GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light-Emitting Diode (LED) Parking Lot Lighting, Phase I

Host Site: T.J.Maxx, Manchester, New Hampshire

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
C.B.T. Development

June 2010

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

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Demonstration Assessment of Light-Emitting Diode (LED) Parking Lot Lighting at T.J.Maxx in Manchester, NH Phase I

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Preface

This document is a report of observations and results obtained from a lighting demonstration project conducted under the U.S. Department of Energy (DOE) Solid-State Lighting Technology Demonstration GATEWAY 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 plaza 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 alternative 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.

Summary

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a commercial parking lot lighting application, under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program. In this project, a total of 28 [22-400W (nominal) high-pressure sodium and 6- 400W metal halide] luminaires manufactured by Spaulding were replaced with 25 120 light-emitting diode (LED) luminaires manufactured by BetaLED®, in a shopping center parking lot where T.J.Maxx is the flagship tenant. Each LED luminaire is controlled by an integral occupancy sensor that varies its operation between "high" and "low" light output settings.

The BetaLED product achieved an estimated payback in this installation of about 3 years because of high electricity ($0.14/kWh) and maintenance costs incurred by the conventional products at this location. Using the lower national average electric rate of $0.104/kWh and more typical maintenance rates results in a payback slightly more than 5 years. The 58% energy savings supporting these payback calculations is largely attributable to the 47% reduction in average light levels for the "high" output setting.

Despite the reduction in light levels, the parking lot still meets the "Basic" minimum horizontal illuminance of 0.2 footcandle (fc) recommended by the Illuminating Engineering Society of North America in RP-20-98. As designed, the installed lighting systems would produce a minimum illuminance value of 0.2 fc at one point in the parking lot at the time of replacement, defined as 70% of initial lumen output (L_{70})[1]. When the lighting system is operating in the "low" setting and is near end of life, this value would be below 0.2 fc. However, the sensor only operates the light in low setting when the sensor does not detect movement. The LED luminaires offer the flexibility of reducing energy consumption overnight, when the lot is unoccupied, but raising illumination levels when occupants are present.

In terms of user acceptance, 30 out of 32 respondents in a survey of store employees in the plaza said they would recommend this installation be used elsewhere. Most thought that lighting quality was improved following the LED substitution. The plaza employee responses to the survey were quite positive overall.

This report describes Phase I of II. Phase I examined the lighting performance and projected energy savings from the new installation. Phase II is to provide a detailed review over time of the actual operation of the luminaires.

Occupancy sensors in parking lots are still relatively new. GATEWAY has participated in a few other demonstrations of the technology in Beaverton, Oregon, and West Sacramento, California, but each installation continues to be unique. Through the combination of these and additional efforts GATEWAY hopes to characterize the operating profile of bi-level operation luminaires in parking lots for a myriad of commercial establishments (e.g., corporate campuses, grocery stores, and general retail).

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[1] Lighting Research Center & the Alliance for Solid-State Illumination Systems and Technologies; February 2005; "LED Life for General Lighting: Definition of Life" http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/ASSIST-LEDLife-revised2007.pdf.

Acronyms and Abbreviations

A	ampere(s)
BUG	backlight, uplight, and glare
CBEA	Commercial Building Energy Alliances
CCT	correlated color temperature
CRI	color rendering index
CV	coefficient of variation
DOE	U.S. Department of Energy
fc	footcandle(s)
HID	high-intensity discharge
HPS	high-pressure sodium
IESNA	Illuminating Engineering Society of North America
K	Kelvin
kW	kilowatt(s)
kWh	kilowatt-hour(s)
LCS	luminaire classification system
LDD	luminaire dirt depreciation
LED	light-emitting diode
LLD	lamp lumen depreciation
LLF	light loss factor
Lm/W	lumen(s) per watt
mA	milliampere(s)
MH	metal halide
MWh	megawatt-hour(s)
PMH	pulse-start metal halide
PNNL	Pacific Northwest National Laboratory
PSNH	Public Service of New Hampshire
SSL	solid-state lighting
Std. Dev.	standard deviation
V	volt(s)
VA	volt-ampere(s)
W	watt(s)

Contents

Figures

Tables

1.0 Introduction

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in a commercial parking lot application conducted by Pacific Northwest National Laboratory (PNNL) in Manchester, New Hampshire, during November and December 2009. The project was supported under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program. Other participants in the demonstration project included Cass Thurston of CBT Development Consultants, CW Companies (plaza property manager), and JDC/Manchester Limited Partnership (plaza owner). PNNL conducted the measurements and analysis of the results. PNNL manages several related demonstrations for DOE and represents DOE's perspective in the conduct of the work.

DOE supports such demonstration projects to develop real-world experience and data with SSL products in general illumination applications. DOE's approach is to carefully match applications with suitable products and form teams to carry out the needed project work. Other project reports and related information are available on DOE's SSL website[1].

CBT Development was incurring high costs for parking lot maintenance from frequent lamp replacement in the parking lot of a shopping center and was considering replacing the lighting to reduce costs. The developer had already determined that poor power quality was the root cause of the premature lamp failures and was also ready to replace the 25-year-old luminaires on the plaza. While designing the new lighting system, the plaza architect learned about other GATEWAY demonstrations as well as the Commercial Building Energy Alliances (CBEA) *LED Site Lighting Performance Specification* (CBEA specification) [2], and contacted PNNL to learn more about both programs.

The CBEA specification focuses exclusively on light-emitting diode (LED) products and is performance based, meaning that it is intended for lighting designers, engineers, architects, and manufacturer application engineers to conform to when designing the site. The overall power density is set by lighting zone along with minimum illuminance values. The specification also sets requirements on the luminaire light source color quality [both correlated color temperature (CCT) and color-rendering index (CRI)]; light distribution (amount of lumens emitted in different zones); and other aspects of the luminaire.

The luminaires were purchased and installed by the property owner during November 2009.

[1] http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html.
[2] The full CBEA specification and additional information about the specification can be found at http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/led_site_lighting_spec_06_09.pdf.

2.0 Methodology

2.1 Site Description

T.J.Maxx Plaza is located near the southern end of Manchester, New Hampshire. The plaza is on a four-lane collector road surrounded by other commercial plazas as shown in Figure 2.1. The frontage road, South Willow Street / Route 28, is several feet above the parking lot elevation. The parking lot covers approximately 151,000 square feet and has 385 parking spaces.

In addition to the anchor, T.J.Maxx, the plaza houses a variety of smaller retail stores. There is also a free standing ATM that is accessible 24 hours a day. Most stores are open from 9:30 or 10:00 AM until 9:00 or 9:30 PM. On the evenings of site visits, most employees had left by 10:00 PM.

Figure 2.1. T.J.Maxx Plaza Aerial View (Source: Google Earth)

Preliminary modeling of the lot helped determine the appropriate size of replacement luminaires. The 13 existing pole locations were to remain, which fixed pole spacing at approximately 110 ft × 150 ft. Altering the mounting height of the luminaires was considered but deemed unnecessary; the mounting height remained the same for both the baseline installation and the new installation at 33 ft above finished grade, using a 30-ft pole atop a 3-ft concrete base.

2.2 Existing Luminaires

The luminaires originally installed at the T.J.Maxx plaza were Spaulding “Cambridge” series 400W high-pressure sodium (HPS) with a Type V distribution (model number CE-400-HPS) (see Figure 2.2). Most recently, Philips Ceramalux 400W HPS lamps had been installed, with a 50,000 initial lumen rating, a CCT of 2100K, and a CRI of 21. The ballast type is assumed to be constant wattage autotransformer (also known as CWA), based on the manufacturer’s published information.

Additionally, some of the original HPS luminaires near the T.J.Maxx had been replaced with metal halide (MH), with two poles, each supporting three 400W metal halide luminaires (see Figure 2.3). Other exterior sources include metal halide downlights and fluorescent wrap-around luminaires used under the canopy, and metal halide bollards at the entrances to the parking lot. Some luminaires mounted to the canopy were replaced with LED luminaires, but these were not part of the study. The freestanding walk-up ATM has its own HPS wall pack lighting system.

Figure 2.2. Original HPS Luminaires

Figure 2.3. Original Metal Halide Luminaires (Visible Behind HPS Luminaires)

2.3 New Luminaires

Various options were considered when the owner began looking to replace the existing luminaires. One of the designs considered was a pulse-start metal halide (PMH) system, but it was eventually discarded in favor of the LED option after illuminance and payback calculations were conducted. The plaza architect and developer heard about the CBEA specification and an LED installation at a Walmart in Leavenworth, Kansas, which was also a GATEWAY demonstration.

2.3.1 Alternate Option: Pulse-Start Metal Halide Area Luminaires

Originally, the plaza owner was considering a PMH luminaire. Ruud Lighting (manufacturer of conventional luminaires; subsidiary division BetaLED manufactured the LED luminaires actually installed) provided a lighting design using “Medium Aviator” luminaires (BAA-AVM-V-T3-320PMH, see Figure 2.4). The Aviator has a Type III distribution (Figure 2.5); a backlight, uplight, and glare (BUG) rating of B3-U3-G5 and a luminaire efficiency of 73%. A 320W pulse-start metal halide lamp was selected with a 33,000 lumen output, nominal CCT of 4000K, and a CRI of 65. The design assumes a luminaire with magnetic ballast and an input power of 368W. Based on this information, the initial luminaire efficacy calculates to 65 lumens per watt (LM/W).

Figure 2.4. PMH Luminaire

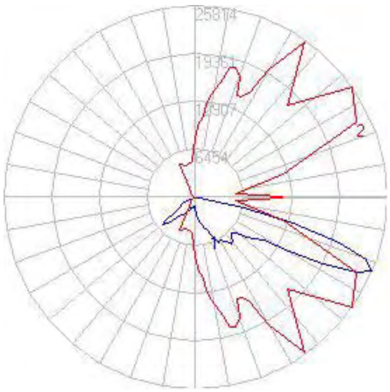

Figure 2.5. PMH Candela Polar Plots

2.3.2 Installed Option: LED Area Luminaires

BetaLED provided the LED design that was ultimately installed at the plaza. The luminaire selected was the BetaLED The Edge® Area Light (BLD-T3-102-LED-B-UH-BZ-TL) with adjustable arm and bronze finish to match the existing poles. See Figure 2.6 for an image of the luminaire. Based on manufacturer data, the luminaire has Type III distribution (Figure 2.7) and a BUG rating of B3-U1-G3. The LEDs had a nominal CCT of 6000K and a CRI of 70.

The Edge luminaires are modular, assembled from arrays (BetaLED nomenclature of "bars") of 20 LEDs each to provide the desired lumen output. The installed luminaire had an assembly of 6 bars totaling 120 LEDs. The plaza owner chose occupancy sensors to reduce the lighting from high output (driven at 525 mA) to low output (175 mA) on a given pole when no movement is detected near that pole. Table 2.1 provides the BetaLED data for different drive currents.

Table 2.1. BetaLED Luminaire Lumen Output and Power Draw*

Drive Current (mA)	Lumen Output	Input Power (W)
175	6,300 lumens	78
350	10,500 lumens	156
525	13,650 lumens	234

*Values per manufacturer's catalog sheet, at 25°C and 480V.

The luminaire efficacy changes with the respective drive currents as follows: from 81 Lm/W at 175 mA to 63 Lm/W at 525 mA.

Figure 2.6. BetaLED Luminaire

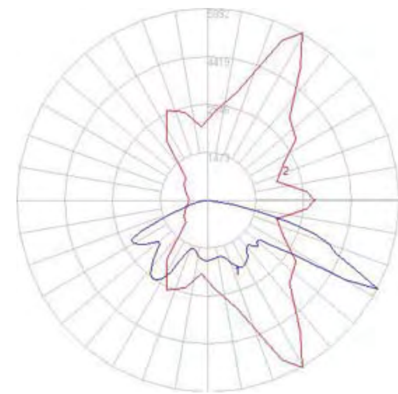

Figure 2.7. BetaLED Candela Polar Plots

2.4 Installation

Prior to their replacement, the existing luminaires were cleaned, relamped, and operated for over 100 hours before baseline illumination and power measurements were taken[1]. Following this period, the HPS luminaires were replaced with the LED luminaires; power and illumination measurements were repeated.

The 25 LED luminaires were installed in 12 hours (roughly 30 minutes per luminaire) with no notable issues. Figure 2.8 shows the LED luminaires installed at the plaza.

Figure 2.8. Parking Lot After Installation of LED Luminaires (Source: BetaLED)

[1] IESNA LM-54-99, “IESNA Guide to Lamp Seasoning,” recommends operating discharge lamps for 100 hours so that measurements can establish initial or rated lumens. The output of HID lamps in the 0-100 hour range typically reduces between 8% and 10%.

2.5 Power and Energy

Voltage and current were measured to calculate the power draw of the different types of luminaires, and then multiplied by operating hours to estimate the energy usage of the plaza. The mixture of high/low operation is only estimated at this point since longer term metering has not yet occurred. In Phase II of this evaluation, equipment will be installed to document the actual mixture of high and low operating states of the luminaires.

2.5.1 Power Measurements

Power measurements for both the existing HPS luminaires and LED luminaires (Table 2.2) were taken at the same point in the circuit.

Table 2.2. Power Measurements

	Existing Luminaires		New LED Luminaires	
	HPS	MH	LED High Output	LED Low Output
Measured Voltage (V)	472	470	470	470
Measured Current (A)	2.1	3.0	1.0	0.5
Power (VA)*	991.2	1,410	470	235
Number of Luminaires Measured	2	3	2	2
Power per Luminaire	496	470	235	118[2]

* Power factor was not measured.

2.5.2 Power Density Analysis

Power density is a component of many state and regional energy codes. New Hampshire energy code allows for a power density of 0.15 W/ft^2 in a parking lot. All three lighting systems were within the limits of the New Hampshire energy code. Of the three lighting systems considered, the LED system has the lowest power density[3] as shown in Table 2.3. In addition, the LED system uses occupancy sensors to further curb the energy usage of the system, an option not commonly available for HID.

[2] The measured power (volt-amperes) for LED luminaires operated at low-output was 118 W. Per the manufacturer's catalog sheet; this configuration should draw 78 W when in low output. The high output power (volt-amperes) measured was 235 W, almost exactly the power draw specified in the manufacturer's catalog sheet for high output. The source of the difference in power was explored, but no definite cause was determined. During Phase II of this project, the power draw will be measured for multiple units and at different times. These new measurements will be closely reviewed to see how the data relates to the manufacturer's catalog data.

[3] LPD is calculated using maximum installed power, so 235W per luminaire was used for the LED.

Table 2.3. Energy Calculations – Lighting Power Density

System	Qty	Source Type	Luminaire Power (W)	Total Power (W)	Total Power (W)	Parking Lot Area (ft^2)	Site Lighting Power Density
Existing Installation	22	HPS	496	10,912	13,732	151,000	0.09
	6	MH	470	2,820			
Alternate Option	25	PMH	368	9,200	9,200	151,000	0.06
Installed Option	25	LED-High	235	5,850	5,850	151,000	0.04

2.5.3 Energy Analysis

Power density limits are typical for code compliance in many energy codes (e.g., ASHRAE/IESNA Std. 90.1 or Title 24). However, in terms of expected energy use, the operation of the luminaire is just as important as the maximum power of the luminaire. For example, California's energy code, Title 24, now includes a lighting curfew that requires reductions in light levels after the building has closed, in recognition that it does not make sense to light a parking lot to the same levels when no one is using it. New Hampshire code does not include any such curfew requirement; however, the plaza owner chose to use occupancy sensors anyway to capture additional savings when the parking lot is not being used.

Table 2.4 provides the expected energy use of the different lighting systems. All systems are controlled via timeclock and assumed to operate for 12 hours per night on average.

Table 2.4. Energy Calculations

System	Qty	Source Type	Luminaire Power (W)	Total Power (W)	Hours	Energy (kWh)	Total Energy (kWh)	Reduction
Existing Installation	22	HPS	495	10,912	4,380	47,794	60,147	N/A
	6	MH	470	2,820	4,380	12,352		
Alternate Option	25	PMH	368	9,200	4,380	40,296	40,296	33%
Installed Option	25	LED-High	235	5,850	1,825	10,676	15,658	74%
		LED-Low	78	1,950	2,555	4,982		

Note: The LED system is assumed to operate in high output mode for 5 hours and low output mode for 7 hours. These assumptions will be verified in Phase II of the project evaluation..

Figure 2.9. Visual Comparison of LED and HPS Areas of the Lot

2.6 Illuminance

Illuminance for the HPS installation was measured after 10:00 PM on November 11, 2009, along an approximately 110 ft × 150 ft area marked out in a 10 ft × 10 ft measurement grid consisting of 130 measurement points (one point was obscured by a parked vehicle). The temperature was 25°F (-4°C) and the weather conditions were dry, clear, and cold.

Illuminance was measured for the LED installation along the same 10 ft × 10 ft measurement grid after 9:00 PM on December 14, 2009. The temperature was 30°F (-1°C) and weather conditions were cloudy. The measured values obtained for both illuminance systems are listed in Table 2.5.

The maximum illuminance of the HPS system was nearly six times that of the LED, boosting the average illuminance values of the HPS system while resulting in markedly worse uniformity ratios. The HPS system does not meet RP-20-98 since the max:min uniformity ratio is 28:1, exceeding the RP-20-98 limit of 20:1.

Table 2.5 indicates that the LED system produced a minimum illuminance value roughly fifty percent higher than that of the HPS, while average illuminance was slightly more than half.

Table 2.5. Horizontal Illuminance at Pavement

	HPS	LED (High Output)	RP-20-98	CBEA
Average	3.81 fc	2.03 fc		
Maximum	16.74 fc	2.94 fc		
Minimum	0.60 fc	1.03 fc	0.2 fc	0.5 fc
Max/Min	27.90:1	2.85:1	20:1	10:1
Avg/Min	6.34:1	1.97:1		
Std. Dev	3.51 fc	0.51 fc		
Coefficient of Variation	0.92	0.25		

Table 2.6 compares HPS and LED illuminance values at both high output and low output. The low output values were calculated rather than measured because the motion sensors prevent readings in the low state. The values were calculated using lumen multipliers when operating the LED system at the different drive currents as discussed in section 2.3, and multiplying these values with the maximum, minimum, and average illuminance values.

Table 2.6. T.J.Maxx Illuminance Projections

	Measured HPS Values	Measured LED Values (High Output)	Projected LED Values (Low Output)
Average	3.81 fc	2.03 fc	0.94 fc
Maximum	16.74 fc	2.94 fc	1.36 fc
Minimum	0.60 fc	1.03 fc	0.48 fc
Max/Min	27.90	2.85	2.83
Avg/Min	6.34	1.97	1.96
Std. Dev	3.51 fc	0.51 fc	0.51 fc
Coefficient of Variation	0.92	0.25	0.25

Table 2.7 is a comparison of the illuminance for the HPS system (measured), the PMH option (modeled), and the LED system (measured). The calculation grid for the computer modeling contained the same number of points and location as the measured grid points. Both the alternate option and the installed option produced very similar results for all of the uniformity metrics considered, including avg/min, max/min, standard deviation, and the coefficient of variation. Neither of the systems considered produced the same maximum illuminance as the original installation. It is partially this extreme maximum value that skewed the uniformity measures of the HPS system.

Table 2.7. T.J.Maxx Illuminance Projections

	HPS Values	PMH Option (Modeled)	LED Option
Average	3.81 fc	3.71 fc	2.03 fc
Maximum	16.74 fc	5.53 fc	2.94 fc
Minimum	0.60 fc	1.95 fc	1.03 fc
Max/Min	27.90	2.84	2.85
Avg/Min	6.34	1.90	1.97
Std. Dev	3.51 fc	0.81 fc	0.51 fc
Coefficient of Variation	0.92	0.22	0.25

In terms of minimum illuminance, which is the metric of concern in both RP-20-98 and the CBEA specification, both designs produced a higher initial minimum illuminance than the existing system. In terms of average illuminance, the PMH design would have produced virtually the same value as the original HPS system. The installed LED design produced 55% of the average illuminance of the original installation.

The initial illuminance values presented in Table 2.7 are useful for field measurements when comparing new systems. However, long-term illuminance must also be considered, taking into account lamp lumen depreciation (LLD) and luminaire dirt depreciation (LDD), which together combine with other factors to comprise the overall light loss factor (LLF). Section 6.1.4, Lumen Maintenance, of RP-20-98 states, "Each design should provide the required minimum lighting levels at time of relamping. Therefore, design should be based on the relamping program to be used (see section 8.2.2, Lamp Lumen Depreciation)." This requirement is meant to ensure that sufficient illuminance is provided on the site until the light sources are replaced. Section 8.2.2 of RP-20-98 further states:

> A light source's gradual loss of lumen output due to normal in-service aging characteristics is subject to wide variances depending upon the type of source used. Manufacturers' published data for each type and size can be used to predict the LLD rate and to estimate lamp mortality. These predictable losses and life expectancies should be used to develop a program of planned maintenance for lamp replacement based upon the values of illuminance levels established for the lighting design, and to achieve the most favorable economy of lamp replacement. Group relamping normally results in the lowest overall replacement cost and provides the greatest service level through maintaining a low lamp outage rate. Group relamping at about 70 percent of rated life represents good practice[4].

Therefore, the values in Table 2.8 represent illuminance at the time of relamping and assume the same LDD of 0.90.

[4] IESNA LM-20-98, "IESNA Lighting for Parking Facilities," p.9.

The LLD value applied to the PMH design is 0.75 and was derived by dividing the mean lumens/initial lumens. For most high-intensity discharge (HID) lamp manufacturers, the mean lumens are measured at 40% of rated life, whereas relamping is recommended at 70% of rated life. In lieu of detailed lumen depreciation data, most designers defer to using the mean lumen data. In contrast, the end of useful life for LEDs is defined as when the light output has faded to 70% of the initial light output, or in other words when an LLD value of 0.70 has been reached.

Table 2.8 not only examines the illuminance at the time of relamping, but also the illuminance across different areas of the parking lot. The front aisle is the section where cars drive along the storefronts and is separate from the rest of the parking lot. This is an area of higher pedestrian/vehicle conflict because customers are crossing from the main parking lot to the stores. In the CBEA specification, this area has a higher minimum illuminance than the main parking area. The LED system produced less illuminance in this area than the PMH option. The far perimeter consists of the set of parking spots along the perimeter outside the main parking lot.

Table 2.8. Illuminance at Time of Relamping – Entire Site

	PMH Option (LLD = 0.75, LDD = 0.90, LLF = 0.675)			LED Option (LLD = 0.70, LDD = 0.90, LLF = 0.63)		
	Front Aisle	Main Parking	Far Perimeter	Front Aisle	Main Parking	Far Perimeter
CBEA-LZ 2 Minimum	**1.00 fc**	**0.50 fc**	**0.20 fc**	**1.00 fc**	**0.50 fc**	**0.20 fc**
CBEA-LZ 2 Max/Min	**10:1**	**10:1**	**10:1**	**10:1**	**10:1**	**10:1**
Average	1.70 fc	2.38 fc	1.87 fc	0.90 fc	1.29 fc	1.15 fc
Maximum	3.88 fc	4.23 fc	3.76 fc	5.63 fc	3.06 fc	2.80 fc
Minimum	0.43 fc	0.98 fc	0.71 fc	0.16 fc	0.38 fc	0.23 fc
Max/Min	9.02	4.32	5.30	16.44	8.05	12.17
Avg/Min	3.95	2.43	2.63	5.63	3.39	5.00
Std. Dev	0.24 fc	0.55 fc	0.30 fc	0.21 fc	0.59 fc	0.31 fc
Coefficient of Variation	0.14	0.23	0.16	0.23	0.46	0.27

The lowest of the three minimum illuminance values, when rounded to one significant digit, is 0.2 fc or the minimum requirement in RP-20-98. However, it should be noted that minimum illuminance values are often extreme values and do not necessarily represent a quantity of measurement points at or under 0.2 fc (i.e., such an extreme value may appear in only one or a few locations and is not really representative of the overall quality of illumination). In this case, the value occurs because the parking lot pole layout and the angled orientation of the façade cause geometry issues and shadowing. The minimum point could have been rectified by an additional luminaire, which would have also affected some of the other results.

3.0 Economics

3.1 Maintenance and Energy Schedules

LED luminaires typically require a higher initial investment than conventional (e.g., HID) luminaires that achieve the same performance. For such investments to achieve the relatively short payback periods that many commercial establishments require for upgrading equipment, sites must often consider factors such as maintenance savings in addition to energy savings. In many cases, the deferred or reduced maintenance offers more potential return than does the value of the energy saved.

3.1.1 Utility Energy Schedules and Incentives

The T.J.Maxx Plaza uses electricity supplied by Public Service of New Hampshire (PSNH), part of the Northeast Utilities System. Due to the plaza's size, and because each tenant is individually metered, the plaza falls into rate "G" for commercial customers with less than 100 kW of connected load. Table 3.1 shows the calculated combined rate based on PSNH's published rates effective January 1, 2010. This rate is somewhat higher than the national average of $0.104/kWh reported as of December 15, 2009[1].

Table 3.1. Melded Rate Calculation

	Rate G, Commercial <100 kW		
Melded Rate	kWh	Cost per kWh	Cost
Monthly Usage	4819.46		
Three-Phase Service Charge			$22.24
kW Distribution Charge	5.86	$6.73	$39.44
kWh Distribution Charges	500	$0.06	$27.84
	1000	$0.01	$13.80
	3319.46	$0.00	$16.20
kW Transmission Charge		$3.38	$19.81
kWh Transmission Charges	500	$0.01	$6.09
	1000	$0.00	$4.58
	3319.46	$0.00	$8.17
kW Stranded Cost Recovery Charges		$0.70	$4.10
kWh Stranded Cost Recovery Charges	4819.46	$0.01	$49.16
System Benefits Charge		$0.00	$15.90
Electricity Consumption Tax		$0.00	$2.65
Energy Charge		$0.09	$431.82
Total			$661.79
Total per kWh		$0.14	

At some sites, either the utility or a local energy-efficiency program sponsor provides financial incentives for energy efficient technologies. The plaza owner spoke several times with PSNH regarding

[1] Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State; Electric Power Monthly; U.S. Energy Information Administration; November 2009; http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html

financial incentives, but the utility did not provide any incentives for this project. PSNH generally provides incentives based on the kilowatt-hour savings for outdoor lighting projects. They do not take maintenance savings—which were a major factor in this installation—into account. At this time, PSNH only considers LED products in "custom projects," not their standard rebate programs. The utility only accepts LED products that are on the ENERGYSTAR® or Designlights Consortium lists and uses a cost/benefit analysis to approve the project.

3.1.2 Maintenance

As is often the case elsewhere, anticipated maintenance savings is the largest contributor to the payback for this installation. According to service records, the T.J.Maxx Plaza has been paying an average of $11,000 per year for spot relamping, or $400 per luminaire per year in maintenance. Industry estimates range from $150 to $300 per luminaire per relamp cycle for group relamping. A more typical maintenance cost of $215 was used for some calculations, based on a previous demonstration, to show payback under more typical conditions[2]. According to the plaza owner, the high lamp failure rate appears to be caused by voltage fluctuations in the supply. In addition to replacing the existing luminaires, a device to "clean" (better regulate) the power was installed. For this reason, the payback was calculated using both actual maintenance rates and more typical maintenance rates.

Aside from power quality, primary factors for relamping typically include the life of the light source and the operating hours of the lighting system. Metal halide rated lamp life is typically between 10,000 hours and 20,000 hours, though actual life might vary.

BetaLED estimates lifetimes on their products using depreciation rates provided by the chip manufacturer for given operating temperatures and drive currents. Luminaires are tested at 25°C per IESNA LM-79[3] and the standard BetaLED drive current is 350 mA, yielding an estimated lifetime of 70,000 hours for products in the standard configuration. However, BetaLED also claims a 0.25% increase in lumen output for each degree below 25°C in which the luminaire is operated. In addition, for products controlled by the optional occupancy sensor configuration, the drive current drops to only 175 mA in the low state. This combination of lower temperature and lower drive current results in estimated lifetimes "greater than 150,000" hours according to the manufacturer.[4]

Such luminaire lifetime claims are based on several assumptions and statistical extrapolations of limited test data. These claims also presume that lumen output from the LED chips is the primary determinant of luminaire lifetime (i.e., that the electronic circuitry in the luminaire and the integrity of the luminaire housing, etc., will be maintained over the period and that practical lifetime is reached when lumen output levels no longer meet the needs of the application). Because LED outdoor lighting products are still relatively new in the marketplace, a general lack of field experience under real-world conditions currently precludes confirmation of this claim. A 70,000-hour life corresponds to about 8 years at constant (i.e., 24 hours per day, 7 days per week) operation (e.g., longer than any of the current generation of LED products has existed), thus the need to rely on statistical extrapolation of the limited data available

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[2] Application Assessment of Bi-Level LED Parking Lot Lighting; U.S Department of Energy; February 2009; http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_raleys.pdf.

[3] IESNA LM-79, "Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products."

[4] TD-13 Recommended BetaLED Lumen Depreciation (LD) Factors; BetaLED; 2010; http://www.betaled.com/RuudBetaLed/media/RuudBetaLedMediaLibrary/PDF%20Files/TD-13_Recommended_BetaLED_LD_Factors.pdf

to date. Only time will prove the validity of such estimates. GATEWAY will continue to monitor this and other sites to contribute to the growing body of field experience.

Dirt is another maintenance factor that requires consideration. Over time, dirt and grime tend to build up on the optical assembly of the luminaire, regardless of the light source. In theory, when the lamp in a conventional product is replaced, the luminaire is cleaned. In practice, deliberate cleaning during relamping often does not occur, although loose dirt may be dislodged when the luminaire is opened. In contrast, eliminating the relamping requirement as a result of using LEDs means that dirt will inevitably continue to accumulate on the LED luminaire unless something is done to prevent it, such as developing a cleaning schedule. The GATEWAY program is currently collecting real-world data on dirt depreciation of LED luminaires over extended operating periods to investigate the importance of periodic cleaning.

3.2 Payback

Using pricing, installation, and maintenance information provided by the plaza owner, simple payback was calculated for both the installed BetaLED products and an alternatively proposed traditional PMH upgrade. The estimated first cost of the new metal halide system was $18,020, while the actual cost of the LED was $46,640. Installation cost was assumed to be the same for both systems, at $13,930, because the number of poles, heads, and installation times were identical. Multiple scenarios were examined using both actual energy costs and national average costs, as well as a range of maintenance costs. Some selected results are listed in Tables 3.2 through 3.4 below.

Table 3.2. Best-Case Payback using Actual Electric Rates and Actual Maintenance Costs

Type	Equipment Cost	Maintenance Cost[5]	Annual Energy Cost	Total Savings	Payback (years)
Existing		$11,000.08	$8,096.69		
Proposed PMH	$28,020.00	$9,821.50	$5,595.45	$3,679.82	7.61
LED	$47,125.00	$1,250.00	$2,590.77	$15,256.00	3.09

Table 3.3. Payback using National Average Electric Rates and Actual Maintenance Costs

Type	Equipment Cost	Maintenance Cost	Annual Energy Cost	Total Savings	Payback (years)
Existing		$11,000.08	$6,014.69		
Proposed PMH	$28,020.00	$9,821.50	$4,156.62	$3,036.65	9.23
LED	$47,125.00	$1,250.00	$1,924.57	$13,840.19	3.40

Table 3.4 Worst-Case Payback using National Average Electric Rates and Typical Maintenance Costs

Type	Equipment Cost	Maintenance Cost	Annual Energy Cost	Total Savings	Payback (years)
Existing		$6,020.00	$6,014.69		
Proposed PMH	$28,020.00	$5,375.00	$4,156.62	$2,503.07	11.19
LED	$47,125.00	$1,250.00	$1,924.57	$8,860.11	5.32

[5] Maintenance costs were estimated with a flat cost per luminaire per year that attempts to include both scheduled (i.e. relamping) and unforeseen costs.

Reduced maintenance is a major source of savings in this project. The power quality problems reported by the owner sharply reduced lamp life (to approximately 40% of rated) and required expensive spot relamping due to frequent failures. When using a lower spot maintenance cost of $215 per luminaire per year ($215 was the value used in another GATEWAY demonstration and is in the middle of the industry typical range), the payback period for this plaza increased from 3 to 5 years. Because a power quality device was installed and the luminaires were converted to LEDs at the same time, it is difficult to precisely determine how each change will independently affect the maintenance costs. However, payback was estimated with multiple maintenance rates, and in all cases the payback for the LED system was notably lower than the PMH system.

4.0 User Feedback

The GATEWAY program considers user feedback on the quality of LED lighting as part of the overall evaluation. If a product fails to maintain or improve the visual appearance of the site relative to the incumbent technology, significant resistance to its use is likely, and therefore the product is unlikely to be adopted on a wider scale regardless of the unit energy or financial savings it offers. In addition, quantitative analysis of the numbers in isolation of any qualitative response does not capture the full benefit of the substitution by disregarding other aspects that influence human perception, such as color rendition, glare, light trespass, and ability to detect objects.

4.1 Tenant Survey

CW Companies, the plaza property manager, distributed a survey to tenants during January 2010. Store employees were asked to respond to questions addressing several relevant aspects of lighting quality and to provide any additional comments on the new area (parking lot) lighting. All questions were carefully worded to minimize introduction of bias into the responses.

Sixty questionnaires were distributed among the tenants at the plaza. Of those, 32 questionnaires were completed and returned, for a 53% response rate.

Overall, responses to the LED luminaires were quite positive. All respondents indicated that the new installation was equivalent to or better than the existing installation. Only one respondent did not think this type of lighting should be used at other locations, though no further explanation was provided. One respondent asked for more information. Two respondents questioned the cost of the installation and the potential effect on their rent. As explained by the owner, the tenants pay the utility costs proportionally, based on the square footage of their individual space, and will have the energy savings passed on to them. The plaza owner will realize savings through reduction in maintenance costs, which are expected to be significant.

Three respondents assumed that the lights saved energy, and two commented on the high/low settings with motion sensors. There were several comments that new system improved safety and security. One employee commented that new lighting “shows stores are open.” Some commented on the improved “color” and “brightness.” Two commented on the high/low settings with motion sensors.

See Appendix B for the survey questions, summary responses, and comments received (verbatim).

5.0 Discussion

The BetaLED product achieved an estimated payback of about 3 years because of the previous system's high maintenance and energy costs. However, poor power quality issues that resulted in shorter lamp life drove a significant portion of the previous maintenance cost. Equipment to improve power quality was installed simultaneously with the new luminaires, so that some of the previous maintenance costs would presumably be avoided even if the old luminaires were retained.

Using the national average electric rate and lower maintenance costs, a payback of up to 5 years might result if the project were located elsewhere. However, the associated energy savings of 58% supporting these payback periods was achieved by reducing photopic illuminance by a similar amount (47%) and using motion sensors to reduce illuminance levels even further when the area is unused. Despite these reductions, in all cases illumination levels appear to meet or exceed IESNA recommendations.

However, the values in Table 2.8 show that the LED system did not meet the CBEA specification in terms of either minimum illuminance (in two areas: front aisle and main parking) values or uniformity. The minimum illuminance could have been met by increasing either the number of LEDs or the drive current within the luminaire, though this would also negatively affect the energy savings as well as payback. Drive current would also negatively impact product lifetime. Based on the feedback received, the LED system was considered a success and the CBEA specification may be further revised to consider retrofit applications.

The LED system has the distinct advantage of modular output that can be more precisely tailored to the needs of a specific application when compared to both the existing installation and the proposed PMH alternative. Still, the PMH system was calculated to have higher average illuminance (3.71 fc average for the PMH vs. 2.03 fc average for the LED), which suggests a potential for additional savings in the PMH by downsizing it to a more appropriate level even if its design flexibility is not as great as with the LED.

In terms of performance over the longer term, lumen depreciation affects each of the sources differently. The end of useful life for the LED system is the point at which light output reaches L_{70}, whereas the PMH system would have depreciated to 78% of initial illuminance after only about 8,000 hours (or 40% of rated life). The rate of change of the LED system is assumed to be the slowest of the systems under consideration, based on catalog data.

Regarding user acceptance, 30 out of 32 respondents to the employee survey said that they would recommend LEDs be used elsewhere. Most thought that lighting quality was improved following the LED substitution. The employee responses to the survey were quite positive overall (see Appendix B). Several tenants questioned the cost of the installation, apparently not realizing that the structure of the agreement between the property owner and tenants means that energy cost savings will be passed on to the tenants while maintenance savings go to the property owner to pay for the installation.

Underlying the estimated payback period are the assumptions that there is no difference between installation labor for the LED and PMH units and that luminaires would not need to be replaced prior to end of rated life. Limited historical field experience exists for LED outdoor lighting products at this writing; hence, their expected lifetime remains only a projection.

Appendix A

HPS and LED Illuminance Values Across the Measured Grid

The tables below provides the measured illuminance values (in footcandles, fc) for both products across the measured grid. Vehicles were parked along one portion of the lot and precluded the taking of readings in those locations (shown as blank cells in the table).

Table A.1. HPS Illuminance Values (fc)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	16.74	13.85	7.97	3.20	1.49	0.79	0.66	0.85	1.75	3.90	7.87	12.92	13.95
2	13.22	11.99	7.91	4.11	1.74	0.94	0.77	1.10	1.92	3.45	5.83	8.84	11.26
3	8.89	8.38	6.25	3.72	1.74	1.00	0.87	1.09	1.83	3.09	4.60	6.03	7.05
4	5.32	4.98	4.48	3.21	1.61	0.99	0.85	1.15	1.80	2.80	3.66	4.10	4.26
5	1.78	1.97	2.51	2.41	1.61	0.97	0.84	1.08	1.72	2.48	3.09	3.05	2.92
6	1.52	1.76	2.33	2.23	1.52	0.94	0.78	1.00	1.62	2.40	2.97	2.72	2.43
7	2.70	2.65	2.88	2.28	1.32	0.86	0.72	0.82	1.43	2.49	3.32	3.21	3.01
8	4.92	4.93	4.08	2.58	1.37	0.79	0.72	0.78	1.33	2.76	4.40	5.37	5.50
9	8.37	7.93	5.54	2.85	1.38	0.74	0.60	0.77	1.46	3.24	6.18	9.11	9.81
10	11.44	5.16	5.42	2.90	1.28	0.62	0.60	0.63	1.53	3.54	7.29	11.95	13.78

Table A.2. LED Illuminance Values (fc)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	2.18	2.48	2.32	2.38	2.19	1.56	1.44	1.41	1.90	2.08	2.27	2.14	2.00
2	2.54	2.80	2.88	2.56	2.00	1.59	1.36	1.44	1.84	2.14	2.75	2.94	2.72
3	2.36	2.40	2.47	2.29	1.88	1.50	1.39	1.38	1.70	1.99	2.55	2.60	2.57
4	2.19	2.34	2.48	1.91	1.53	1.36	1.28	1.25	1.54	1.74	2.43	2.71	2.51
5	2.26	2.31	2.23	1.76	1.46	1.15	1.25	1.30	1.44	1.67	2.07	2.42	2.55
6	2.29	1.80	2.12	1.68	1.37	1.15	1.03	1.23	1.48	1.64	1.95	2.21	2.40
7	2.38	2.00	2.33	1.71	1.53	1.46	1.16	1.40	1.63	1.68	2.20	2.43	2.56
8	2.27	2.31	2.57	1.85	1.72	1.66	1.15	1.52	1.67	1.99	2.62	2.94	2.58
9	2.72	2.44	2.62	2.40	1.97	1.66	1.14	1.53	2.05	2.44	2.82	2.86	2.74
10	2.58	2.37	2.26	2.50	1.80	1.70	1.25	1.52	2.11	2.60	2.93	2.71	

Appendix B

T.J.Maxx Plaza Tenant Survey (Conducted January 2010)

1. Did you notice that new parking lots lights were installed? (Apart from notification that they were to be replaced)

Responses	Number	Percentage
Yes	29	90.6%
No	3	9.4%

2. Have you overheard or otherwise received direct feedback from store customers about the change in parking lot lighting?

Responses	Number	Percentage
Yes	12	37.5%
No	20	62.5%

2a. If you answered ‘yes’, were the comments generally favorable or unfavorable?

Responses	Number	Percentage
Favorable	11	91.7%
Unfavorable	0	0.00%
Other	1	8.3%

3. In general, do you think the lighting improves or worsens the appearance of the parking lot?

Responses	Number	Percentage
Improves	25	78.1%
About the Same	7	21.9%
Worsens	0	0.00%

4. In general, does the replacement lighting system provide more light, less light, or about the same as the original parking lot lights?

Responses	Number	Percentage
More	25	78.1%
About the Same	7	21.9%
Less	0	0.00%

5. In general, how satisfied are you with the new parking lot lighting?

Responses	Number	Percentage
Very Satisfied	20	62.5%
Satisfied	12	37.5%
Dissatisfied	0	0.00%

6. In general, how would you rate the new parking lot lighting?

Responses	Number	Percentage
Excellent	19	59.4%
Very Good	11	34.4%
Good	2	6.3%
Fair	0	0.00%
Poor	0	0.00%

7. Would you recommend this type of parking lot lighting system be used as other public locations?

Responses	Number	Percentage
Yes	30	93.8%
No	1	3.1%
Other	1	3.1%

8. Do you have any additional comments about the new parking lot lighting system?

- *“I think that the new parking lot lighting helps to increase safety and security within the plaza and that is always a good thing.”*
- *“The lot is much more brighter and shows stores are open.”*
- *“The lights appear brighter so I feel safer at night going to my car. Also the parking lot looks classier w/ the new lights. We do worry about the cost of installing the lights to our overall rent.”*
- *“I like that all the lights work now - they didn't before. Would like more info about lights – they’re good but is there any benefit to them? Less energy use? Less overall light pollution?”*
- *“They are noticeably brighter than before, a better "color" light also. I usually close the store, so I have to be here at night. It's nice to have brighter lights.”*
- *“Please move the handicap ‘cone’ that's right in front of Panera Bread. It is right where I open my car door when I park in the handicap spot. It should be at the head of the parking space. Thank you.”*
- *“Nice coming in at 5:00AM + having lights on! :)”*
- *“I really like that they use less energy and that it is better for the environment. I also really like how this plaza is kept looking very nice. Job well done!”*
- *“I would like to tell you that this is the most efficient and well maintained plazas that I have ever worked in. Whoever takes care of this plaza does an outstanding job! :) Store Mgr Payless Shoe Source.”*
- *“Unnecessary expense at this time; I am sure the tenants have to pay for it and might have to lay employees off due to the high charges.”*
- *“Like the motion detectors - good savings - just as bright as other lights they just give off a different color light that takes some time to get used to.”*
- *“Saves electricity :) ”*
- *“Once I was told did notice it as soon as I came in the parking lot.”*
- *“I like that any movement at all the light comes on and you never have worry about being in a dark parking lot anymore. I also like that it is not wasted when it is not needed.”*