GATEWAY DEMONSTRATIONS

Demonstration Assessment of Light-Emitting Diode (LED) Retrofit Lamps

Host Site: Bonneville Power Administration, Portland, Oregon

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

Study Participants:
Pacific Northwest National Laboratory
U.S. Department of Energy
Bonneville Power Administration

July 2011

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

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Demonstration Assessment of Light-Emitting Diode (LED) Retrofit Lamps in the Lobby of Bonneville Power Administration, Portland, OR

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Preface

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

Executive Summary

This report describes the process and results of a demonstration of solid-state lighting (SSL) technology in the lobby of the Bonneville Power Administration (BPA) headquarters building in Portland, Oregon. The project involved a simple retrofit of 32 track lights used to illuminate historical black-and-white photos and printed color posters from the 1930s and 1940s. BPA is a federal power marketing agency in the Northwestern United States, and selected this prominent location to demonstrate energy efficient light-emitting diode (LED) retrofit options that not only can reduce the electric bill for their customers but also provide attractive alternatives to conventional products, in this case accent lighting for BPA's historical artwork.

BPA replaced the artwork track lighting as an energy project in 2001, where halogen PAR38 reflector lamps were replaced with 15W and 23W reflectorized compact fluorescent (CFL) lamps. While this dramatically reduced energy use, it also diminished the drama and visibility of the art. Both CFL lamp types produced a soft, wide pool of light that was too wide to concentrate light on the wall displays. Consequently, brightly lit areas above the artwork became a distraction rather than drawing the viewer's eye to the art.

This GATEWAY demonstration compared the lighting performance of the Cree PAR38 12W LED lamp to the two types of CFLs in terms of lighting quality, power quality, energy use, and life-cycle cost. Although both CFLs emit more light than the Cree PAR38 LED replacement lamp, the narrower light distribution of the LED product concentrates the lumens on the artwork and minimizes the amount of light striking the wall above the art. Vertical illuminances measured for the LEDs on the face of the artwork average 1.4 times higher than the 23W PAR38 CFL and 3 times higher than the 15W R30 CFL. The LED lamps also increased the vertical illuminance contrast ratio between the artwork and the surrounding wall, compared to both the 23W PAR38 and the 15W R30 CFL lamps.

Life-cycle cost analysis was not expected to show rapid payback on the LED installation compared to the CFL products for the following reasons:

1. The power draw of all three lamps is similarly low, although the LED lamp is the lowest. However, to some observers, the lowest-wattage (15W) CFL lamp did an unacceptable job of lighting the artwork, so it was unfair to compare the cost and performance of the LED lamp to this underperforming CFL lamp. (The output and distribution of the R30 CFL lamp is much better suited to the low ceilings of residential applications than this commercial lobby application.) The 23W CFL lamp produced a more acceptable illuminance than the 15W CFL, but also failed to focus more light on the art than the surrounding wall.

2. BPA pays their local utility a very low melded retail electrical rate ($0.0695 per kilowatt-hour (kWh)) due to the large proportion of hydro power in the area.

3. At the time of this study, the LED replacement lamp cost was very high ($108 each, compared to $4.03 for the R30 CFL lamp and $13.05 per PAR38 CFL lamp).

The 16-year life-cycle costs of the three systems installed in the BPA lobby are as follows. The lamp used prior to 2001, a 90W halogen PAR38, is included as a fourth system for comparison:

- $7,890 for the Cree LED LRP38 lamps
- $6,835 for the Philips EL/A 15W R30 CFL lamps
- $9,163 for the TCP 23W PAR38 CFL lamps
- $26,329 for the original 90W halogen PAR38 lamps.

Because of the low electrical rates and the high cost of the LED lamps, there is no payback for the LED lamps compared to the 15W CFL lamping, but payback occurs in year 9 when LED lamps are compared to the 23W CFL lamping. The LED's 50,000 hour expected lamp life (to 70% lumen maintenance) reduces the number of lamp changes compared to the CFL lamps (8000 hours expected mean life). The spot-relamping labor cost of $30 helps make this lamp cost-effective in time, but it takes 9 years before the energy and maintenance savings exceed the initial cost premium of the LED lamp. Annual operating hours are 3120, so relamping occurs on average every 2.5 years for the compact fluorescent, and every 16 years for the LED. (If the same life-cycle cost analysis is done with more typical U.S. electric rates, the payback time is compressed. At $0.10/kWh, the payback time drops to less than 8 years, and at $0.15/kWh, the simple payback drops to less than 7 years.)

Even though the color temperature was around 2700K for all three lamps, color quality improved with the LED lamping, from a color rendering index (CRI) of 82 for the CFL to a CRI of 93 for the LED. The LED lamp emits more energy in the long-wavelength red region of its spectral power distribution, improving its rendering of red tones in architectural finishes and artwork in the lobby.

Power quality also improved with these LED lamps, although that is a function of the electronics design of these lamps, rather than a feature of LED lamps universally. Power factor increased from 0.50 or 0.55 for the incumbent CFLs, up to 0.94 for the LED lamp.

This simple changeout of lamps has raised the visibility of the lobby's historical photos and posters and improved their appearance. BPA is pleased to demonstrate an effective, energy-efficient alternative to screwbase compact fluorescent lamps to their staff and customers.

Acronyms and Abbreviations

BLCC	Building Life-Cycle Cost
BPA	Bonneville Power Administration
CALiPER	Commercially Available LED Product Evaluation and Reporting
CCT	correlated color temperature
CFL	compact fluorescent lamp
CO_2	carbon dioxide
CRI	color rendering index
DOE	U.S. Department of Energy
fc	footcandle(s)
K	kelvin
kg	kilogram(s)
kWh	kilowatt-hour(s)
LED	light-emitting diode
LPW	lumen(s) per watt
NO_X	nitrogen oxide
PAR	parabolic aluminum reflector (number following PAR indicates maximum diameter of lamp in eighths of an inch)
PF	power factor
PNNL	Pacific Northwest National Laboratory
PV	present value
R	reflector-shape lamp (number following R indicates maximum diameter of lamp in eighths of an inch)
SO_2	sulfur dioxide
SSL	solid-state lighting
THD	total harmonic distortion
W	watt(s)

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1.0 Introduction

As part of an ongoing effort to investigate energy-efficient alternative technologies for its customers, the Bonneville Power Administration (BPA) recently retrofitted some of the lighting in the lobby area of its Portland, Oregon headquarters building (Figure 1) with solid-state lighting (SSL) products. The project involved a simple retrofit of track lighting used to illuminate historical black-and-white photos and printed color posters from the 1930s and 1940s. BPA is a federal power marketing agency in the Northwestern United States, and this prominent lobby is ideal for demonstrating new lighting technologies to BPA employees, visitors, and customers. This simple installation shows that reducing energy use and maintenance costs can also result in a better lit environment. The lobby artwork is more noticeable and more appealing because the new lighting makes it easier to see important visual details.

In 2001, BPA had performed an energy retrofit on the lobby artwork track lighting. Originally lamped with incandescent PAR38 reflector lamps with a 30-degree beam that focused light on the changing artwork collections, the track heads had been retrofitted with 15W R30 and 23W PAR38 compact fluorescent (CFL) reflector lamps. This reduced energy use dramatically, but also diminished the drama and visibility of the art. Both versions of the compact fluorescent lamps deliver a soft, wide pool of light (similar to a cosine distribution, with a beam angle close to 120 degrees), which is too wide to concentrate light onto the objects. Instead, the wide beam produces the highest illuminance on the wall above the artwork. The highlighted upper wall becomes a distraction, since it is the most brightly lighted section of wall. The 15W CFL R30 lamp, designed for low-ceiling residential applications, delivers insufficient light to make the artwork conspicuous. The 23W CFL PAR38 lamp does a somewhat better job because of its higher light output. However, neither does an acceptable job of illuminating the art.

The GATEWAY Project objectives included improving visibility of the lobby artwork and demonstrating the lighting quality and lamp appearance of the new light-emitting diode (LED) replacement lamps for visitors and BPA staff. BPA is also interested in demonstrating the energy and cost savings potential of this new technology, and partnered with Pacific Northwest National Laboratory (PNNL) to document the lighting performance before and after the retrofit.

Figure 1. BPA Headquarters Building in Portland, Oregon. (Photo courtesy of BPA.)

2.0 Methodology

BPA performed the retrofit to LED replacement lamps approximately 5 months before GATEWAY became involved in the evaluation. Therefore, one step in this demonstration project was to identify and reinstall the previous lighting system to provide a baseline for the evaluation. In addition, a special work plan was developed to ensure an adequate basis for comparison among the products.

2.1 Work Plan for this GATEWAY Demonstration

The work plan involved several steps intended to provide information on the comparative performance and costs of the different lighting products, despite the demonstration's involving only a few samples installed in a small physical space. The steps included the following:

- Identify two corners of the lobby for comparative lamping. Two opposite corners were selected to get two different types and sizes of artwork. BPA and PNNL agreed this would be a qualitative comparison, without the rigor of independent photometric testing and monitoring of long-term performance. Wherever possible, photometry based on CALiPER[1] program reports would be used for lamp performance information.

[1] CALiPER (Commercially Available LED Product Evaluation and Reporting) is a Department of Energy program to independently test and report performance on SSL products. See http://www1.eere.energy.gov/buildings/ssl/caliper.html.

- Document the programming of the lobby lighting control system to estimate number of hours of operation per year.
- Document the details of the previous compact fluorescent lamping of the lobby track lighting, including lamp catalog information, wattage, color, beam angle, and the illuminances produced on the lobby walls. (These lamps had been in place in the lobby for an indeterminate period of time, so they were not new.) Document the details of replacement LED lamping of the lobby track lighting, along with the illuminances produced on the walls. (All of the LED lamps had been installed in the lobby by October 1, 2010, so the lamps had been operating for 5 months when GATEWAY performed the evaluation.)
- Lamp the track lighting for the two corners with the two types of compact fluorescent lamps. One CFL lamp type was used in one corner, the second in the opposite corner. The lamps were aimed to deliver the best possible pattern of light on the artwork. These are called the "BEFORE" conditions.
- Take illuminance measurements on the artwork walls and photograph the installations.
- Re-lamp the track lighting for both corners with the LED replacement lamps, aiming them to provide the best possible pattern of light on the artwork. These are called the "AFTER" conditions.
- Take illuminance measurements on the artwork walls and photograph the installations.
- Perform a life-cycle cost study and document the relative performance of the lamps in a GATEWAY report.

2.2 Demonstration Site Description and Background

In 2010, BPA procured Cree PAR38 LED integral replacement lamps for distribution to different sites to demonstrate the lighting characteristics and energy savings that the lamps offer. They retained one set of these LED lamps for their headquarters building in Portland. The lobby welcomes visitors and staff to the building, and at the time of this study displayed photographs and posters that illustrate the history of the dams and power systems that brought hydro power to the Northwest in the 1930s. The artwork displays are lighted with track lighting that provides flexibility when the artwork changes. There is no dimming on the artwork lighting circuits that might affect lamp life.

BPA has promoted responsible energy use for decades, and had relamped the lobby track lighting in 2001 with compact fluorescent lamps. Originally lamped with medium-base halogen PAR38 lamps that focus light into a 30-degree "flood" beam, the compact fluorescent lamps produced a very different quality of light. Although the draw about 20-25% of the power drawn by the halogen lamps they replaced, the compact fluorescent lamps produce a very soft pool of light, with a beam angle of approximately 120 degrees.[2] This produced a very soft flood of light on the wall, which did not effectively draw the eye to the artwork. To compensate for such a wide beam angle, 30-inch track extenders were added to help bring the light closer to the featured artwork. This solution was left in place as a demonstration of CFL energy efficient incandescent lamp replacements, but was modified for the LEDs. (See Figures 3 and 5.)

[2] "Beam angle" is an approximate angle at which the light intensity falls to half the maximum value in the beam. It approximates the visual size of the beam as it is projected onto a surface. It is calculated by finding the maximum luminous intensity (candela value) projected from the lamp, and then identifying the angle from the center of the beam at which the intensity drops to 50% of that value. For a symmetrical beam of light, it is twice the angle from the center of the beam to the angle at the 50% candela value.

By October 1, 2010, many of these compact fluorescent lamps were changed out to the Cree 12W LRP38 LED integral replacement lamps that deliver a 20-degree beam, with a color and character more similar to the original halogen lamps except that the beam angle was narrower than the halogen lamps' 30-degree angle. Because the beam angle is so much narrower, and because there are only two track heads available per track, these LED lamps produced a pair of pronounced light ovals on the walls, with gaps between them that left the center artwork slightly shadowed. This uneven light pattern was improved by eliminating the track extender and mounting the track heads directly to the track, creating a longer throw distance that enlarged the oval of light and made the resulting pattern of light on the artwork more uniform across the wall. The effect of the lamp beam angle on the artwork wall is illustrated in Figure 2.

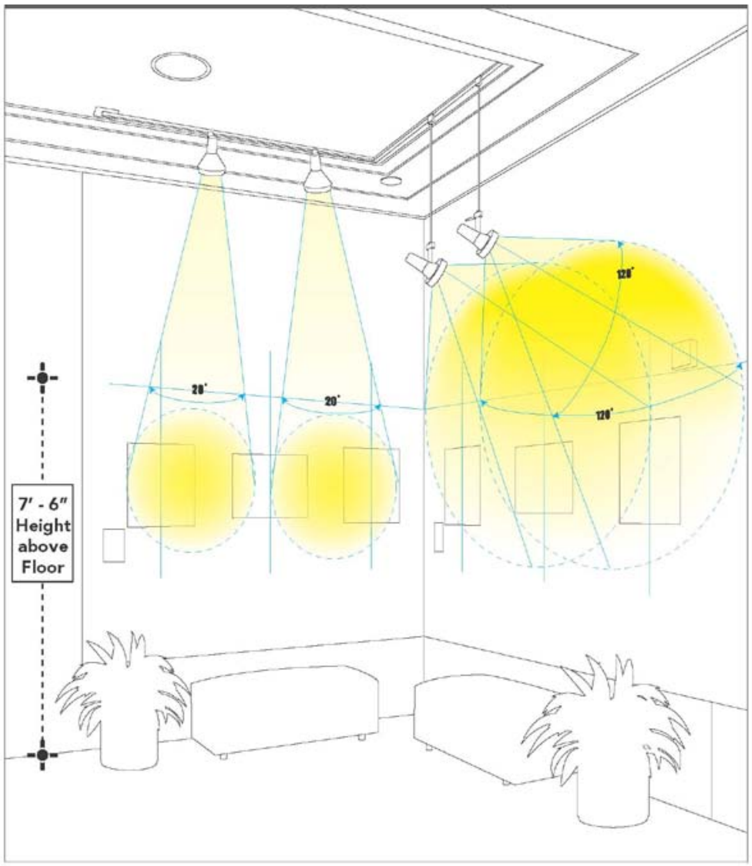


Figure 2. The effect of different lamp beam angles on lighting patterns on artwork walls. The 20-degree beam angle from the LED replacement lamp is illustrated on the left, and the 120-degree beam angle from the CFL reflector lamps on the right.

The narrower beam of light increases the illuminance on the artwork and reduces the light on the wall around the art. The higher contrast draws the eye to the artwork more effectively.

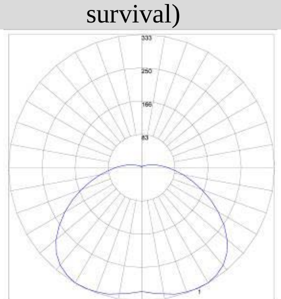
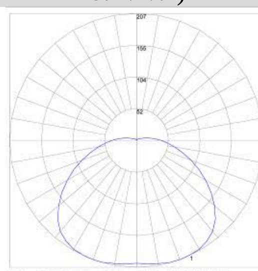
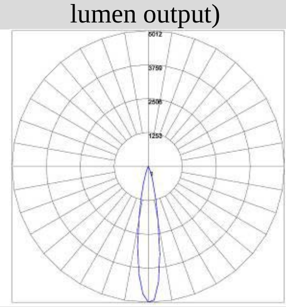
2.3 Comparison of CFL and LED Lamps

Table 1 compares the features of the CFLs to the LED replacement lamps. The two different CFL types were installed on different sides of the lobby:

- Philips EL/A R30 15W 120V 2700K reflector lamps, installed as shown in Figure 3, and
- TCP PF3823 23W 3000K 120V PAR38 lamps, installed as shown in Figure 5.

Some color variation among the CFL lamps is observable in the installation photos.

Table 1. Comparison of CFL and LED replacement lamps. Center beam candlepower, beam angle, lumens, watts, CCT, and CRI were taken from CALiPER reports for the Philips and Cree lamps. The TCP data were derived from manufacturer's technical specification sheets. Candela curves were approximated.

Lamp description and nominal power	TCP 23W PAR38 CFL	Philips 15W EL/A R30 CFL	CREE 12W LRP38 LED
Center beam candlepower	310	236	4465
Beam angle (to 50% candlepower)	118°	110°	18°
Lumens	1038	841	565
Power (watts)	23	15.8	11.2
Efficacy (lumens per watt)	45.1	53.2	50.4
Published lamp life	8000 hrs (to 50% lamp survival)	8000 hrs (to 50% lamp survival)	50,000 hrs (to 70% lumen output)
Polar plot showing candlepower distribution from lamp (CFL curves are adapted from photometry from similar lamp types). Plot scales vary.			
Photo of lamp			
CCT, CRI	2700K, 82	2740K, 82	2667K, 93

CCT = color correlated temperature
CRI = color rendering index

The Cree LED replacement lamp, detailed in Table 1 and shown installed in Figure 4 and Figure 6, is much more similar to halogen in terms of apparent color, even though its CCT of 2667K is similar to the 2700K CCT of the compact fluorescent lamps. The CFL's spectrum is poor in long-wavelength red, and it appears somewhat yellow-green compared to either halogen lamps or the LED lamp. The Cree LED lamp delivers better overall color quality and its similarity to the halogen incandescent spectrum is reflected in its high CRI.

Color quality improved with the LED lamping. All lamps are within 50K of 2700K (warm) color temperature. Both CFL lamps exhibit a CRI of 82; the Cree LED lamp's CRI is 93. The LED lamp also emits more energy in the long-wavelength red region of its spectral power distribution, improving its rendering of red tones, wood colors, and skin color. (This is mentioned separately because red hues are under-represented in the calculation of CRI values.)

All three of the lamps are similar in power draw (in watts) and efficacy (lumens per watt or LPW), so the advantage of the Cree lamp for this application is not its energy efficiency or high lumen output. In fact, its total lumen output is only slightly over half that of the 23W compact fluorescent. The Cree lamp's advantage lies in its ability to concentrate those lumens in a narrow cone, which is much more suitable for accent lighting. The Cree lamp also emits less spill light at high angles. Lumens emitted from 60 to 90 degrees from the CFL lamp's center axis are responsible for the distracting wall brightness high above the art in the respective photos of their installations.

When comparing lamps for accent lighting, center-beam candela values and the full light distribution from the lamp are more important than simply lumens or LPW alone.

Figure 3. Lobby photos lighted with Philips EL/A R30 compact fluorescent lamps (BEFORE). Note high level of illumination above the artwork. (Photo by Mike Hoffman, PNNL.)

Figure 4. Lobby photos lighted with Cree LRP38 LED lamps (AFTER). Note that the beam is much more focused on the intended target. (Photo by Mike Hoffman, PNNL.)

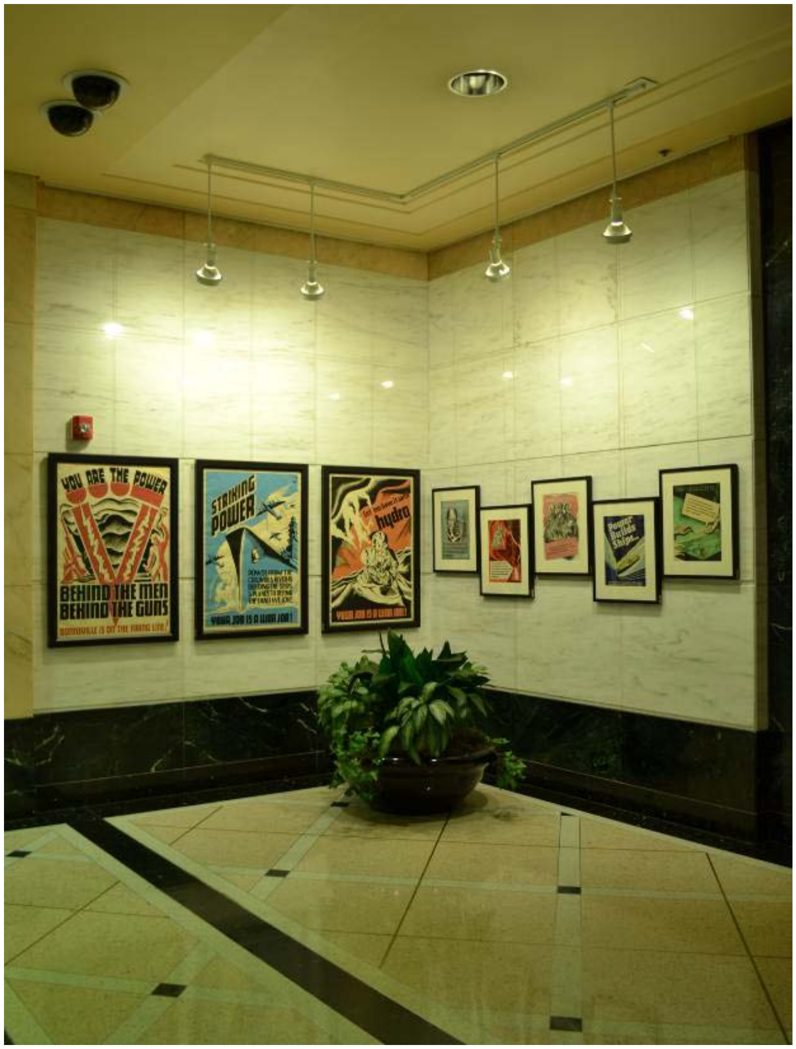


Figure 5. Lobby poster art lighted with TCP FP3823 PAR38 compact fluorescent lamps (BEFORE). (Photo by Mike Hoffman, PNNL.)

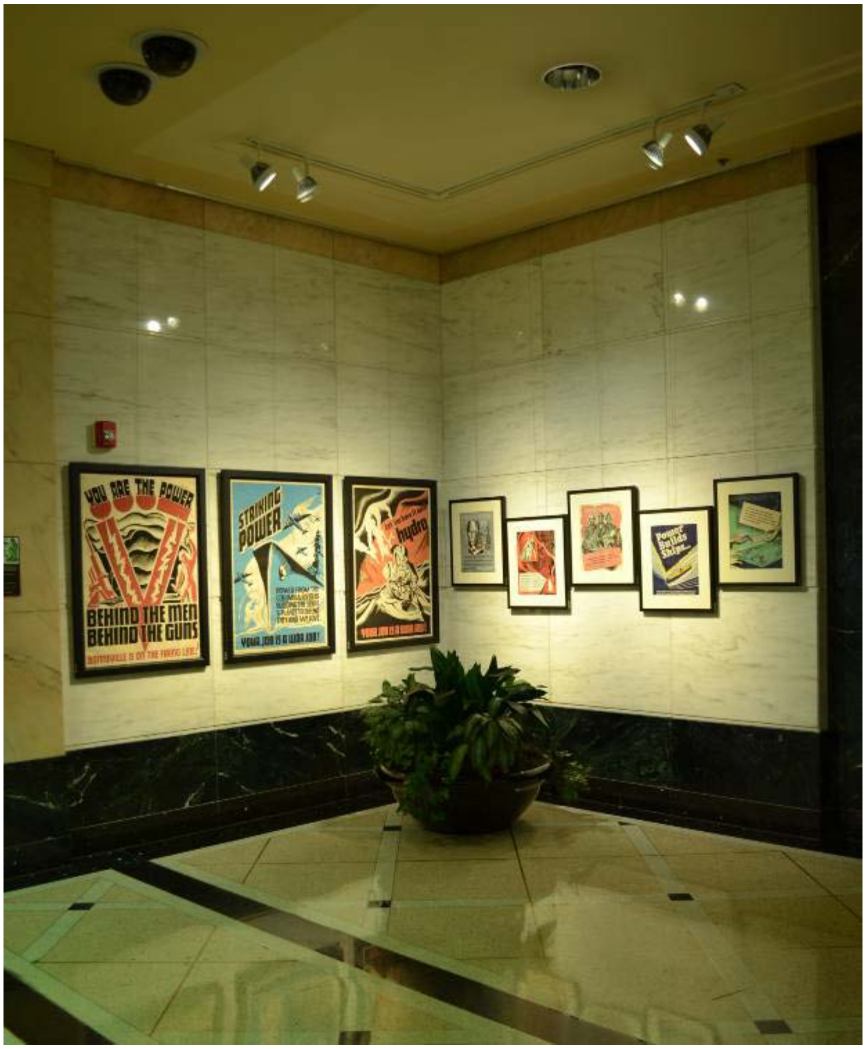


Figure 6. Lobby poster art lighted with Cree LRP38 LED lamps (AFTER). (Photo by Mike Hoffman, PNNL.)

3.0 Before and After Illuminance Measurements

Illuminance measurements were taken on and above the poster art and photographic art under the compact fluorescent lamping (BEFORE) and the LED lamping (AFTER). The wireframe figures showing the illuminances are grouped below and correspond to Figure 3 through Figure 6, respectively.

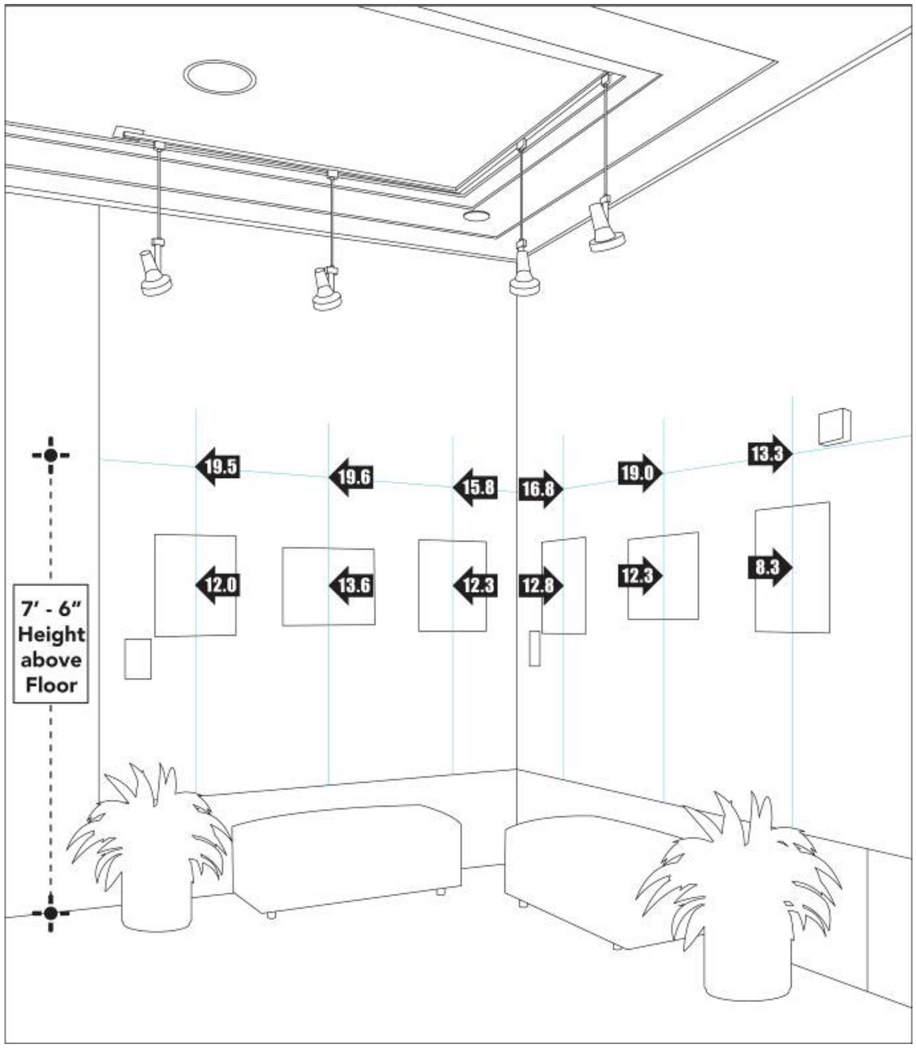


Figure 7. Vertical illuminances measured on photography wall, using Philips 15W EL/A R30 CFL lamps. Corresponds to Figure 3 photograph.

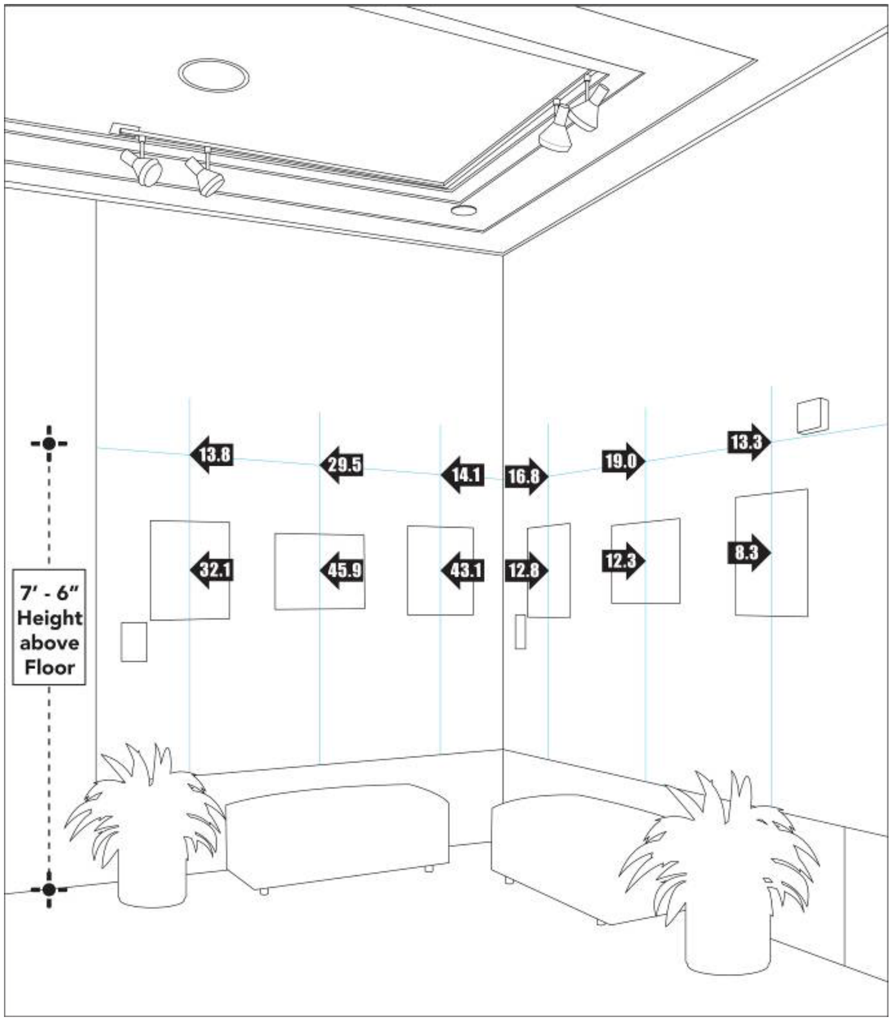


Figure 8. Vertical illuminances measured on photography wall, using Cree 12W LRP38 LED lamps. Values are in footcandles (AFTER). Corresponds to Figure 4 photograph.

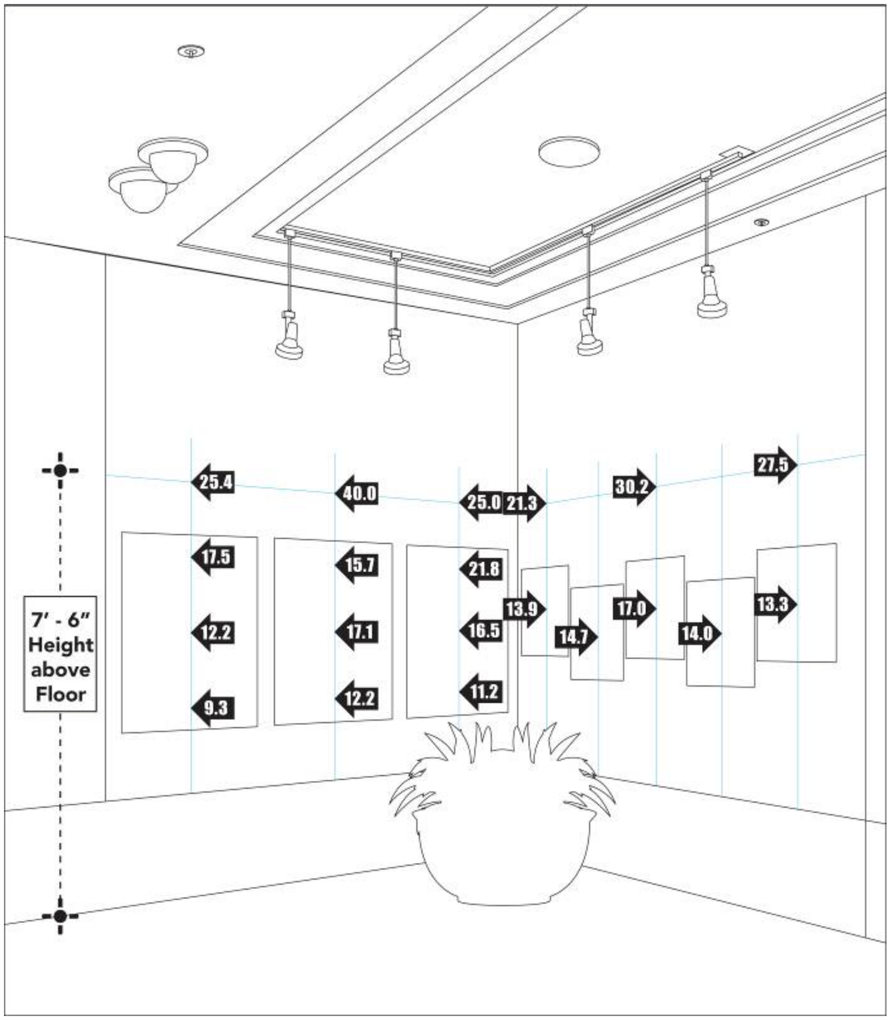


Figure 9. Vertical illuminances measured on poster art wall lighted with TCP 23W PF3823 3000K compact fluorescent lamps. Values are in footcandles (BEFORE). Corresponds to Figure 5 photograph.

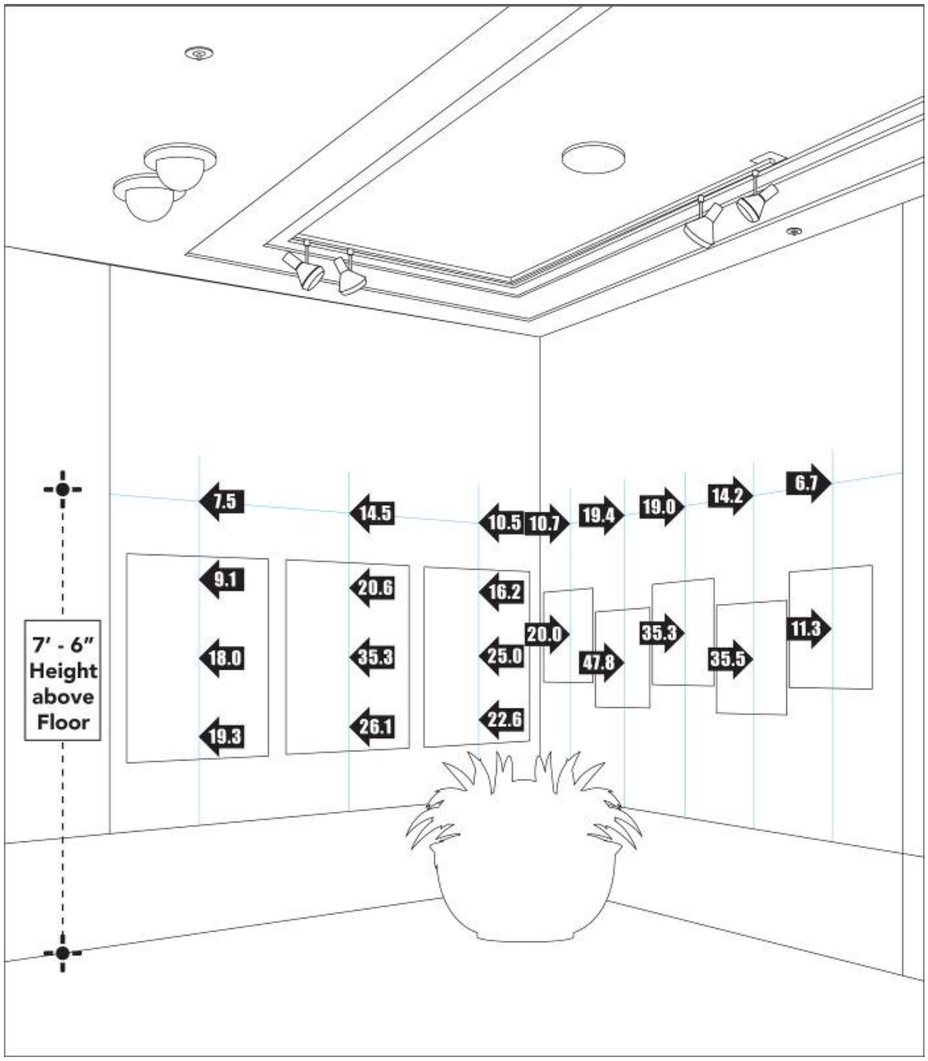


Figure 10. Vertical illuminances measured on poster art wall lighted with Cree LRP38 LED replacement lamps. Corresponds to Figure 6 photograph.

Table 2 summarizes the light level changes due to the lamping change. The vertical illuminances measured on the artwork **increased** by a factor from 1.6 to 3 when using the Cree LED PAR38 lamps. Above the posters, the average vertical illuminances **decreased** (because more light was focused on the posters rather than the wall) compared to the wider spread 23W compact fluorescent lamps. However, in the case of the photograph wall, the Cree LED lamp produced an increase in all illuminance measurement points relative to the lower wattage compact fluorescent R30 lamp.

In all cases, the Cree LED lamp **increased** the illuminance contrast between the lighted object and the surrounding wall surface. The average illuminance contrast ratio for the photograph walls increased from 0.7 to 1.6 for the LED lamp, and the same contrast ratio for the poster walls increased from 0.5 to 1.9. (The higher contrast ratio equates to more dramatic accent lighting; a lower ratio means a more uniform wallwashing effect.)

Table 2. Illuminance measurements from incumbent CFL lamps ("Before") and LED lamps ("After").

	Lamp Type in Track Lights	Avg. Illuminances Above Artwork	Avg. Illuminances On Artwork	Contrast Ratio (of Object Illum. to Surround Illum.)
Photographs BEFORE	Philips 15W EL/A R30 CFL	17.3 fc	11.9 fc	0.7
Photographs AFTER	Cree 12W PAR38 LED	22.2 fc	36.0 fc	1.6
Posters BEFORE	TCP 23W CFL PAR38	28.2 fc	14.7 fc	0.5
Posters AFTER	Cree 12W PAR38 LED	12.8 fc	24.4 fc	1.9

4.0 Power Quality

Power quality also improved with the LED lamps, although that is a function of the electronics design of this lamp rather than a feature of LED lamps universally. The TCP 23W CFL lamp manufacturer specifications report a power factor (PF) greater than 50% and a total harmonic distortion (THD) less than 150%. The 15W R30 CFL lamps have a PF of 55%, with THD not reported. The PF of the Cree LRP38 LED lamp is 94%, THD unreported. (A higher PF reduces the amount of current a utility must deliver to an electrical device, for the same amount of "work" performed.)

5.0 Economics

5.1 Life-Cycle Cost Analysis

LED retrofit lamps' higher upfront costs are theoretically offset by reduced electricity costs and maintenance costs over the life of the LED lamps. The LED integral replacement lamps used in this retrofit project are on automatic control circuits, operated 12 hours a day, 5 days per week, 52 weeks per year (3120 hours per year). The LED PAR38 lamps have a published useful (L_{70}) life of 50,000 hours, or about 16 years at this rate of usage. 8000 hours is the expected average life for both incumbent compact fluorescent lamps (the point at which 50% of the lamps are expected to have failed), or about 2 years and 6 months.

This economic analysis uses the National Institute of Standards and Technology's Building Life-Cycle Cost (BLCC) software,[3] which calculates the life-cycle costs for energy conservation projects. This software was used to model the present value life-cycle cost of the 32 Cree 12W PAR38 LED lamps installed as part of this GATEWAY project in comparison to the life-cycle costs of two kinds of CFL lighting previously used. Both the CFL base-case and the LED scenarios are based on a 16-year analysis of each system's respective costs. This retrofit project is evaluated in terms of annualized spot-relamping costs (including labor at $30 per lamp), and projected 16-year energy costs, taking into account projected real fluctuations in energy prices. Full detailed reports can be found in Appendices A, B, and C.

[3] Available online at http://www1.eere.energy.gov/femp/information/download_blcc.html.

In the U.S., commercial electricity prices vary greatly from state to state and region to region. As a reference point, the U.S. Department of Energy, Energy Information Administration publishes the Average Retail Price of Electricity to Ultimate Customers by End-Use Sector by State.[4] The national average retail price of electricity to ultimate commercial customers in April 2011 was approximately $0.10 per kilowatt-hour (kWh), and commercial electricity prices ranged from a high of $0.284/kWh in Hawaii to a low of $0.066/kWh in Utah. The melded retail rate that BPA pays the local utility is below the national average at $0.0695/kWh. In general, LEDs are more likely to be economically viable in places where electricity costs are high enough that the energy savings they generate contribute significantly to paying back the high initial cost of LED products.

In addition, LED products have been found to be most cost-effective in installations where maintenance costs are high enough that they help to offset the high initial cost of LEDs. At the BPA headquarters building, most lighting-related maintenance takes place at night, and spot relamping is estimated to cost $30 per bulb.[5]

BLCC comparisons are based on "contractor-level" commercial lamp prices as quoted by a Portland electrical distributor, and confirmed by an online search of comparable prices. The Cree LRP38 LED lamps cost $108 each at the time of this study, replacing compact fluorescent lamps that cost $4.03 (Philips 15W R30) or $13.05 (TCP 23W Par38) each. No labor was included in the initial installation cost of the BLCC model because labor was identical for all three lamp types. It was assumed that all lamps would be spot-relamped when one failed.

The BPA lobby's annualized CFL R30 lamp replacement cost is $424.69 per year, including labor, while the CFL Par38 lamp annual replacement cost is $537.26, and the equivalent cost is $275.56 for the PAR38 LED replacement lamps. (See Appendix A.) While the LED lamps are not expected to require maintenance or to fail in the 16 years of life-cycle analysis, to build a reasonably conservative scenario, the BLCC comparison includes an annual lamp replacement value of

$$\frac{\text{(32 lamps per lobby} \quad \times \quad \text{Lamp cost} \quad \times \quad \text{3120 hours operation per year)}}{\text{Rated Lamp Life}}$$

5.2 Payback Horizons and Economic Feasibility

Table 3 summarizes the input data and life-cycle-cost analysis for the two incumbent compact fluorescent lamps and the replacement LED lamps.

[4] Available online at: http://www.eia.gov/cneaf/electricity/epm/chap5.pdf.
[5] Spot relamping cost for BPA's headquarters building, as quoted by BPA project manager.

Table 3. BPA lobby accent lighting life-cycle cost analysis (including labor) – input data and summary.

	CFL 15W R30	CFL 23W PAR38	LED 12W PAR38
Initial Capital Costs for All Components	$129	$418	$3456
Average Annual Electrical Energy Usage	1577.47 kWh	2296.32 kWh	1118.21 kWh
Average Electricity Cost per kWh	$0.0695	$0.0695	$0.0695
First Year Energy Consumption Cost	$109.63	$159.59	$77.72
Study Period	16 years	16 years	16 years
Discount Rate	3.0%	3.0%	3.0%[6]
Discounting Convention	End-of-year	End-of-year	End-of-year
Present Value (PV), Energy Consumption Costs	$1371	$1996	$972
Annual Value, Energy Consumption Costs	$109	$159	$77
Present Value, Relamping and Lamp Cost	$5335	$6749	$3462
Annual Value, Relamping and Lamp Cost	$425	$537	$276
Present Value, Total Life-Cycle Cost	$6835	$9163	$7890
Annual Value, Total Life-Cycle Cost	$554	$730	$628
Total Annual Emissions			
CO_2	309 kg	449 kg	219 kg
SO_2	0.40 kg	0.58 kg	0.28 kg
NO_X	0.34 kg	0.50 kg	0.24 kg
Comparative PV data over 10 year study period for 12W PAR38 LED lamps vs. 23W PAR38 CFL lamps			
Net Energy Savings from LED Lamping (PV)	N/A	Baseline	$1024
Net Savings from LED Lamping (PV)	N/A	Baseline	$1273
Savings-to-Investment Ratio	N/A	Baseline	1.42
Adjusted Internal Rate of Return	N/A	Baseline	5.28%
Estimated Simple Payback Occurs in Year	N/A	Baseline	9

In this lobby space with 32 accent lights, the LED replacement lamp compares favorably against the TCP 23W PAR38 CFL lamp, but the initial cost is not recouped until year 9 of operation. The energy savings plus the savings due to reduced relamping labor costs take that long to balance the high initial cost of the lamps. The total present value (PV) energy savings are $1024, and the total PV life-cycle cost savings are $1273.

The LED replacement lamp is **not** more economical than the 15W compact fluorescent R30 lamp, either in initial cost or life-cycle cost over the 16-year period. The inexpensive CFL and its low wattage means that even with more frequent lamp changes, the low-wattage CFL system is more than $1000 less expensive to install and operate than the LED. However, from a lighting designer's perspective, this CFL lamp does an inadequate job of illuminating the artwork in the lobby, so it could be argued that it is not a fair competitor for the LED PAR38 replacement lamp, unless energy use is the sole criterion.

As an example of how important lamp cost is to this life-cycle cost analysis, if the LED PAR38 replacement lamp were half the price (i.e., $54), the simple payback compared to the 15W R30 CFL would be 6 years, and the simple payback compared to the 23W PAR38 CFL would be only 3 years.

[6] Standard discount rate for the government building sector, as provided by BLCC program.

Similarly, if the lamp cost were to remain fixed but the melded electric rate rose to the national average of $0.10/kWh, the simple payback of the LED lamp compared to the 23W CFL lamp shortens to occur in year 8. Or, at $0.15/kWh, the simple payback occurs in year 7.

Many factors determine whether an LED system is cost-effective for a given site. This report focuses only on the initial investment, energy, and maintenance costs. In general, an LED lighting system can be cost-effective when electric utility rates are higher than average, hours of operation are long, and labor costs for relamping are high, none of which are the case in the BPA lobby. There are other factors that could affect the calculation of value and payback, such as embedded energy cost or the cost of disposal of lamps and increased waste. At this time these are difficult to quantify, and will vary according to location, so they are not included in this study.

6.0 Lessons Learned

For accent lighting, compare replacement lamps on the basis of light distribution, rather than just lumens or watts

In the BPA headquarters lobby, compact fluorescent lamps significantly reduced energy use compared to the original halogen PAR38 lamps in the track lighting, but also resulted in a substandard light distribution for the application. The LED replacement lamps installed in this demonstration restored the intended light pattern and appearance on the artwork because the lamps emit light in a narrower, higher-intensity cone that delivers more lumens to the artwork than the surrounding wall area. The suitability of characteristics such as beam angle and center beam candlepower should always be considered in addition to lumens and watts when choosing replacement lamps for a given lighting application.

LED replacement lamps may not pay back quickly when compared against other efficient sources, such as CFLs, but that may not be the point of a retrofit

Economic payback rates depend in part on the power difference between the incumbent system and the replacement system. Since compact fluorescent lamps are already efficient and low in wattage, for example, an LED replacement system takes longer to show an economic benefit. In this case, however, CFLs were not delivering acceptable focused artwork lighting, so they do not really comprise an appropriate base case for this application. The new LED replacement lamps are much more effective and more comparable to the original halogen PAR38 track lighting, and against that original product would have shown a greatly reduced simple payback due to the significant energy savings.

Good-quality LED replacement lamps are more economically viable in spite of their high initial cost when the following apply:

- Electric rates are higher than average (e.g., greater than $0.10/kWh melded rate)
- Labor costs for relamping are high because of hard-to-reach locations, areas where skilled labor is costly, the need for access outside of normal work crew hours, access to the space is limited because of special security clearance, clean room requirements, etc.
- Hours of operation are extensive (e.g., greater than 60 hours per week).
- Power savings of the LED system compared to incumbent lighting system is high, while delivering the desired lighting characteristics
- Artwork preservation is a priority.

LED replacement lamps can improve color quality and power quality compared to compact fluorescent

Check the LED product specifications or CALiPER[7] testing for color metrics (CCT, CRI, etc.) to ensure the product meets the basic requirements of the application, but remember that color metrics do

[7] CALiPER is a DOE program to independently test and report performance on solid state lighting products. See http://www1.eere.energy.gov/buildings/ssl/caliper.html

not always communicate color quality as well as the human visual system perceives it. Often a mockup is the best way to evaluate color quality.

Check the LED product specifications or CALiPER testing for power factor. For most commercial applications the power factor should be no less than 0.70,[8] and some applications have stricter requirements. Local electric utilities and ENERGY STAR specifications may provide additional guidance on product selection.

See it and try it before you buy it

Color and beam metrics are imperfect, and you can't always anticipate how a lamp will look installed. It is important to see several samples of the lamp installed before committing to a large order or specification of replacement lamps.

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[8] ENERGY STAR Program Requirements for Integral LED Lamps, Version 1.4. http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf

Appendix A

BPA Lobby Input Data for Life-Cycle Cost Analysis

Appendix A: BPA Lobby Input Data for Life-Cycle Cost Analysis

BPA Lobby - Artwork Accent Lighting - Input values for Life Cycle Cost Analysis

Incumbent CFL Lamping (2 types), LED Lamping, and Halogen Lamping

Area	Lamp Qty	Incumbent Manuf.	Lamp	Rated Life (hours)	Watts	Operating hours per year	Total Annual Energy Use (kWh)	Lamp Cost (Small quantity Contr. CFL prices from Platt Elec 7 Apr '11, Cree lamp cost is averaged internet price from 5 lowest retailers)	Initial cost for lamps for whole installation	Operating hours per year	Number of replacement lamps needed per year	Annual lamp replacement cost for lobby	Annual $30 per lamp spot replacement labor cost	Lobby Accent Ltg - Annual spot relamping and lamp cost
Lobby														
Accent Lighting (Philips CFL lamp)	32	Philips	EL/A R30 15W	8000	15.8	3120	1577.472	$ 4.03	$ 128.96	3,120	12.48	$ 50.29	$ 374.40	$ 424.69
Accent Lighting (TCP CFL lamp)	32	TCP	PF3823 23W 3000K	8000	23	3120	2296.32	$ 13.05	$ 417.60	3,120	12.48	$162.86	$ 374.40	$ 537.26
Accent Lighting (Cree LED lamp)	32	Cree	PAR38 LED 12W LRP38 2700K	50000	11.2	3120	1118.208	$ 108.00	$ 3,456.00	3,120	2.00	$215.65	$ 59.90	$ 275.56
Original Accent Lighting (90W halogen) evaluated for comparison	32	Generic	PAR38 Halogen 90W 30deg	2500	90	3120	8985.6	$ 6.50	$ 208.00	3,120	39.94	$259.58	$1,198.08	$1,457.66

Appendix B

Summary Life-Cycle Cost Calculations

Appendix B: Summary Life-Cycle Cost Calculations

NIST BLCC 5.3-10: Summary LCC

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

General Information

File Name:	C:\Documents and Settings\D3Y335\My Documents\Life-Cycle Cost Analysis\projects\BPA 16 year study\BPA 16 year BLCC.xml
Date of Study:	Mon May 30 11:53:25 PDT 2011
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	BPA Lobby
Project Location:	Oregon
Analyst:	Naomi Miller
Base Date:	April 1, 2010
Service Date:	April 1, 2010
Study Period:	16 years 0 months (April 1, 2010 through March 31, 2026)
Discount Rate:	3%
Discounting Convention:	End-of-Year

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

Alternative: Cree LED Par38

LCC Summary

	Present Value	Annual Value
Initial Cost	$3,456	$275
Energy Consumption Costs	$972	$77
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$3,462	$276
Non-Annually Recurring OM&R Costs	$0	$0
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
Total Life-Cycle Cost	$7,890	$628

Alternative: Philips 15W EL/A CFL

LCC Summary

	Present Value	Annual Value
Initial Cost	$129	$10
Energy Consumption Costs	$1,371	$109
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0

Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$5,335	$425
Non-Annually Recurring OM&R Costs	$0	$0
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
Total Life-Cycle Cost	$6,835	$544

Alternative: TCP 23W CFL PF3823

LCC Summary

	Present Value	Annual Value
Initial Cost	$418	$33
Energy Consumption Costs	$1,996	$159
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$6,749	$537
Non-Annually Recurring OM&R Costs	$0	$0
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
Total Life-Cycle Cost	$9,163	$730

Alternative: Generic Halogen 90W Par38 30 deg FL

LCC Summary

	Present Value	Annual Value
Initial Cost	$208	$17
Energy Consumption Costs	$7,810	$622
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$18,311	$1,458
Non-Annually Recurring OM&R Costs	$0	$0
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
Total Life-Cycle Cost	$26,329	$2,096

Appendix C

Summary Life-Cycle Cost Calculations

Appendix C: Comparative Analysis of Life Cycle Cost

NIST BLCC 5.3-10: Comparative Analysis

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

Base Case: TCP 23W CFL PF3823

Alternative: Cree LED Par38

General Information

File Name:	C:\Documents and Settings\D3Y335\My Documents\Life-Cycle Cost Analysis\projects\BPA 16 year study\BPA 16 year BLCC.xml
Date of Study:	Mon May 30 12:00:40 PDT 2011
Project Name:	BPA Lobby
Project Location:	Oregon
Analysis Type:	FEMP Analysis, Energy Project
Analyst:	Naomi Miller
Base Date:	April 1, 2010
Service Date:	April 1, 2010
Study Period:	16 years 0 months(April 1, 2010 through March 31, 2026)
Discount Rate:	3%
Discounting Convention:	End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
Initial Investment Costs:			
Capital Requirements as of Base Date	$418	$3,456	-$3,038
Future Costs:			
Energy Consumption Costs	$1,996	$972	$1,024
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$6,749	$3,462	$3,287
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	$0	$0
	------------	------------	------------
Subtotal (for Future Cost Items)	$8,745	$4,434	$4,311
	------------	------------	------------
Total PV Life-Cycle Cost	$9,163	$7,890	$1,273

Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	$4,311
- Increased Total Investment	$3,038

Net Savings	$1,273

Savings-to-Investment Ratio (SIR)

SIR = 1.42

Adjusted Internal Rate of Return

AIRR = 5.28%

Payback Period

Estimated Years to Payback (from beginning of Service Period)

Simple Payback occurs in year 9

Discounted Payback occurs in year 11

Energy Savings Summary

Energy Savings Summary (in stated units)

Energy	-----Average	Annual	Consumption-----	Life-Cycle
Type	Base Case	Alternative	Savings	Savings
Electricity	2,296.3 kWh	1,118.2 kWh	1,178.1 kWh	18,846.5 kWh

Energy Savings Summary (in MBtu)

Energy	-----Average	Annual	Consumption-----	Life-Cycle
Type	Base Case	Alternative	Savings	Savings
Electricity	7.8 MBtu	3.8 MBtu	4.0 MBtu	64.3 MBtu

Emissions Reduction Summary

Energy	-----Average	Annual	Emissions-----	Life-Cycle
Type	Base Case	Alternative	Reduction	Reduction
Electricity				
CO2	449.16 kg	218.72 kg	230.44 kg	3,686.38 kg
SO2	0.58 kg	0.28 kg	0.30 kg	4.75 kg
NOx	0.50 kg	0.24 kg	0.25 kg	4.07 kg
Total:				
CO2	449.16 kg	218.72 kg	230.44 kg	3,686.38 kg
SO2	0.58 kg	0.28 kg	0.30 kg	4.75 kg
NOx	0.50 kg	0.24 kg	0.25 kg	4.07 kg