARD HOUSE SIDE	0	0.0
UPWARD TOTAL	0	0.0
TOTAL FLUX	4468	100.0

ALL CANDELA, LUMENS AND COEFFICIENT OF UTILIZATION VALUES IN THIS REPORT ARE BASED ON ABSOLUTE PHOTOMETRY.

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

REPORT NUMBER: ITL59388 DATE: 10/16/07
PREPARED FOR: BETA LIGHTING, INC.

FLUX DISTRIBUTION BY SOLID ANGLE

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

	LUMENS	PERCENT OF LAMP
FORWARD LIGHT	2894.	64.8
FL (0- 30)		7.3
FM (30- 60)		33.0
FH (60- 80)		23.9
FVH(80- 90)		0.6
BACK LIGHT	1574.	35.2
BL (0- 30)		8.8
BM (30- 60)		21.0
BH (60- 80)		5.3
BVH(80- 90)		0.1
UPLIGHT	0.	0.0
UL (90-100)		0.0
UH (100-180)		0.0
TRAPPED LIGHT	0.	0.0
TOTAL FLUX	4468.	100.0

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

REPORT NUMBER: ITL59388 DATE: 10/16/07
PREPARED FOR: BETA LIGHTING, INC.

CANDELA TABULATION

	STREET SIDE	LATERAL ANGLE										
		0.0	5.0	15.0	25.0	35.0	45.0	55.0	56.0	65.0	75.0	85.0
	90.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	87.5	16.	16.	16.	13.	9.	8.	11.	11.	15.	8.	4.
	85.0	31.	31.	31.	32.	29.	27.	36.	39.	68.	38.	12.
	82.5	52.	53.	55.	57.	61.	69.	86.	90.	149.	151.	30.
	80.0	94.	95.	98.	103.	110.	126.	172.	183.	299.	356.	99.
	77.5	169.	170.	174.	182.	191.	221.	299.	318.	484.	634.	335.
	75.0	295.	296.	299.	309.	324.	372.	499.	530.	736.	876.	636.
	72.5	515.	517.	521.	535.	554.	624.	814.	851.	1065.	1141.	891.
	70.0	772.	776.	782.	796.	826.	942.	1198.	1246.	1420.	1388.	1088.
	67.5	1074.	1080.	1108.	1157.	1237.	1405.	1682.	1720.	1772.	1580.	1255.
V	65.0	1479.	1490.	1522.	1581.	1683.	1881.	2104.	2123.	2014.	1672.	1379.
E	62.5	1884.	1890.	1901.	1933.	2000.	2154.	2290.	2290.	2053.	1698.	1429.
R	60.0	1869.	1871.	1870.	1904.	1952.	2075.	2154.	2142.	1916.	1686.	1493.
T	57.5	1649.	1651.	1644.	1674.	1717.	1841.	1970.	1968.	1863.	1845.	1707.
I	55.0	1960.	1968.	2016.	2115.	2148.	2256.	2411.	2426.	2416.	2219.	1593.
C	54.0<<	2397.	2391.	2383.	2409.	2388.	2450.	2561.	2562.	2466.	2130.	1460.
A	52.5	2315.	2314.	2361.	2437.	2444.	2415.	2343.	2319.	2068.	1643.	1199.
L	50.0	1684.	1683.	1620.	1458.	1324.	1260.	1231.	1218.	1145.	1115.	1123.
	47.5	1007.	1002.	969.	962.	954.	969.	1001.	1002.	1016.	1046.	1113.
A	45.0	839.	834.	831.	833.	814.	820.	838.	843.	888.	982.	1114.
N	42.5	751.	749.	749.	732.	708.	719.	752.	760.	838.	961.	1113.
G	40.0	726.	723.	717.	702.	689.	706.	739.	748.	826.	947.	1101.
L	37.5	715.	711.	703.	692.	687.	706.	738.	746.	819.	932.	1079.
E	35.0	705.	701.	696.	694.	694.	712.	743.	750.	814.	915.	1048.
	32.5	701.	699.	700.	701.	705.	723.	750.	756.	809.	896.	1011.
	30.0	707.	705.	710.	710.	716.	733.	755.	760.	804.	876.	972.
	27.5	719.	718.	718.	717.	724.	739.	757.	762.	799.	857.	932.
	25.0	733.	730.	726.	724.	730.	742.	758.	763.	794.	839.	896.
	22.5	742.	739.	736.	735.	737.	747.	762.	765.	790.	824.	864.
	20.0	746.	744.	744.	744.	746.	753.	765.	768.	787.	810.	836.
	17.5	750.	748.	750.	751.	752.	757.	764.	767.	781.	796.	812.
	15.0	755.	753.	753.	755.	756.	759.	762.	764.	774.	782.	790.
	12.5	761.	759.	755.	758.	758.	760.	761.	762.	767.	771.	774.
	10.0	763.	761.	758.	761.	761.	761.	760.	761.	763.	764.	764.
	7.5	763.	762.	760.	762.	761.	761.	758.	759.	760.	758.	756.
	5.0	762.	760.	759.	760.	759.	758.	755.	755.	756.	753.	751.
	2.5	756.	755.	754.	755.	754.	753.	751.	750.	752.	750.	749.
	0.0	748.	748.	748.	748.	748.	748.	748.	748.	748.	748.	748.

PLANE OF MAXIMUM CANDELA

CONE OF MAXIMUM CANDELA

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

REPORT NUMBER: ITL59388 DATE: 10/16/07
PREPARED FOR: BETA LIGHTING, INC.

CANDELA TABULATION

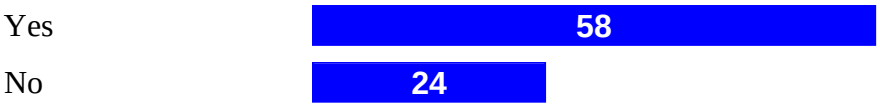
	HOUSE SIDE	LATERAL ANGLE									
		90.0	95.0	105.0	115.0	125.0	135.0	145.0	155.0	165.0	175.0	180.0
	90.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	87.5	3.	3.	3.	3.	4.	3.	3.	3.	3.	3.	3.
	85.0	10.	8.	8.	8.	8.	7.	6.	6.	5.	5.	5.
	82.5	22.	20.	16.	16.	17.	14.	11.	9.	8.	7.	7.
	80.0	38.	33.	30.	25.	26.	27.	20.	15.	13.	12.	11.
	77.5	101.	50.	47.	36.	33.	37.	40.	31.	24.	21.	20.
	75.0	306.	133.	61.	53.	45.	43.	46.	48.	43.	40.	39.
	72.5	537.	308.	142.	72.	61.	59.	55.	58.	58.	56.	56.
	70.0	723.	423.	317.	200.	102.	75.	70.	70.	75.	77.	77.
	67.5	902.	554.	392.	380.	307.	213.	164.	151.	150.	155.	156.
V	65.0	1036.	676.	458.	445.	425.	388.	370.	386.	405.	413.	413.
E	62.5	1106.	762.	528.	502.	491.	453.	437.	446.	458.	461.	460.
R	60.0	1213.	863.	599.	557.	546.	516.	500.	506.	510.	508.	506.
T	57.5	1311.	903.	670.	611.	591.	571.	560.	563.	561.	554.	550.
I	55.0	1169.	916.	741.	664.	633.	608.	611.	622.	616.	600.	594.
C	54.0<<	1113.	919.	761.	679.	652.	616.	623.	641.	636.	616.	611.
A	52.5 |	1063.	971.	813.	715.	671.	637.	642.	677.	686.	668.	662.
L	50.0 |	1089.	1033.	887.	766.	705.	666.	663.	714.	760.	764.	758.
	47.5 |	1122.	1094.	966.	818.	737.	689.	682.	738.	818.	867.	866.
A	45.0 |	1157.	1150.	1048.	878.	766.	708.	695.	757.	856.	933.	937.
N	42.5 |	1179.	1198.	1124.	959.	797.	725.	705.	766.	875.	964.	968.
G	40.0 |	1184.	1230.	1189.	1052.	842.	739.	710.	767.	874.	961.	965.
L	37.5 |	1171.	1241.	1237.	1138.	941.	759.	713.	756.	856.	937.	941.
E	35.0 |	1139.	1229.	1267.	1199.	1064.	829.	720.	738.	822.	892.	894.
	32.5 |	1093.	1194.	1282.	1238.	1154.	979.	768.	725.	775.	829.	830.
	30.0 |	1040.	1141.	1278.	1259.	1198.	1083.	899.	765.	749.	773.	772.
	27.5 |	986.	1073.	1245.	1256.	1205.	1115.	988.	866.	790.	763.	756.
	25.0 |	934.	998.	1185.	1238.	1185.	1103.	1008.	913.	831.	775.	762.
	22.5 |	889.	929.	1098.	1184.	1149.	1074.	987.	904.	830.	771.	758.
	20.0 |	851.	873.	992.	1104.	1105.	1042.	961.	885.	815.	763.	751.
	17.5 |	819.	829.	890.	1001.	1038.	1005.	937.	869.	806.	762.	752.
	15.0 |	793.	797.	818.	888.	947.	949.	910.	857.	804.	770.	761.
	12.5 |	775.	775.	779.	799.	843.	867.	857.	830.	798.	776.	769.
	10.0 |	763.	762.	760.	760.	768.	782.	786.	780.	771.	764.	760.
	7.5 |	755.	753.	750.	746.	744.	742.	739.	737.	736.	736.	733.
	5.0 |	750.	748.	745.	742.	740.	738.	734.	731.	730.	730.	727.
	2.5 |	748.	747.	746.	744.	744.	743.	740.	738.	738.	738.	735.
	0.0 |	748.	748.	748.	748.	748.	748.	748.	748.	748.	748.	748.

CONE OF MAXIMUM CANDELA

Appendix C – User Feedback Questionnaires

Lighting Summary Statistics Report, FAA Staff

Did you notice that new lights were installed on the walkway? **(82 responses)**



Overall night-time visibility in the area where the lights are installed.
Average: **4.351852**

Ability to navigate the stairs at night.
Average: **4.226415**

Ability to recognize faces at night.
Average: **4.234043**

The presence of unwanted glare.
Average: **3.846154**

Adequacy of the amount of light.
Average: **4.392857**

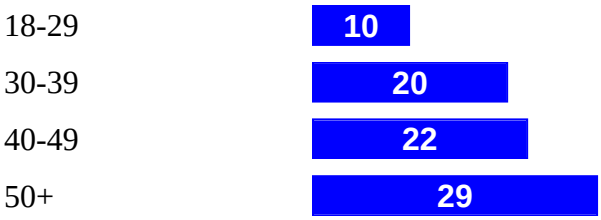
Depth and appearance of shadows.
Average: **4.078431**

Overall appearance of the building and site at night.
Average: **4.339623**

Overall perception of safety in the area surrounding the lights.
Average: **4.285714**

My overall opinion of the lighting in this area is that is has been:
Average: **4.464286**

Eyes age with time and are impacted differently by light, therefore, it helps for us to know your general age. Please indicate which age group applies to you: **(81 responses)**



Gender **(80 responses)**

Weighted questions

Overall night-time visibility in the area where the lights are installed.	**4.351852**	(54)
Ability to navigate the stairs at night.	**4.226415**	(53)
Ability to recognize faces at night.	**4.234043**	(47)
The presence of unwanted glare.*	**3.846154**	(52)
Adequacy of the amount of light.	**4.392857**	(56)
Depth and appearance of shadows.	**4.078431**	(51)
Overall appearance of the building and site at night.	**4.339623**	(53)
Overall perception of safety in the area surrounding the lights.	**4.285714**	(56)
My overall opinion of the lighting in this area is that is has been:	**4.464286**	(56)

---

*This question received an average score between “no change” and “somewhat improved,” meaning that while the responses varied a little more on this topic than the others, the majority still rated the LED product as at least as good or better than the original HPS.

Questionnaire for FAA Security Force Personnel[2]

The FAA is collaborating with the US Department of Energy and Beta Lighting to evaluate an alternative type of plaza/walkway light. Six fixtures have been installed near the walkway between Buildings 300 & 316, replacing the High Pressure Sodium (HPS) fixtures normally employed. The test fixtures are easily distinguished by their bluish-white light as compared to the more yellowish color of the standard lights.

We seek the perspectives of security personnel in terms of the new lighting's perceived impact on the ability to carry out their related duties and other impacts, though also recognize that a thorough evaluation is difficult given the limited area under study. At the end of the questionnaire is space to record any additional thoughts or observations you may have. We very much appreciate your time and effort filling out the questionnaire.

Please indicate on the scales provided (circle the appropriate response) your opinion on the following statements, relative to the original HPS fixtures:

1. *Under the new lights, the ability to distinguish / identify faces or objects is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

2. *Under the new lights, the ability to detect movement is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

3. *Under the new lights, the ability to navigate territory on foot is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

4. *Under the new lights, the ability to perform manual tasks is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

[2] Responses were hand-written on this blank form. See User Feedback section of the report for results.

5. *Under the new lights, the ability to distinguish color is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

6. *Under the new lights, the ability to read text is*

Greatly Improved	Improved	No Change	Decreased	Greatly Decreased

7. *Under the new lights, shadowed areas appear to be*

Much more numerous	More numerous	No Change	Fewer	Much Fewer

8. *Under the new lights, areas within the shadows appear to be*

Much Darker	Darker	No Change	Lighter	Much Lighter

9. *Under the new lights, glare appears to be*

Much Worse	Worse	No Change	Better	Much Better

<u>Other thoughts or observations</u>

Appendix D – Economic Analysis Data

NIST BLCC 5.3-07: Input Data Listing

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Documents and Settings\d3g346\My Documents\Projects\SSLs\Streetlamp LCCs\BLCC Analysis\FAA.xml
Date of Study:	Thu Mar 06 16:03:52 PST 2008
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	FAA outdoor lighting
Project Location:	New Jersey
Analyst:	Doug Elliott
Base Date:	April 1, 2008
Service Date:	April 1, 2008
Study Period:	22 years 10 months (April 1, 2008 through January 31, 2031)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are REAL (exclusive of general inflation)

Energy: Electricity

Price per Unit:	$0.10300
Demand Charge:	$0
Utility Rebate:	$0
Rate Schedule:	Commercial
State:	New Jersey

Additional Economic Assumptions

Labor Rate per hour	$85.00
High Pressure Sodium Luminaires	
Lamp Replacement	
New Lamp Price	$41.00
Estimated Time for Task (hours)	0.75
Site Relamp Cost	$104.75
Relamp cycle (# of years)	5.48
Annualized relamp costs	$19.12
Ballast Replacement	
New Ballasts Price	$150.00
Estimated Time for Task (hours)	1.25
Site Cost for Replacing Ballasts	$256.25
Reballast cycle (# of years)	10
Annualized reballast costs	$25.63
Luminaire Replacement	
New Complete Luminaire Price	$400
Estimated Time for Task (hours)	2.50
Material & Labor for Replacing Luminaire	$607.40
Expected Life (years)	25
LED Luminaires	
New 3-Bar Luminaire	$725
New 2-Bar Luminaire	$575
Estimated Time for Task (hours)	2.50
3-Bar Total Replacement Cost	$932.40
2-Bar Total Replacement Cost	$782.40
Expected Lifetime (years)	22.83

Alternative: HPS, Existing Fixture

Energy: Electricity

Annual Consumption: 425.0 kWh

Initial Investment

Initial Cost (base-year $): $0

Annual Rate of Increase: 0%

Expected Asset Life: 0 years 0 months

Residual Value Factor: 0%

Recurring OM&R: Lamp Replacement

Amount: $19

Annual Rate of Increase: 0%

Recurring OM&R: Ballast Replacement

Amount: $26

Annual Rate of Increase: 0%

Component: Luminaire Replacement

Initial Investment

Initial Cost (base-year $): $608

Annual Rate of Increase: 0%

Expected Asset Life: 25 years 0 months

Residual Value Factor: 8.7%

Alternative: 3-bar SSL

Energy: Electricity

Annual Consumption: 342.0 kWh

Component:

Initial Investment

Initial Cost (base-year $):	$932
Annual Rate of Increase:	0%
Expected Asset Life:	22 years 10 months
Residual Value Factor:	0%

Alternative: 2-bar SSL

Energy: Electricity

Annual Consumption: 228.0 kWh

Component:

Initial Investment

Initial Cost (base-year $):	$782
Annual Rate of Increase:	0%
Expected Asset Life:	22 years 10 months
Residual Value Factor:	0%