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Downlight LED Lighting Form-Factor Assessment

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The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

Disclaimer

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Abbreviations

ASHRAE	
BLCC	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CALiPER	Building Life-Cycle Cost
CCT	Commercially Available LED Product Evaluation and Reporting
CFL	correlated color temperature
CRI	compact fluorescent lamp
DOE	color rendering index
ECM	U.S. Department of Energy
EEM	energy conservation measure
FEMP	energy efficiency measure
fc	Federal Energy Management Program
GPG	foot-candle, a unit of illuminance (lumens/ft^2)
GSA	Green Proving Ground
GWh	U.S. General Services Administration
HVAC	gigawatt-hour(s)
IES	heating, ventilation, and air-conditioning
K	Illuminating Engineering Society
kWh	kelvin
LCC	kilowatt-hour(s)
LED	life-cycle cost
LFL	light-emitting diode
LE	linear fluorescent lamp
LER	luminaire efficacy
lm	Luminaire Efficiency Rating
lm/W	lumen(s)
lx	lumen(s) per watt
M&V	lux
MOL	measurement and verification
NEMA	mean overall length
NIST	National Electrical Manufacturers Association
PF	National Institute of Standards and Technology
PNNL	power factor
SOW	Pacific Northwest National Laboratory
SSL	scope of work
THD	solid-state lighting
TWh	total harmonic distortion
V	terawatt-hour(s)
W	volt(s)
	watt(s)

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I. Summary

This report provides information about the evaluation of a field installation of a one-for-one Light-Emitting Diode (LED) lamp replacement that uses the existing fluorescent ballast. The evaluation was part of a study conducted by Pacific Northwest National Laboratory (PNNL) for the Green Proving Ground program (GPG). The evaluation includes field-collected energy data, light-level data, and occupant and system installer survey responses. The report also provides recommendations based on the data collected during this field evaluation as well as other research-based sources, for applying this technology to other locations.

A. RECOMMENDATIONS

This study of a 4-pin non-dimmable LED replacement product for compact fluorescent (CFL) downlight products involved obtaining measurement and survey data to evaluate the effectiveness of an LED product as a direct replacement of 4-pin CFL downlight products. The following recommendations for lighting upgrade project work for CFL downlights is based on this collected data, as well as the current knowledge of CFL and LED technologies.

- The energy savings of over 40% found in this study is likely realistic for most applications, but actual performance will vary depending on the wattage of existing CFL products, the type of existing fluorescent ballasts, and the output of the LED replacement product.
- The lighting measurements taken as part of this study did identify differences in the uniformity of distribution of light between the CFL and LED technologies. These are typically an artifact of the directional nature of the LED technology and how it is affected by the specific geometry of the existing downlight fixture. Fixtures from one project to another will vary, but the differences noted in this study are not anticipated to be detrimental to the function of the lighting in the space.
- The favorable occupant acceptance of the technology documented in this report is likely relevant to most applications because downlight fixture formats across sites are generally similar.
- The installer responses indicate that the LED replacement product is a relatively easy and issue-free product to install. This product characteristic should be relevant to all applications because installation of this product does not vary with differences in sites or locations.
- The study results show that, for the product evaluated, the simple payback can be as low as 2.9 years. For reference, a worst-case scenario would be one in which the CFL ballast failed soon after the LED lamp was installed, which could result in a simple payback of 7.1 years, but this is unlikely. Any simple payback is likely to become even shorter as the price of LED products continues to fall. However, product cost and cost-effectiveness, because they are dependent on specific product and site labor costs, need to be evaluated on a case-by-case basis.

- Similar products in 2-pin versions designed to fit other existing fixture architectures are also available and the same recommendations offered here should generally apply to them, as well.
- LED technology is inherently dimmable and many products, including those developed for CFL direct replacement, have been produced to provide dimming when the existing CFL ballast is suitable. Note that LED dimming requires match of the ballast or driver to the appropriate dimmer control and is not automatically compatible with all advanced lighting control systems. Dimming of some early LED products has shown the potential for flickering and spectral (color) distribution changes. These effects can also be found in fluorescent and incandescent products and the LED industry has improved greatly in these areas. However, as with any lighting project, these technology characteristics should be considered when making specific product choices.

The numeric and survey results of this one study cannot necessarily be applied to all applications because every site is different. However, these results do verify the general applicability of the LED replacement product for typical general area lighting. Based on the favorable results of the projects we investigated, we conclude that the LED replacement product evaluated in this study should be included as a viable option when considering retrofitting or re-lamping existing downlight fixtures in U.S. General Services Administration (GSA) facilities. A due-diligence approach to technology and product selection is strongly advised.

Project Process Guidance

A five-step decision process is recommended for GSA to follow in selecting facilities and pairing them with the best products for specific applications.

Targeting begins with an evaluation of the existing lighting technology and lighting design coupled with strategic decisions about cost-effectiveness thresholds. Clearly, regions with the highest energy costs will yield the greatest returns; however, the results of this study indicate cost-effectiveness even at relatively low energy rates of $0.06/kWh.

Many LED **options** are competing in the existing downlight space; they range from a simple lamp replacement using the existing fluorescent ballast to a free-form retrofit installed in a bare fixture housing. The replacement decision must consider the existing lighting system configuration, life-cycle cost, expected useful life, and whether it provides a segue to any future lighting control strategies.

A first step toward successful installation is to require that products under consideration meet the appropriate category under **ENERGY STAR®** (LED downlights) and be listed on ENERGY STAR's respective qualified product lists. Federal users are required to purchase products that meet ENERGY STAR standards. In cases where ENERGY STAR (or another federally approved body, *e.g.*, the Federal Energy Management Program [FEMP]) does not provide a covered category, end-users must exercise a greater level of due diligence.

GSA maintains its own **Facilities Standards for the Public Buildings Service (P-100)** that set forth criteria for lighting performance requirements, performance attributes, prescriptive requirements, and electrical performance requirements. These criteria govern all facets of lighting and lighting equipment installed within GSA facilities and, while P-100 does not directly specify LED products, it does provide guidance on illumination requirements and target performance levels. In addition to P-100, technology-specific LED criteria should be included in the solicitation package.

The final step is to **develop performance-based specifications** that are site/application-specific. A starter specification that provides basic performance criteria is included in Part D of the Summary Findings and Conclusions (Section VI). These are application-based criteria that convey to the manufacturers how the LED solution must perform and under what conditions. Things such as the type of fixture in which the product will be installed in, initial illuminance levels, spacing criteria (uniformity), room surface reflectances, and ceiling height, are addressed. With this information, manufacturers are able to perform the necessary calculations or modelling to propose the appropriate product for each application.

Use Cases

LED pin-based retrofits can be applied in many or most pin-based CFL downlight applications, as long as basic compatibility exists. This would involve having appropriate 4-pin configuration downlights with wattages from 26 to 32 and ballasts that are compatible with the LED product. LED replacement products for existing pin-based CFL downlights are being produced to work with most existing CFL 4-pin product ballasts. The LED downlight product demonstrated in this study provided light output at a value somewhere between that of the light provided by a 26W CFL and a 32W CFL. This makes them a viable retrofit for these existing CFL installations when general lighting is needed. This is typically good for applications such as hallways and open lobby type areas. In cases where the light from a specific downlight is needed to illuminate a specific object or task, more careful consideration of the resulting lighting levels would be needed. The following additional use case guidance can be applied to quickly assess viable options:

- Always verify with the manufacturer or through hands-on trial that the lamp will work on your specific existing ballast without any operating or performance issues[1]. Look for existing manufacturer or other sources of longer term experience with specific LED lamp and CFL ballast combinations to avoid any possible long-term operating effects.
- If the CFL pin-based downlights in your space have experienced multiple ballast failures, the existing ballasts are likely not to last much longer and an LED option that runs on the CFL ballast is likely not a good option because ballast replacement may be imminent. In this case, consider using an LED kit replacement[2] or new downlight fixture that includes a dedicated LED driver. If existing CFL ballast replacement is imminent, the economics of a complete LED kit or new downlight may be justified.
- If the CFL pin-based downlights in your space have been operating for a long period of time (10 years or more under normal office operation), most of the CFL ballast life is likely to have been used up, the existing ballasts may not last much longer, and an LED option that runs on the CFL ballast is likely not a good option. In this case, also consider using an LED kit replacement or new downlight fixture that includes a dedicated LED driver.
- If your facility has more than one type of existing ballast in the lighting zone that is targeted for the LED downlight project, investigate carefully to make certain all ballasts are compatible with the LED retrofit product. If existing ballast types are unknown, or it is impractical to verify their compatibility with an LED replacement product, consider using an LED kit replacement or new downlight fixture that includes a dedicated LED driver.

[1] Early LED replacement products for CFL downlights have experienced performance issues related to wiring that are being or have since been addressed. See NGL Downlight study report referenced in Appendix D.

[2] See NGL Downlight study report referenced in appendix D.

B. BACKGROUND

The United States consumes roughly 700 TWh of energy for lighting or about 19% of total annual electricity use, and the commercial indoor sector consumes fully 50% of that amount. Linear fluorescent lighting fixtures are by far the most dominant interior lighting source in commercial buildings; they represent almost 70% of the lighting energy use and comprise about 80% of the lamp inventory (DOE 2012a). Although commercial downlights represent a much smaller percentage of fixtures, their high maintenance costs and directional lighting nature present a significant retrofit opportunity for solid-state lighting[3] (SSL).

In 2013, the U.S. Department of Energy (DOE) FEMP conducted a study characterizing the indoor lighting market for federal facilities. This study estimated that GSA has 95,000 CFL-based downlights in its buildings portfolio. Based on this estimated count and the findings from this GPG evaluation study, it is estimated GSA could save 5.7 GWh of electricity per year (over $600,000 per year at the US national average electricity rate) with deployment of SSL in all 95,000 CFL downlight applications.

This report covers the findings of the energy and performance portion of a GSA study that investigated a product that saves energy in the CFL downlight space. The following is an overview of the existing and new technology.

Fluorescent Downlights (existing technology)

Commercial sector recessed downlights perform at an overall luminaire efficacy of 28 to 46 lm/W. CFL technology has a rated life in the range of 10,000 to 12,000 hours and a ballast life of 10 years. The short lamp life coupled with the high number of fixtures in a typical commercial building make CFL downlights maintenance intensive.

LED Downlight Retrofit Products

Many commercial downlights use Edison-based screw-in incandescent or CFL lamps. Pin-based CFL products that use 2 to 4 pins to attach to the power socket also have a significant share of the commercial market. Current product offerings for retrofitting existing pin-based CFL downlights range from one-for-one lamp replacements using the existing fluorescent ballast to retrofit kits that only use the fixture housing. The LED replacement technology selected by GSA for this study, hereinafter referred to as "LED-A," is a one-for-one LED lamp replacement that uses the existing fluorescent ballast. The manufacturer claims a rated life of 50,000 hours to L_{70}.[4]

Naming Convention

GSA policy is to not specifically identify manufacturers, but rather, more broadly, technologies. Therefore, the LED product for replacement of the CFL 4-pin downlight lamp is referred to as "LED-A" throughout the rest of this report.

[3]Solid-state lighting is an "umbrella" term that refers to semi-conductor-based light technologies.

[4] L_{70} refers to the number of hours until 70% of the initial full light output is reached.

C. STUDY DESIGN AND OBJECTIVES

This study evaluated the performance and applicability of specific LED-A products in downlight installations and is centered on four critical areas: energy efficiency, photometric performance, occupant response and acceptance, and cost-effectiveness. The first three of these required site screening and selection, followed by pre-/post-installation measurement of energy and light levels and the collection of occupant and installer opinions using surveys. Cost-effectiveness was evaluated using measurement and verification (M&V) data coupled with projections of product cost, maintenance cost, ballast life, and energy price sensitivity.

While LED technology generally offers dimming capabilities, this study did not evaluate product dimming and therefore, it was unnecessary to log energy use over time. At each site, instantaneous voltage and current readings were taken pre- and post-installation for several fixtures to establish the baseline and power reduction attributable to the technology.

PNNL conducted in situ photometric measurements on work surfaces within three building locations to verify light levels and determine changes in distribution and uniformity of the lighting with the LED retrofit. Horizontal and vertical light levels were measured using grids in accordance with Illuminating Engineering Society (IES) recommendations and GSA P-100 standards.

PNNL also conducted pre- and post-installation surveys that queried the installation contractors about their experience with the installation of the technology.

Demonstrations were conducted in buildings in three cities:

- *Auburn, Washington* - The GSA Regional Headquarters Building is a 105,770 square foot building constructed in 1932 (and includes an addition built in 1965) that is located south of Seattle, Washington. The study area involving downlights includes the dining area serviced by 6” aperture, vertically oriented, 1-lamp, pin-based CFL downlights arranged 6’ x 6’ on-center.

- *Dallas, Texas* - The Cabell Federal Building is an approximately 1,000,000 square foot building constructed in 1971 that is located in downtown Dallas, Texas. The study area involving downlights includes common areas and corridors. These areas are serviced by 8” aperture, 2-lamp, horizontally mounted, pin-based CFLs spaced 4’ on-center with some variations due to room partitions.

- *Philadelphia, Pennsylvania* - The Veterans Administration Center is a 418,181 square foot building constructed in 1996 that is located just north of Philadelphia, Pennsylvania. The study areas are the corridors that are also serviced by 8” aperture, 2-lamp, horizontally mounted, pin-based CFLs arranged in three luminaire clusters spaced 4’ on-center.

Table 1 lists key quantitative and qualitative performance objectives, metrics and data requirements, success criteria, and the M&V results for the study.

Table 1: Summary of Performance Objectives and Results

Objectives	Target	Results
Reduce Energy Usage	Reduce kWh/yr.	40-50% savings
Cost-Effectiveness Requirements	less than 10 year simple payback	At $0.1062/kWh and using RS Means labor rate data, simple payback ranges from 2.9 yrs. to a possible worst-case value of 7.1 yrs.
Reduce Emissions	kg CO_2 equiv./yr.	40%-50% reductions (greenhouse gas emissions are reduced proportionally to energy reductions)
Meets Recommended Light Level Requirements	IES and P-100 standards	All locations met or exceeded pre-existing light levels (average of ≥15 foot-candles for corridors and common area).
Qualitative Objectives	**Target**	**Results**
Easy Installation	Positive responses to questionnaire regarding ease of installation	Installing contractors reported routine installations for LED-A.
Reduce Maintenance	$/yr.	Not verified as part of M&V, but projected life is expected to increase 400% for LED-A
Maintain Occupant Satisfaction	At minimum, no decrease in satisfaction and, ideally, >70% satisfaction in lighting	The vast majority of occupants who responded to a survey noted little or no decrease in satisfaction when lighting was changed.

D. PROJECT RESULTS/FINDINGS

ENERGY EFFICIENCY

Pre- and post-retrofit electrical conditions were measured in the field by the on-site contractors at each of the project sites. Real power for both technologies was also measured independently at PNNL. The site contractor measurements taken in the field showed significant variability, potentially a product of varying lamp types and conditions at the sites. The different meters used and measurement techniques, etc., likely also contributed to the wide range of values. The PNNL laboratory measurements were conducted consistently in a laboratory setting and are considered the most accurate for purposes of this study. These data show that ***a typical 1-lamp CFL with electronic ballast draws 28W and LED-A product draws 13W, with savings of 53.6%.***

PROTOMETRIC PERFORMANCE

LED-A performance results from the study were varied but showed that all sites experienced an increase in average illuminance with varied changes in uniformity. In Dallas, the average horizontal illuminance level was nearly doubled, likely attributable to the fact that LEDs are generally directional and can do a better job of getting more light out of the fixture housing compared to the omnidirectional CFL product. The open lobby and dining areas in Dallas and Auburn saw uniformity improvement (lower Max:Min ratios), but the corridors in both Dallas and Philadelphia saw the uniformity decrease. In all cases, there was no evidence from the occupant survey responses that these changes caused any concerns.

These data should be considered instructive when evaluating real-world application of LED products, but because they are specific to individual sites they cannot necessarily be directly applicable to other sites. Final application of LED products to actual projects depends on many factors, and due diligence should be taken when selecting products for specific sites.

OCCUPANT RESPONSE AND ACCEPTANCE

Occupant surveys administered at the three evaluation sites provide information about the relative satisfaction of the occupants with both the existing fluorescent lighting and the newly installed LED lighting. The focus of the survey was to determine occupant satisfaction with both of the lighting systems and to identify any significant changes in satisfaction caused by the change to LEDs.

In general, the occupants' responses to the pre-retrofit survey at all three sites indicate the existing fluorescent system was acceptable. Similarly, the occupant responses indicate general acceptance of the new LED-A technology with no significant issues identified.

COST-EFFECTIVENESS

The results of cost-effectiveness analysis using known costs and labor characteristics indicate that LED-A is cost-effective at all expected energy rates, showing typical expected simple paybacks of 2.9 to a potential high of 7.1 years. In addition, the decision process for energy efficiency measures (EEMs) requires a thorough understanding of the existing condition (base case), costs for energy, costs and periods for maintenance and replacement, and must factor in the time value of money for the evaluation period. To evaluate these characteristics of the potential cost-effectiveness of the technology, life-cycle costing (LCC) was used to account for the cash flows over the evaluation period and calculate net present values for competing EEMs. PNNL used the Building Life-Cycle Cost[5] (BLCC) software package developed by the National Institute of Standards and Technology (NIST).

Table 2: Economic Assessment of a 1-lamp CFL to LED-A retrofit

	Baseline: 1-Lamp CFL with Elect. Ballast	LED-A (best to worst case)
Equipment Cost[6]	NA	$22.00 to $38.50
Installation[7]	NA	$16.96 to $55.68
Maintenance[8]	$85.84	$0.00
Energy Rate[9]	$0.1062/kWh	$0.1062/kWh
Energy Consumption Before[10]	112 kWh/yr.	NA
Energy Consumption After	NA	52 kWh/yr.
Energy Saved	NA	60 kWh/yr.
Energy Cost Before	$11.89/yr.	NA
Energy Cost After	NA	$5.52/yr.
Energy Cost Savings	NA	$6.37/yr.
Simple Payback	NA	2.9 yrs. to 7.1 yrs.
Net Present Value[11]	$230	$45 to $100
Savings-to-Investment Ratio	NA	4.2 to 1.8

[5] http://energy.gov/eere/femp/building-life-cycle-cost-programs

[6] Assumed mid-range material cost estimate. Manufacturer notes that the typical cost of this product at the time of report publication has reduced to $15.

[7] RS Means derived labor estimates.

[8] Assumes a 50,000-hour period requiring 4 compact fluorescent lamp replacements.

[9] National average energy rate in February 2015.

[10] Assumes a 4000-hr/yr. operation.

[11] Assumes a 50,000-hour ballast life and discount rate of 3.1%.

Figures 1 and 2 represent sensitivity analyses for energy rates ranging from $0.06 to $0.24/kWh and base material costs for LED-A of $22 for the case in which the CFL ballast is relatively new. Figures 3 and 4 represent similar sensitivities in the worst-case scenario in which the CFL ballast must be replaced during or shortly after the LED lamp is installed. Results in both sets of sensitivities indicate that LED-A is cost-effective at all energy rates.

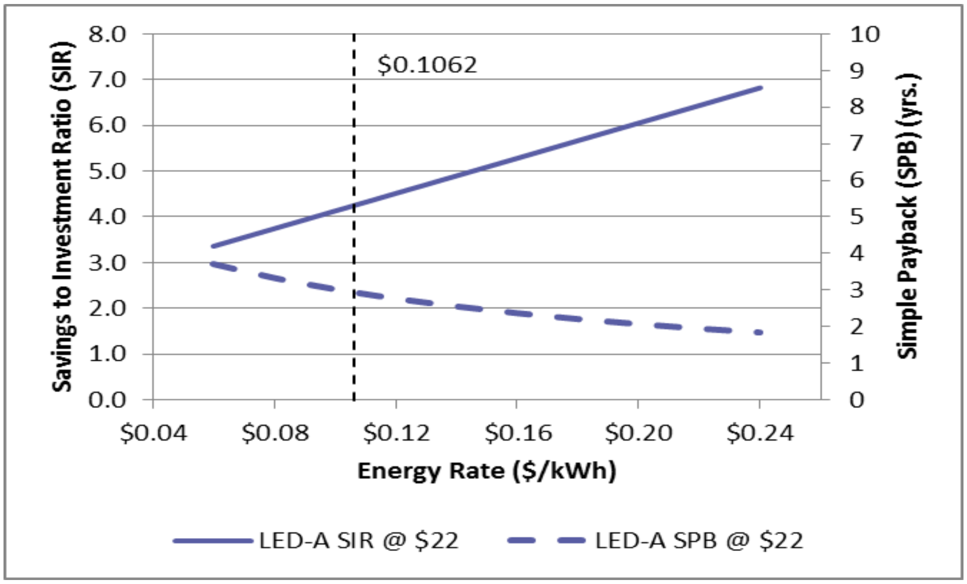


Figure 1: LED-A Savings-to-Investment Ratio and Simple Payback Results (no ballast replacement)

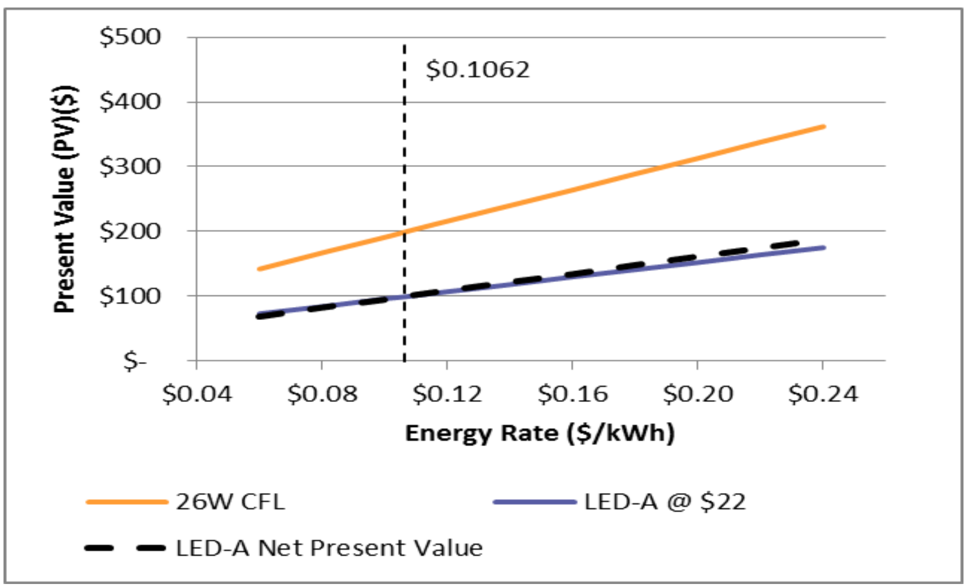


Figure 2: LED-A Present Value Results (no ballast replacement)

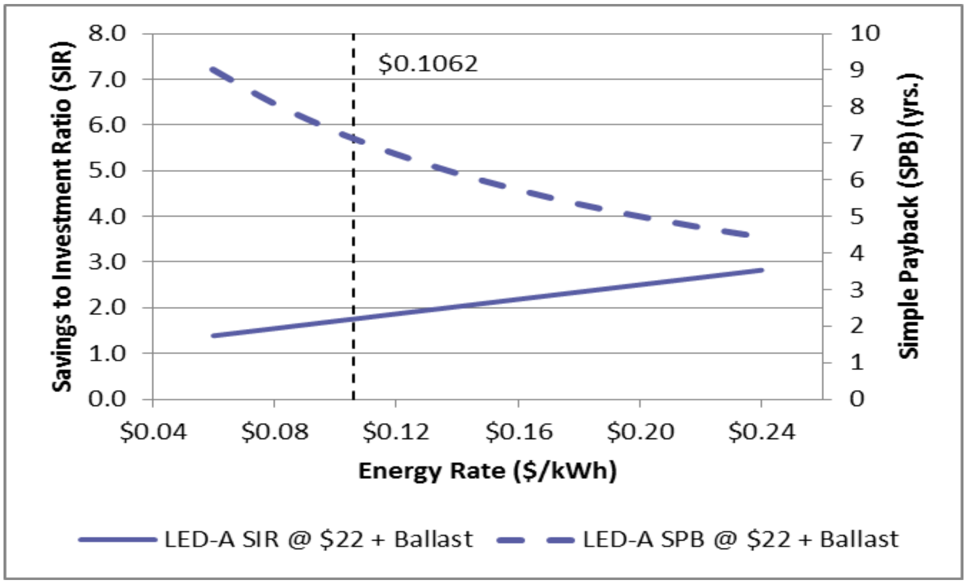


Figure 3: LED-A Savings-to-Investment Ratio and Simple Payback Results (ballast replacement)

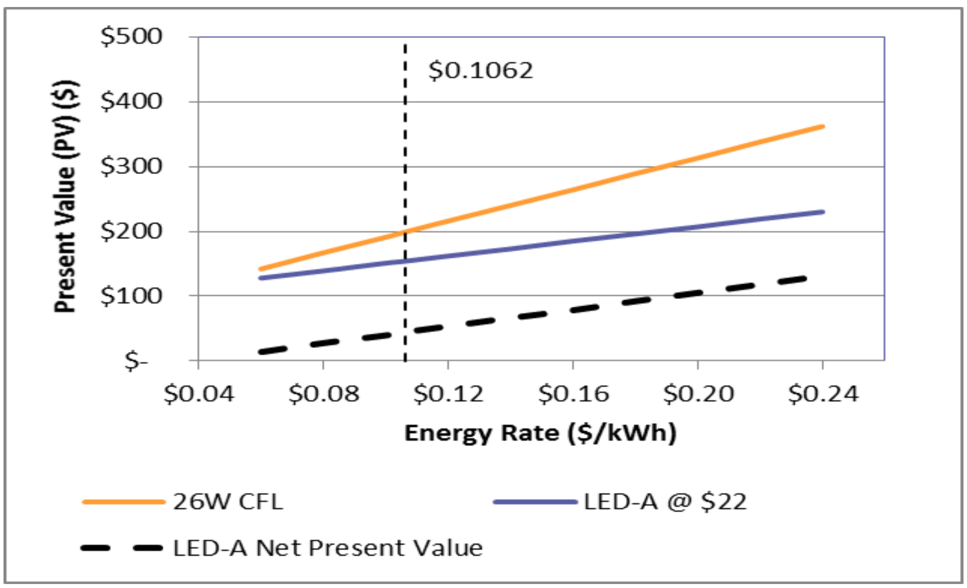


Figure 4: LED-A Present Value Results (ballast replacement)

II. Introduction

The U.S. General Services Administration (GSA) is a leader among federal agencies in actively pursuing energy and water efficiency opportunities for its facilities. Its Green Proving Ground (GPG) program serves as a vehicle for identifying emerging technologies and leveraging its existing buildings portfolio to conduct measurement, verification, and validation. This report provides the results of the downlight portion of a study that looked at the emergence of solid-state lighting (SSL) as a direct competitor of incumbent fluorescent lighting systems, including compact fluorescent lamps (CFL) used in recessed downlights.

A. PROBLEM STATEMENT

The ubiquitous CFL is widely used in commercial buildings and has been the mainstay of interior lighting design since the 1990s. As technology has progressed, incremental improvements in efficiency (efficacy) have been made, resulting in today's CFL systems routinely delivering between 55-65 lm/W. However, compact fluorescent lighting is not without its shortcomings. There is the well-known problem of disposal and environmental concerns associated with mercury, global limitations on phosphor supply affecting lamp cost, and marginal dimming performance to take full advantage of today's sophisticated daylighting and adaptive control systems, just to name a few.

Over the last 10 years, SSL has shown it can compete in just about all applications, including downlights.

Naming Convention

GSA policy is to not specifically identify manufacturers, but rather, more broadly, technologies. Therefore, the light-emitting diode (LED) product for replacement of the CFL 4-pin downlight lamp is referred to as "LED-A" throughout the rest of this report.

B. OPPORTUNITY

In 2013, the U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP) conducted a study characterizing the indoor lighting market for federal facilities.[12] This study estimates GSA has 95,000 CFL-based downlights within its building portfolio. While commercial downlights represent a small percentage of total fixtures, their high maintenance and directional nature presents an additional retrofit application for SSL lighting.

Based on the findings from this GPG evaluation study, it is estimated GSA could save 5.7 GWh of electricity per year (over $600,000 per year at the US national average electricity rate) with deployment of SSL in all 95,000 CFL downlight applications.

[12] DOE FEMP, "Interior Commercial Lighting Market Characterization for the Federal Sector," September 2013.

TECHNOLOGY DESCRIPTION

The LED-A lamp is a direct replacement for a 4-pin CFL that will operate on most existing CFL ballasts. This eliminates the need for any rewiring or dedicated driver, but caution is required to ensure that the CFL ballast and LED lamp are a good match and that the existing CFL ballast has useful life remaining. Figure 5 and the accompanying list of manufacturer's attributes provide an overview of the product.

Figure 5: LED Product Image That Replaces a Compact Fluorescent Lamp

Manufacturer Claims (not verified as part of this study)

- Plug and Play replacement for CFL
- Socket Mount Ballast Wattages G24q 4-pin V, H Electronic 13W, 18W, 26W, 32W, 42W
- Key Features and Specifications:
  - Delivered Lumens: Up to 994 lm
  - Wattage: 13W
  - Input Voltage Source: CFL Ballast
  - Color Temperatures: 2700K, 3000K, 3500K, 4000K
  - Lumen Maintenance: (L_{70}) 50,000 + hours
  - Dimmable: No
  - Enclosed Fixtures: Yes
  - Warranty: 5 years

C. TECHNOLOGY PERFORMANCE CHARACTERIZATION

SOURCE EFFICIENCY (EFFICACY)

Light sources have traditionally been characterized by the efficiency at their source and the common term, efficacy, is used to express their light output in lumens (lm) divided by their input power in watts (W). For fluorescent systems, a ballast is a necessary component to drive the lamp, so any ballast losses are included in the efficacy calculation. ***Typical CFL products, such as a lamp with ballast, operate at 55-65 lm/W.*** LEDs exhibit a wide range in performance at their source and multiple parameters, such as drive current and temperature, impact both light output and input power. ***Generally, as of 2015, the range in LED source efficacy at the package level is 100-130 lm/W.***

FIXTURE EFFICIENCY

All commonly used light sources except LEDs emit light in all directions (omnidirectional). To direct and distribute the light for the task or application fixture, manufacturers designed luminaires with reflective surfaces, geometric reflectors, and optics to direct light out of the fixture in a useful pattern. In addition to getting light out of their fixtures, manufacturers also needed to mitigate occupant glare for everyday tasks and workstation functions. Various types of lenses were developed to diffuse the light and provide "cut-off" for high-angle glare. The result of manipulating an omnidirectional light source comes at the expense of fixture efficiency. For example, the typical downlight fixture housing is only 50-60% efficient. The inherent directionality of LEDs means that a significant portion of the light that would otherwise be lost within the fixture is now directed downward, thereby avoiding losses from fixture optics. The inclusion of a directional light source in a fixture originally designed for an omnidirectional light source typically nets an increase in overall fixture efficiency and, thus, fewer light source lumens are needed to achieve the same light levels. This effect was partially responsible for the generally increased light levels achieved at the test sites when they were retrofit with LEDs.

LUMINAIRE EFFICACY AND LUMINAIRE EFFICACY RATING

One of the fundamental differences between LEDs and incumbent lighting technology is how their light output as a complete fixture is measured. Because of the directionality of LEDs and the lack of standard interchangeable light engines among manufacturers, LEDs must be measured using absolute photometry that measures the light output of the entire luminaire, and the result is net fixture lumens and luminaire efficacy (LE).

Fluorescent technologies use relative photometry, where lamp efficacy and fixture efficiency are measured separately and then combined mathematically for a representation of fixture lumen output and efficiency termed the Luminaire Efficiency Rating (LER). LE for LED products and LER for fluorescent products provide the end-user with a reasonable means to compare luminaires of different technologies. Comparing bare fluorescent lamp ratings (*e.g.*, lamp lumen output) with LED fixture or package output data will not provide the most accurate or reasonable comparison of product or technology capability.

LUMEN DEPRECIATION, RATED LIFE, AND L_{70}

All light sources exhibit lumen depreciation over time. However, they do not depreciate by the same amount or at the same rate. Fluorescent light sources exhibit catastrophic failure at some point in time and their rated life is defined as the number hours until 50% of a large sample of lights tested using a standardized laboratory procedure are still operating. In contrast, it is unlikely for LED packages or modules to fail catastrophically (although it is possible); instead, they depreciate to a point at which their light output no longer meets the needs of the application. The industry defines this point as 70% of the initial light output or L_{70}.

The typical pin-based amalgam CFL maintains approximately 85% of its initial light output at its rated life of 8,000 to 12,000 hours. LED L_{70} values vary, but for the products being evaluated in this study they are claimed by the manufacturers[13] to be in the 50,000-hour range.

[13] LED lifetime ratings are based on lumen depreciation reaching a specified point – typically 70% of initial output. These ratings are derived from laboratory testing of LED packages per LM-80 and TM-21. Manufacturer life ratings of LED products should be based on these test data and referenced to those tests.

III. Methodology

A. TECHNICAL OBJECTIVES

This project evaluated one LED-A technology for use in GSA facilities to help identify and provide guidance for its effective application for energy savings. The evaluation involved

- measurement and verification (M&V) of the energy savings, performance, and power-related characteristics of the retrofit products; and
- development of specifications and guidance material for the widespread application of LED technologies, where appropriate and cost-effective.

Particular attention was given to developing guidance for this LED product type across multiple applications to make the evaluation as generic as possible across GSA sites.

B. CRITERIA FOR SITE SELECTION

The sites for the demonstration and evaluation were identified based on specific criteria that were important in ensuring that useful and applicable data were collected. A survey of the existing lighting fixture types and quantities was also conducted to make sure each site would have the appropriate existing lighting technologies for a successful demonstration and evaluation (see Appendix for survey).

The site selection criteria included the following:

1. Strong project advocate - Identify a strong advocate for the project and space or a specific assigned contact with access to the space and operations. This will greatly facilitate addressing potential issues with both the space and its operation and occupants.
2. Stable space - Identify spaces or areas that have a stable function and are not under consideration for a change in use, unless this is a specific condition needed for the test. Typically, the demonstration project needs to have a consistent test environment for useful pre- and post-retrofit data collection.
3. Appropriate space conditions for anticipated technology
   a. Identify spaces or areas where the conditions and functions are similar to the expected application of the product.
   b. Confirm that the ceiling type is appropriate for the product and for ease of retrofit and metering. Avoid solid (non-drop ceiling grid) unless this is one of the demonstration variables.
   c. Make sure existing controls are not contrary to the test criteria. If they are, determine whether they can be removed or reconfigured. If they can be removed or reconfigured, determine how this might affect any occupant opinions of the retrofit.
4. Reasonable day and evening access
   a. Identify spaces that have available nighttime access when needed. Most non-control lighting measurements typically need to be made without the variable of daylight, making nighttime access important.

   b. Avoid facilities that have additional security constraints. These may come in the form of building access or restrictions associated with the nature of the work in the space.
5. Typical but clean electrical layout
   a. Avoid spaces or areas in which electrical modifications have been made because this may make clean measurement difficult.
   b. Avoid spaces or areas that have configurations that may not be typical.
6. Stable occupants - For retrofit demonstrations in worker environments, avoid interior spaces in which occupants are transient or relocate often because this will severely affect the quality of occupant input.
7. Stable space operation and function - Avoid spaces in which operations may be changing during the demonstration period because this may introduce additional variables to the responses to surveys.

IV. M&V Evaluation Plan

A. TECHNOLOGY SELECTION

GSA has an extensive and diverse portfolio of buildings and requisite lighting systems. The types of luminaires used, specifically troffers and downlights, are driven by multiple factors, including building vintage, prevailing energy code at the time of construction, cost-effective lighting technology during procurement, interior design details, floor plan, and remodels. It is assumed that the prevailing CFL technology is likely a 50/50 split between magnetic and electronic ballasts. Beyond the obligatory energy savings and cost-effectiveness questions, GSA wanted to test the products in as many fixture types as possible.

B. FACILITY DESCRIPTION

After extensive evaluation, three sites were identified as appropriate for the LED technology demonstrations. Each facility (depicted in the photos below) included specific locations for evaluating the chosen LED technologies and specific areas for LED downlight replacement.

FEDERAL OFFICE BUILDING – AUBURN, WA

CABELL FEDERAL BUILDING (7TH FLOOR) – DALLAS, TX

VA DAYCARE BUILDING – PHILADELPHIA, PA

C. TEST PLAN

Specific M&V tasks used to support an effective evaluation of the identified sites included the following:

1. Develop and administer a pre- and post-retrofit survey to identify test area occupant issues and general acceptance of the retrofit lighting conditions. Survey questions were crafted to capture issues related to existing conditions for future retrofit planning and to any post-retrofit technology or application that might apply across various GSA sites and building types.
2. Identify spaces or areas within facilities for conducting tests that meet project evaluation needs. Areas should be large enough to accommodate both reasonable measurement grids and occupant numbers for meaningful survey input. Where possible, each area should be separate from others to avoid the mixing of occupant reactions.
3. Develop and administer a product performance measurement plan to collect all useful data for each technology both before and after technology installation.
    a. Light levels before and after retrofit will be measured using hand-held illuminance meters over a uniform horizontal grid or a specific point measurement system, depending on the technology and area configuration. The same measurement system will be applied for before and after measurements are made in each area.
    b. Light-level measurements in vertical orientations or other planes will be made, as needed, based on application requirements.
    c. Electrical measurements of pre-retrofit and post-retrofit LED fixtures will be made to confirm the power-saving potential of the retrofit products.

Other objectives of the evaluation include the following:

1. Develop applicable cost-effectiveness calculation methods to determine the conditions under which various technology options may be cost-effective.
2. Prepare specifications and guidance information that will be useful to facilities and project personnel when making product and application decisions.

D. INSTRUMENTATION PLAN

Appropriate instrumentation for this evaluation project was used to capture photometric performance data, as well as electrical power data on both pre- and post-retrofit products and their applications. This included:

1. Minolta illuminance meter (hand-held). This instrument was used to measure the illuminance provided by the pre- and post-retrofit lighting products on horizontal and vertical surfaces. The comparison of this data provides for a comparison of light levels and potential lighting uniformity throughout the space.
2. Photo research luminance meter (hand-held). This instrument was used to evaluate the relative luminous intensity of pre- and post-retrofit fixtures as a way of comparing lighting glare in the space from different products.
3. Contractor electrical measurement equipment. The installation contractors supplied their own equipment to measure the power (*i.e.*, amps and volts) draw of the pre- and post-retrofit products. This data will help confirm the potential energy savings from application of the LED technology.

V. Results

The following sections present the results of the data analysis and other evaluations of the product installations, as well as PNNL's knowledge of the LED market and current technology status.

A. ILLUMINATION (LIGHT-LEVEL) COMPARISONS

An important part of any lighting retrofit is achieving desired light levels. A large part of this project was an evaluation of how LED technologies could match existing florescent lighting system light levels. Table 3 and charts (in Figures 6 through 13) provide a view of the photometric performance of the LED-A with the original compact fluorescent technology. Charts are provided showing comparisons of:

- horizontal illuminance (light levels and distribution on floor). This data relates to the primary purpose of the lighting, which is to illuminate tasks and general areas.
- vertical illuminance (light levels and distribution on wall surfaces). This data helps identify how well each technology provides vertical light for surfaces and faces.

The measurement points in each evaluation area were generally arranged as a grid of measurements for each location in which effective measurement was possible. Measurements could not be taken in all locations, but these summary values of representative spaces serve well as a direct comparison of the different technologies for the purposes of this evaluation. The Illuminating Engineering Society of North America (IES) (and by extension GSA P-100) provides recommended illuminance levels based on space type and activity of an average of 15 fc on floors for hallways and corridors, including lobby areas. Key metrics to establish equivalency are the maximum-to-minimum ratio and average illuminance. Lower maximum-to-minimum values generally indicate an improvement in uniformity.

It is important to note that this data represents specific site applications of a specific technology product. Other site applications and other similar format products could perform the same or vastly different (better or worse) depending on the situation and product. This data should be considered instructive in evaluating real-world application of LED products, but it is not intended nor does it definitively determine the appropriateness of these specific applications. Final application of LED products to actual projects depends on many factors.

Table 3 provides a summary comparison of the light and power performance of the LED technology with the original compact fluorescent technology.

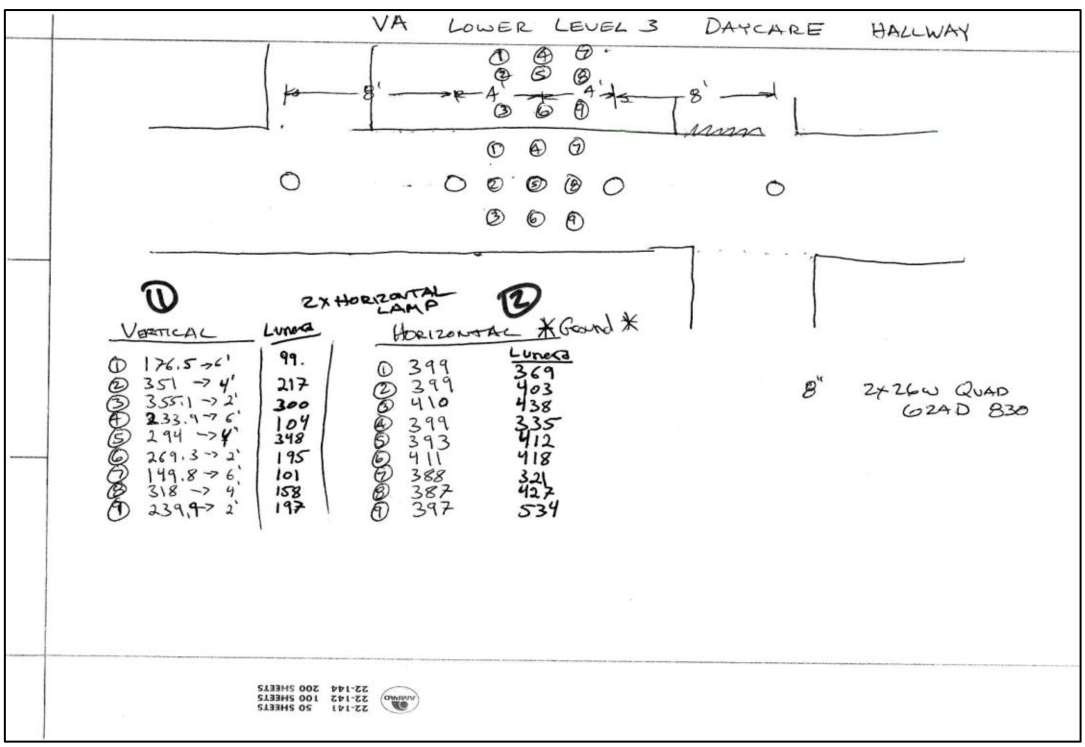
Table 3: Pre- and Post-Retrofit Illuminance Data

Location	Fixture Type	# Lamps	Min. (fc)	Max. (fc)	Max:Min Ratio (uniformity)	Average (fc)	Target IES Average (fc)
Auburn, WA – Dining (LED-A) Pre-Retrofit	CFL Downlight	1	14.6	30.4	2.08	**21.9**	15
Auburn, WA – Dining (LED-A) Post-Retrofit	LED-A	1	16.5	31.2	1.89	**25.5**	15
Dallas TX –7th Floor Lobby (LED-A) Pre-Retrofit	CFL Downlight	2	23.7	43.1	1.82	**35.0**	15
Dallas TX –7th Floor Lobby (LED-A) Post-Retrofit	LED-A	2	32.6	54.3	1.67	**44.8**	15
Dallas, TX – 7th Floor Hallway (LED-A) Pre-Retrofit	CFL Downlight	1	13.4	16.5	1.11	**14.6**	15
Dallas, TX – 7th Floor Hallway (LED-A) Post-Retrofit	LED-A	1	10.9	23.1	2.12	**16.2**	15
Philadelphia, PA – Daycare Corridor Pre-Retrofit	CFL Downlight	2	38.7	41.1	1.06	**39.9**	15
Philadelphia, PA – Daycare Corridor Post-Retrofit	LED-A	2	32.1	53.4	1.66	**40.6**	15

PHILADELPHIA, PA

Downlights evaluated in Philadelphia were located in the hallway shown in the photo below and light level measurements were taken according to the sketches shown in Figure 6. The horizontal light levels in Figure 6 show reasonable horizontal uniformity with some variation around 100 lux. While there is clear variation, a value of 100 lux is typically not noticeable to the human eye in typical workspace conditions.

The vertical illuminance levels in Figure 7 show some variation, but is generally similar. This variation is easily explained by the orientation differences between directional LED products and the omnidirectional fluorescent lamps.



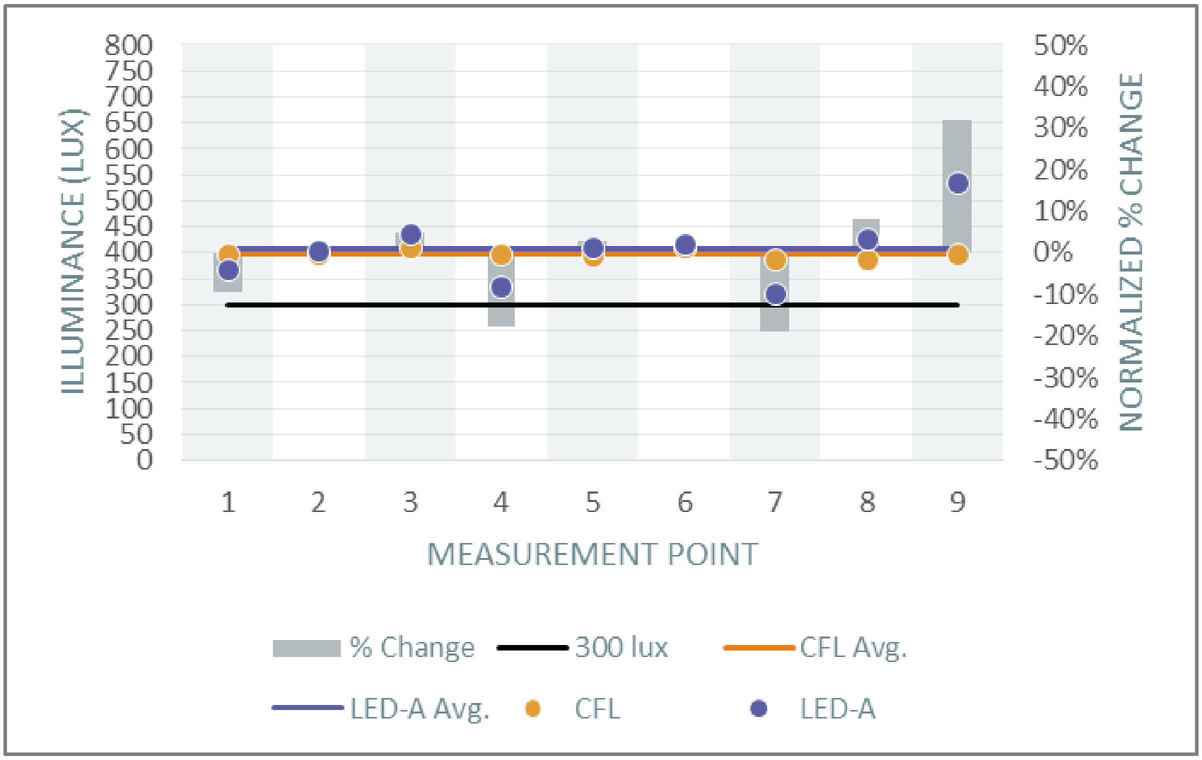


Figure 6: Philadelphia Daycare Hallway Horizontal Illuminance and Normalized Percent Change

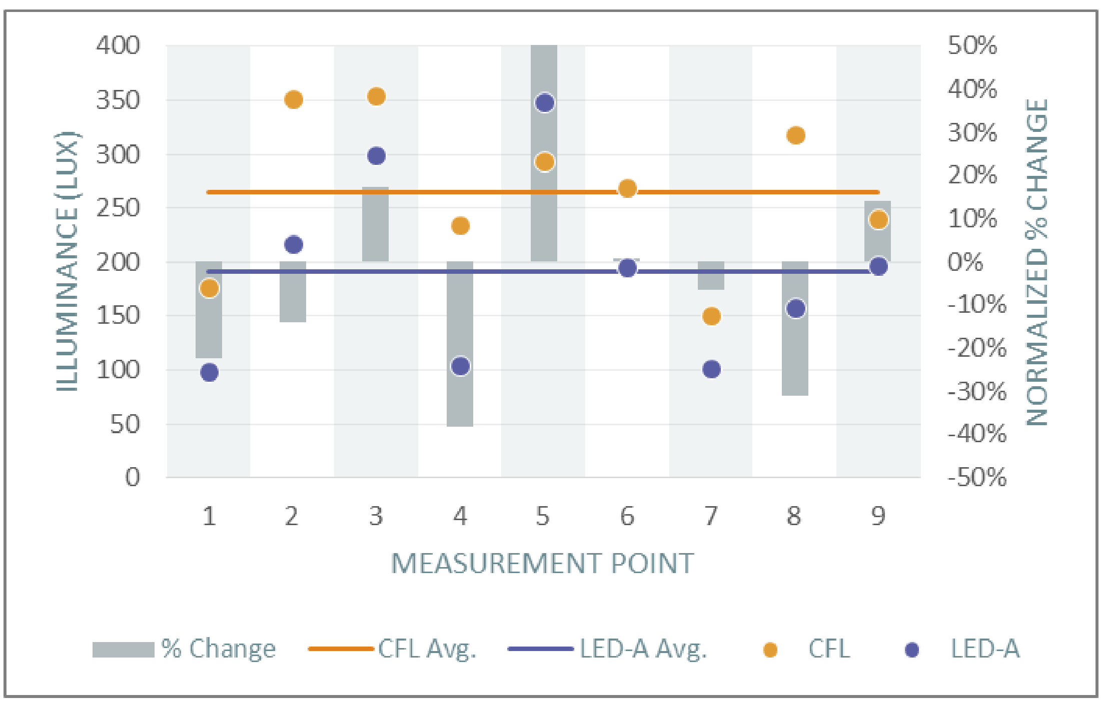
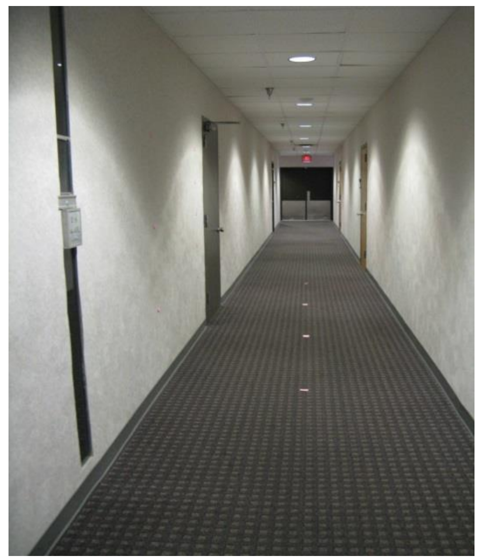


Figure 7: Philadelphia Daycare Hallway Vertical Illuminance and Normalized Percent Change

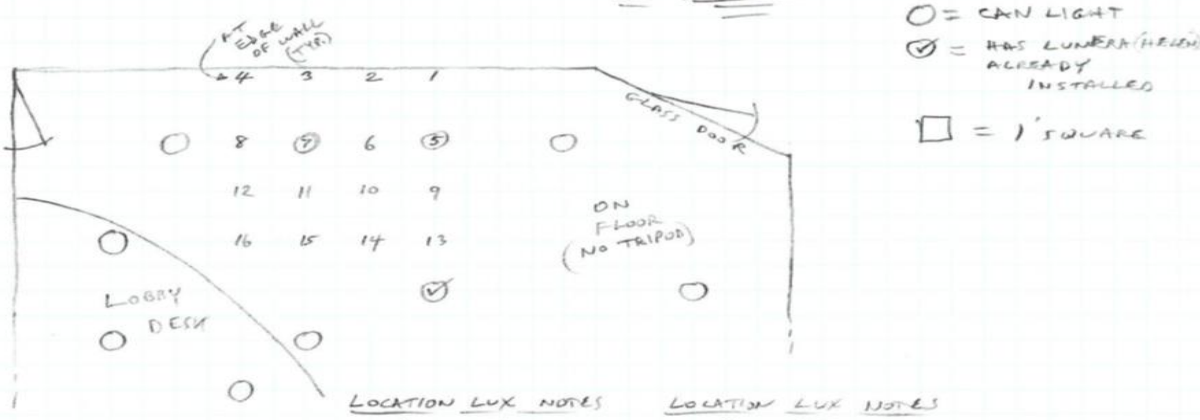
DALLAS, TX

The horizontal light levels in the hallway areas where the LED-A product was installed, shown in the photo below and Figure 8, have more variability with the LED-A product as seen in figure 8. Again, this is possibly due to a product of the more directional nature of the LED product. The majority of differences are in the 50 lux range, which is not likely to be noticeable to the human eye for most hallway and transient areas. Vertical (wall) uniformity and light levels shown in Figure 9 are comparable to the original CFL system.

The measured lighting data presented in Figures 10 and 11 for the lobby areas with retrofitted downlights show similar uniformity with slightly higher light levels with the LED product.



CABELL 7TH FLOOR GSA LOBBY
HORIZONTAL ON FLOOR



LOCATION	LUX	NOTES
1	286	
2	294	
3	288	
4	263	
5	389	
6	399	
7	382	
8	356	

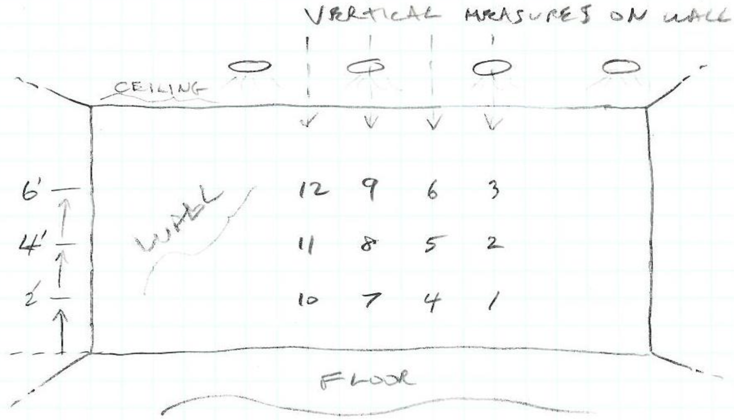
LOCATION	LUX	NOTES
9	427	
10	431	
11	381	
12	356	
13	417	
14	405	
15	282	IN DESK SHADOW
16	237	IN DESK SHADOW

READINGS BETWEEN AND BELOW FIXTURES AS SHOWN

AUG 28, 2014

CABELL 7TH FLOOR GSA LOBBY (OPPOSITE RECEPTION DESK)
VERTICAL MEASURES ON WALL

□ = 1' SQUARE



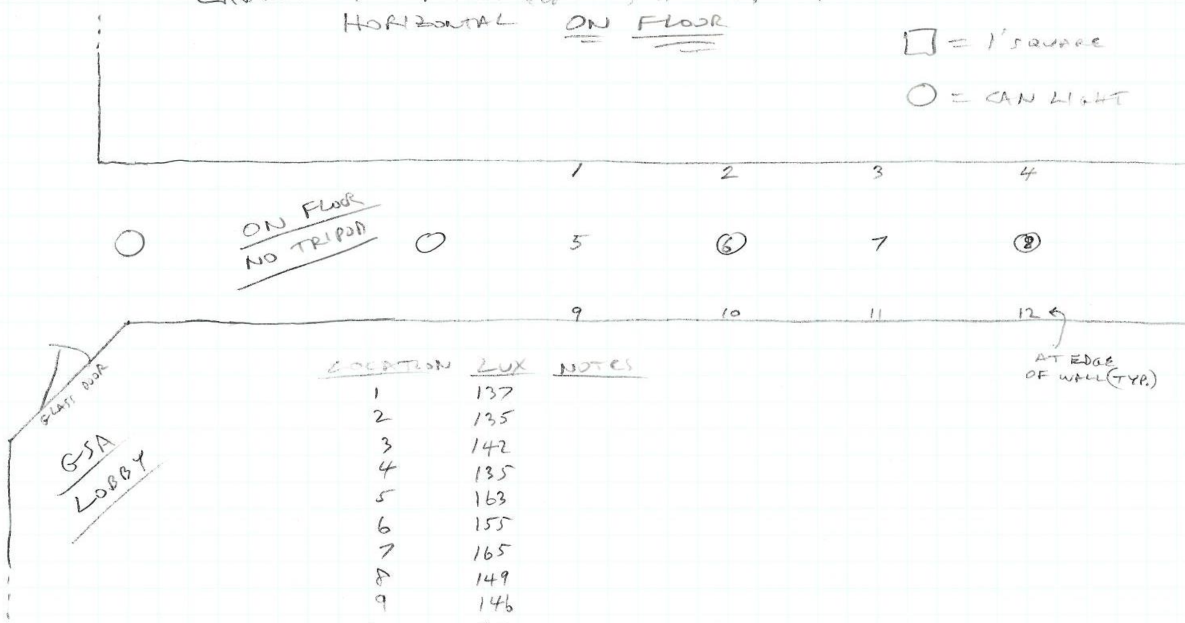
LOCATION	LUX	NOTES
1	196	
2	232	
3	235	
4	195	
5	220	
6	210	
7	189	
8	211	
9	206	
10	180	
11	204	
12	192	

ALL READINGS THIS SITE/DATE:
MINOLTA T-10 38026009/58036018 CAL. 11/16/2013

READINGS BETWEEN/BELOW FIXTURES AS SHOWN

CABELL 7th FLOOR (708-710) HALLWAY w/MAIL SLOT

HORIZONTAL ON FLOOR

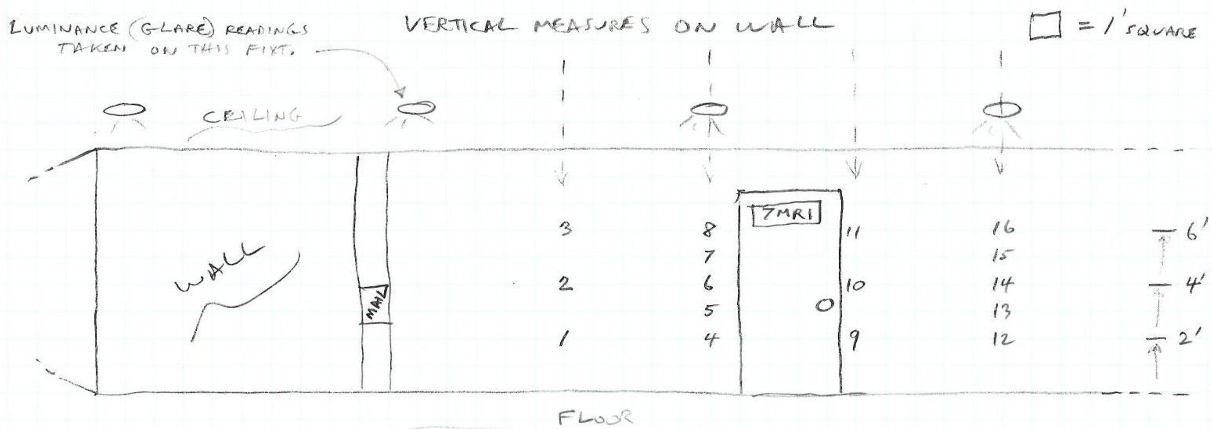


LOCATION	LUX	NOTES
1	137	
2	135	
3	142	
4	135	
5	163	
6	155	
7	165	
8	149	
9	146	
10	134	
11	147	
12	141	

READINGS BELOW AND BETWEEN FIXTURES AS SHOWN

CABELL (708-710) HALLWAY SIDE w/MAIL SLOT CAN LIGHTS

VERTICAL MEASURES ON WALL



LOCATION	LUX	NOTES
1	70	
2	47	
3	28	
4	85	
5	104	
6	151	
7	208	
8	191	AT EDGE OF LIGHT BEAM
9	70	
10	50	

LOCATION	LUX	NOTES
11	28	
12	85	
13	113	
14	146	
15	218	
16	198	AT EDGE OF LIGHT BEAM

READINGS BETWEEN/BELOW FIXTURES AS SHOWN

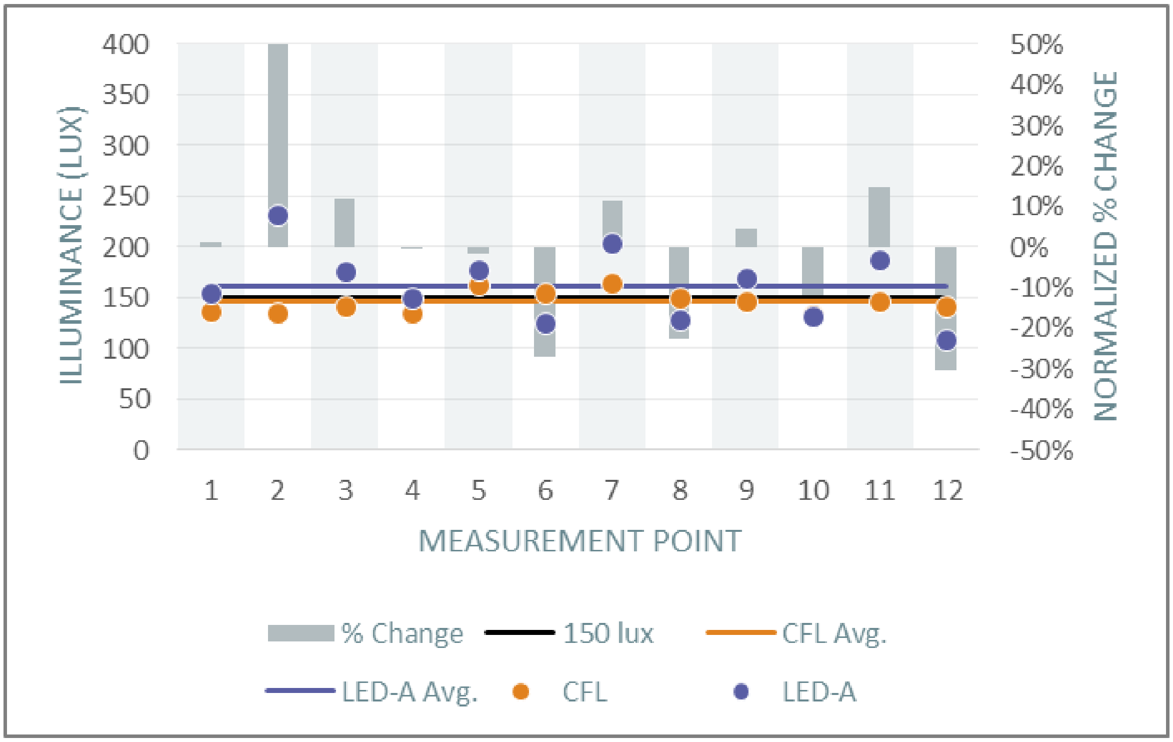


Figure 8: Dallas 7th Floor Hallway Horizontal Illuminance and Normalized Percent Change

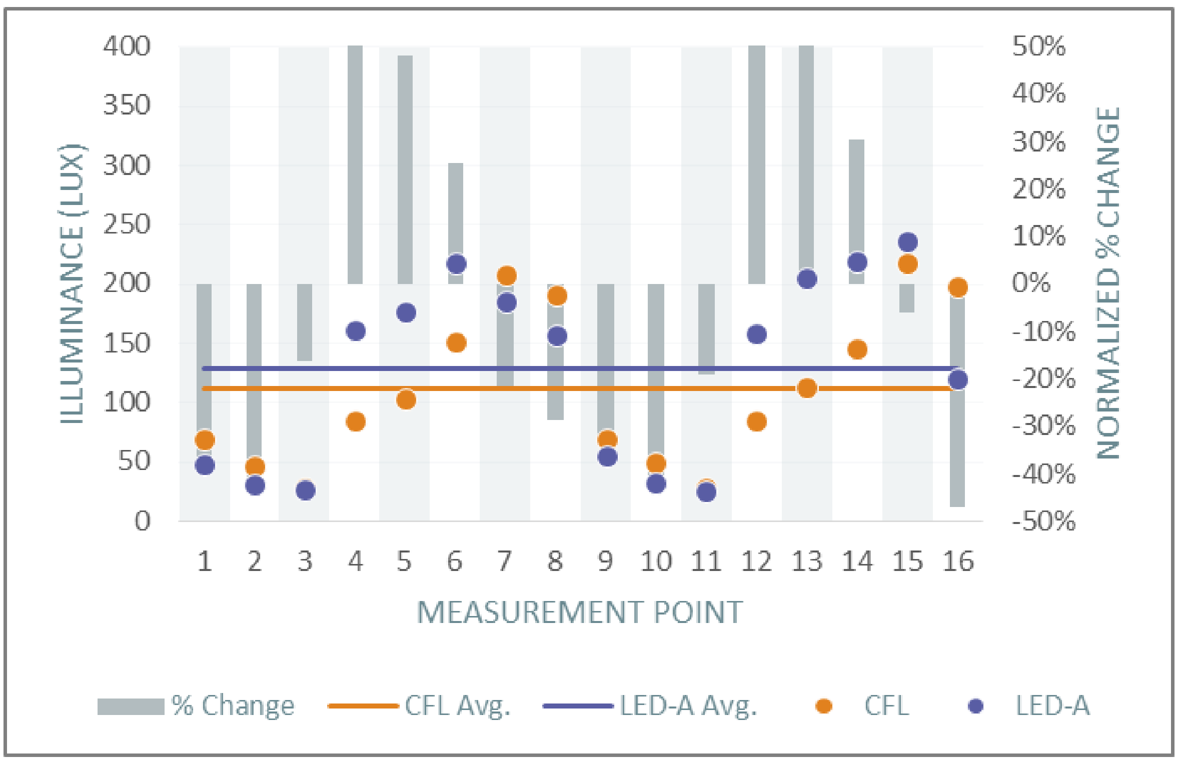


Figure 9: Dallas 7th Floor Hallway Vertical Illuminance and Normalized Percent Change

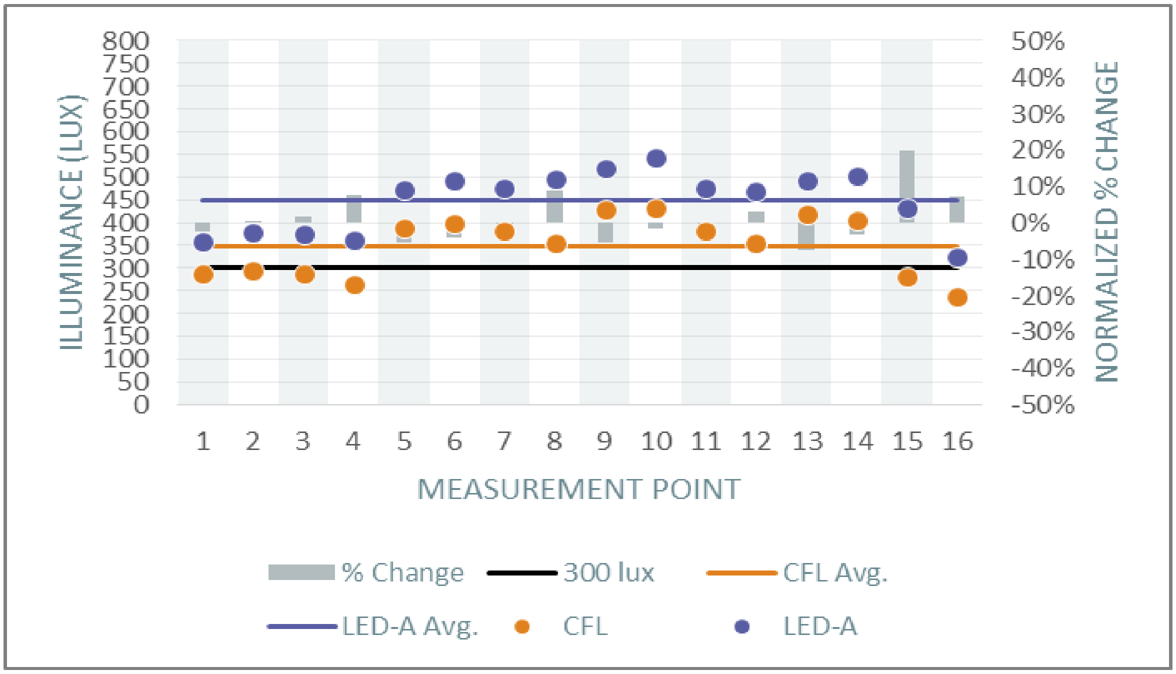


Figure 10: Dallas 7th Floor Lobby Horizontal Illuminance and Normalized Percent Change

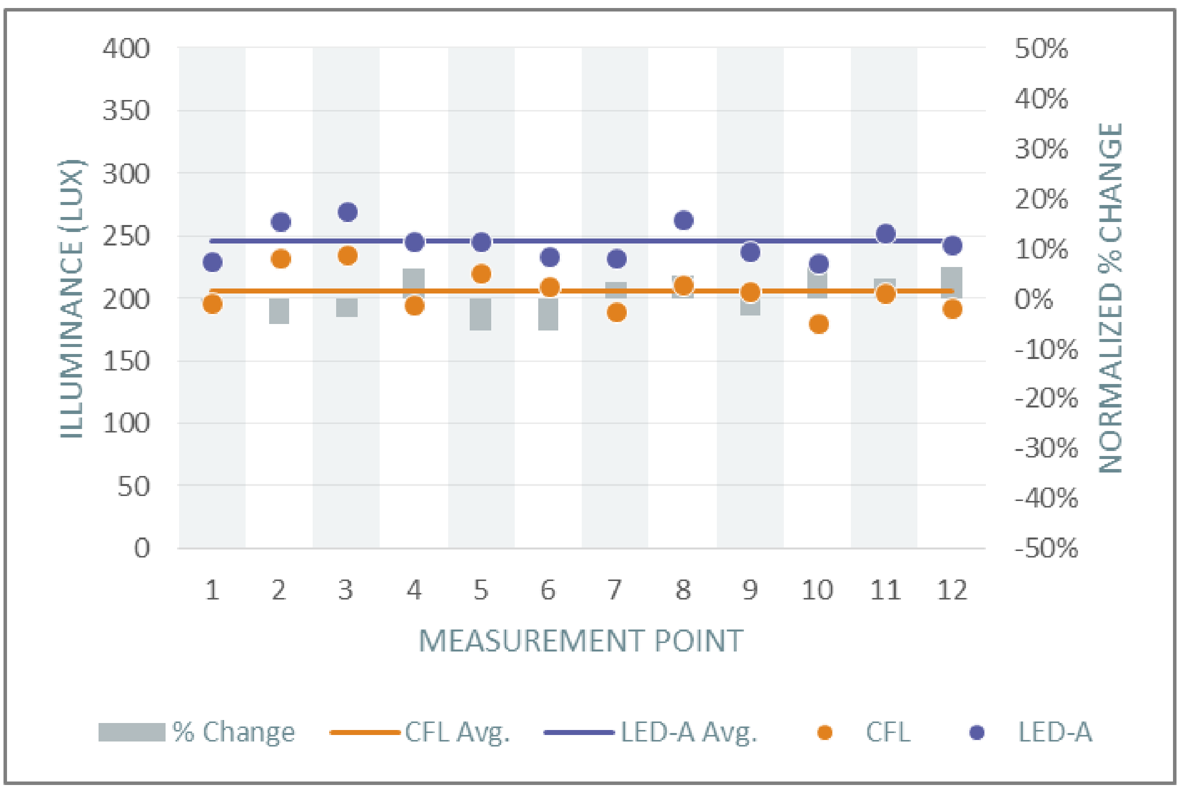


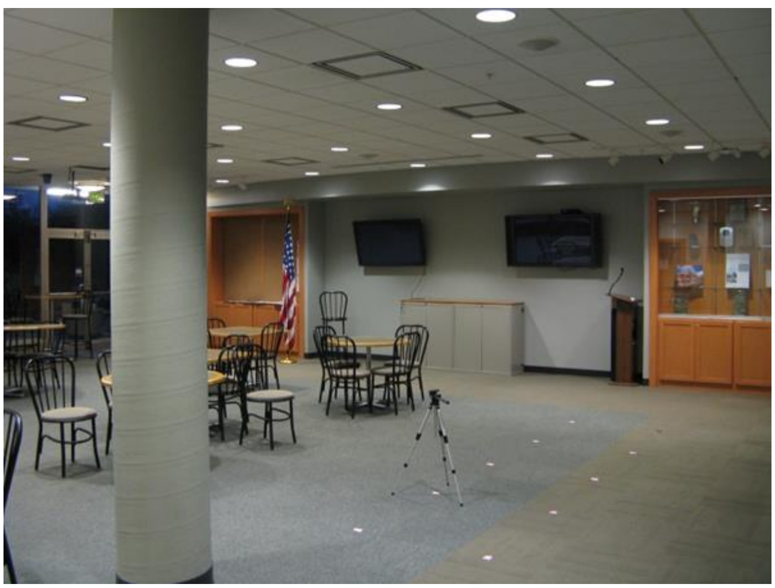
Figure 11: Dallas 7th Floor Hallway Vertical Illuminance and Normalized Percent Change

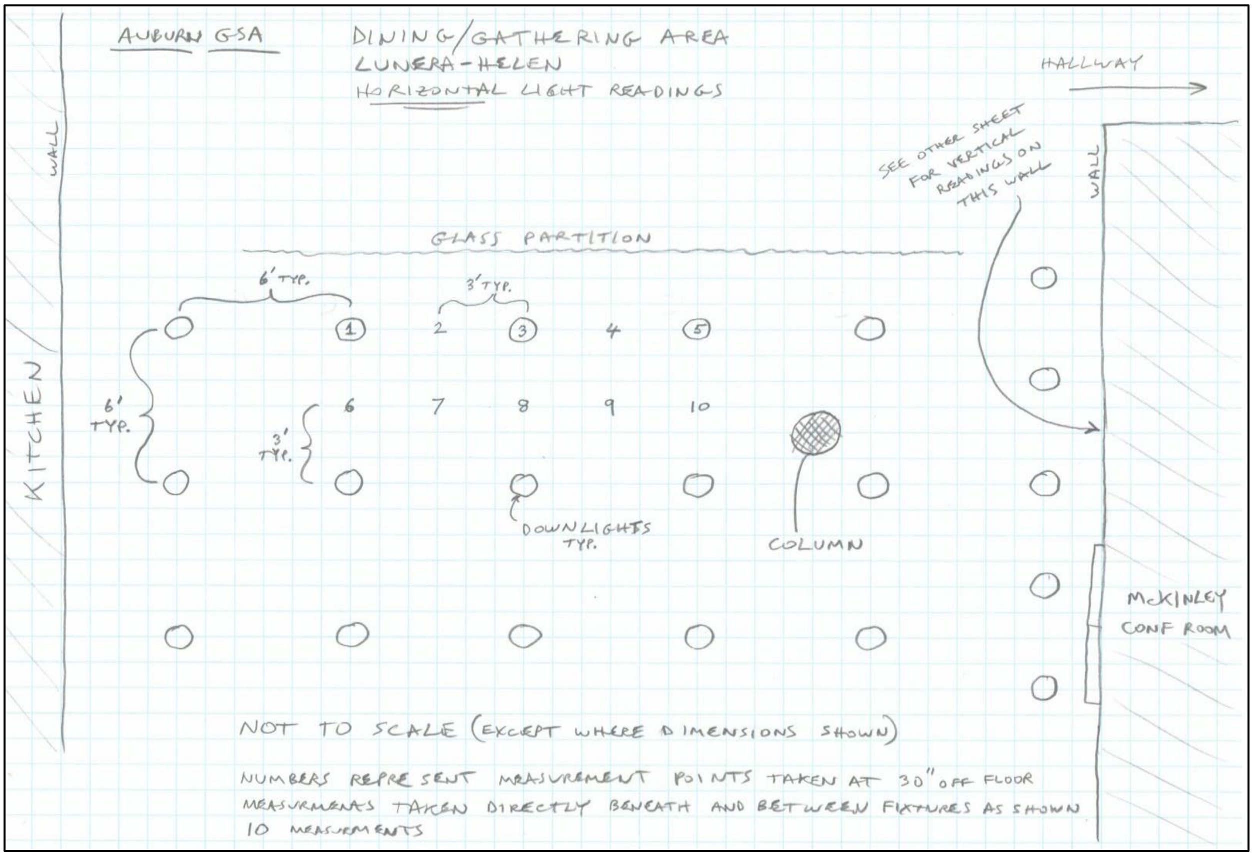
AUBURN, WA

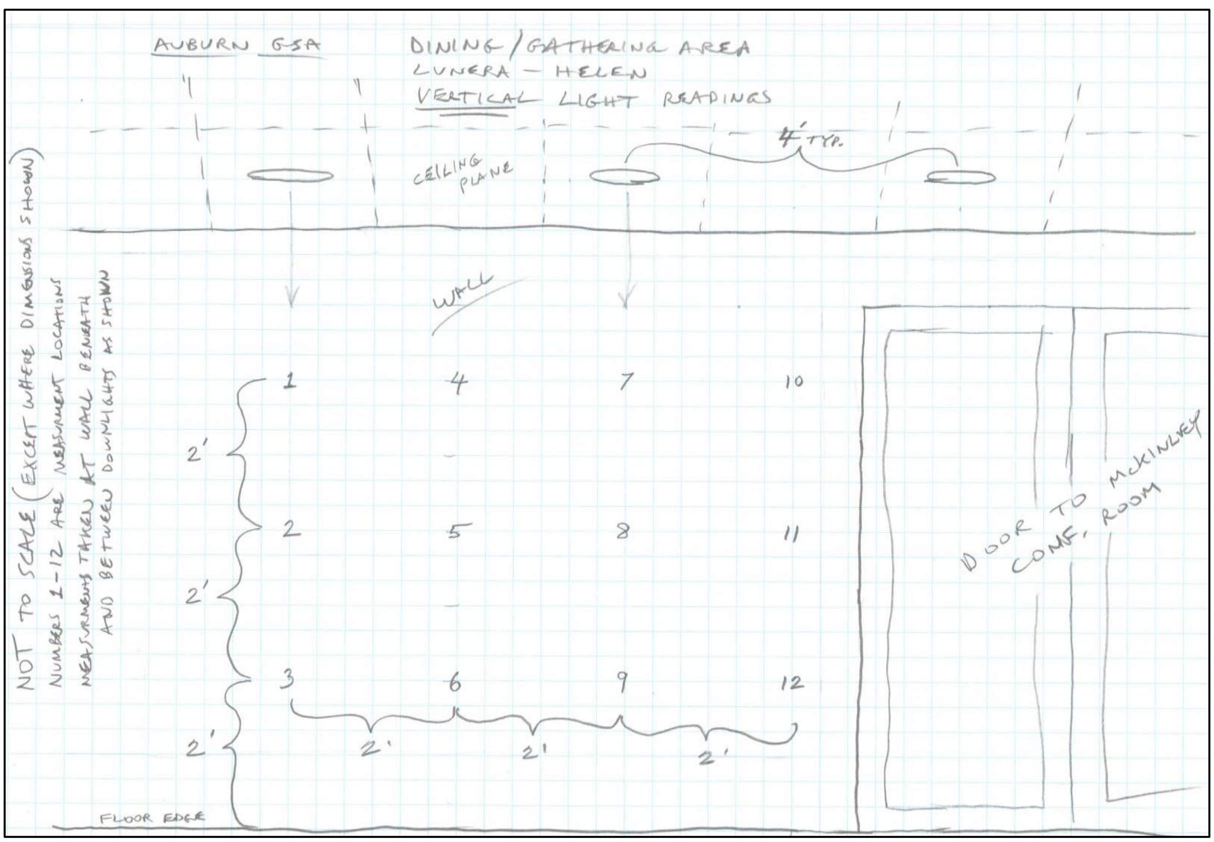
The dining area shown in the photo below where the original CFL downlight products were installed presented some uniformity issues with burned out or failing CFL products. The one burned out unit was replaced and measurements of the existing conditions were taken.

The horizontal light levels presented in Figure 12 show a fair amount of variability likely due to natural difference in the remaining life of the lamps and other natural issues with lamp orientation in recessed fixtures. With the LED-A product installed, the variability decreases a bit but could still be partially attributed to the beam angle of the lamp. It is useful to note that the light levels at the three points directly below fixtures (points 1, 3, and 5) are lower with the LED-A, while the light levels at remaining points between fixtures are consistently higher, indicating that the LED product is doing a better job of distributing the light across the horizontal surface (away from directly below) than the previous CFL lamps.

The vertical wall measurements in Figure 13 were taken at a different location and, in this case, the uniformity and light levels are very similar. This further indicates that the dining area where the horizontal measurements were taken had some initial fixture alignment and lamp degradation issues that affected both pre- and post-retrofit measurements.




AUBURN GSA
DINING/GATHERING AREA
LUNERA-HELEN
HORIZONTAL LIGHT READINGS
HALLWAY
SEE OTHER SHEET FOR VERTICAL READINGS ON THIS WALL
WALL
KITCHEN
GLASS PARTITION
6' TYP.
3' TYP.
DOWNLIGHTS TYP.
COLUMN
McKINLEY CONF ROOM
NOT TO SCALE (EXCEPT WHERE DIMENSIONS SHOWN)
NUMBERS REPRESENT MEASUREMENT POINTS TAKEN AT 30" OFF FLOOR
MEASURMENTS TAKEN DIRECTLY BENEATH AND BETWEEN FIXTURES AS SHOWN
10 MEASURMENTS


AUBURN GSA
DINING/GATHERING AREA
LUNERA – HELEN
VERTICAL LIGHT READINGS
4' TYP.
CEILING PLANE
WALL
NOT TO SCALE (EXCEPT WHERE DIMENSIONS SHOWN)
NUMBERS 1-12 ARE MEASUREMENT LOCATIONS
MEASUREMENTS TAKEN AT WALL BENEATH AND BETWEEN DOWNLIGHTS AS SHOWN
DOOR TO McKINLEY CONF. ROOM
FLOOR EDGE

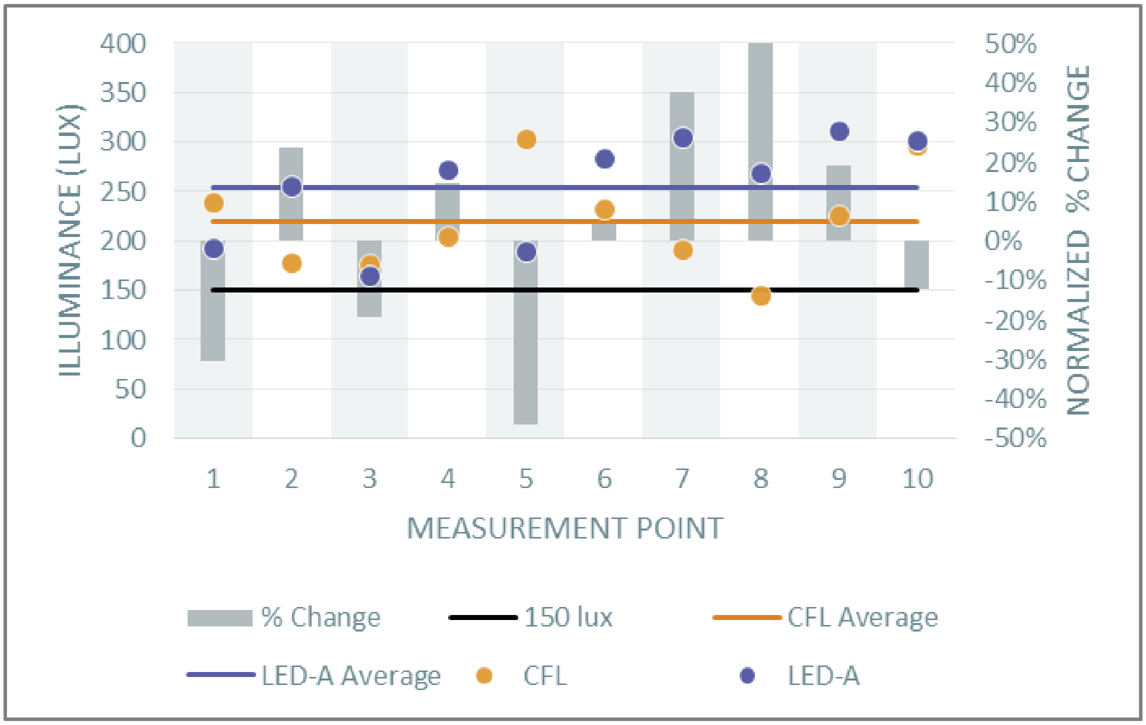


Figure 12: Auburn Dining Area Horizontal Illuminance and Normalized Percent Change

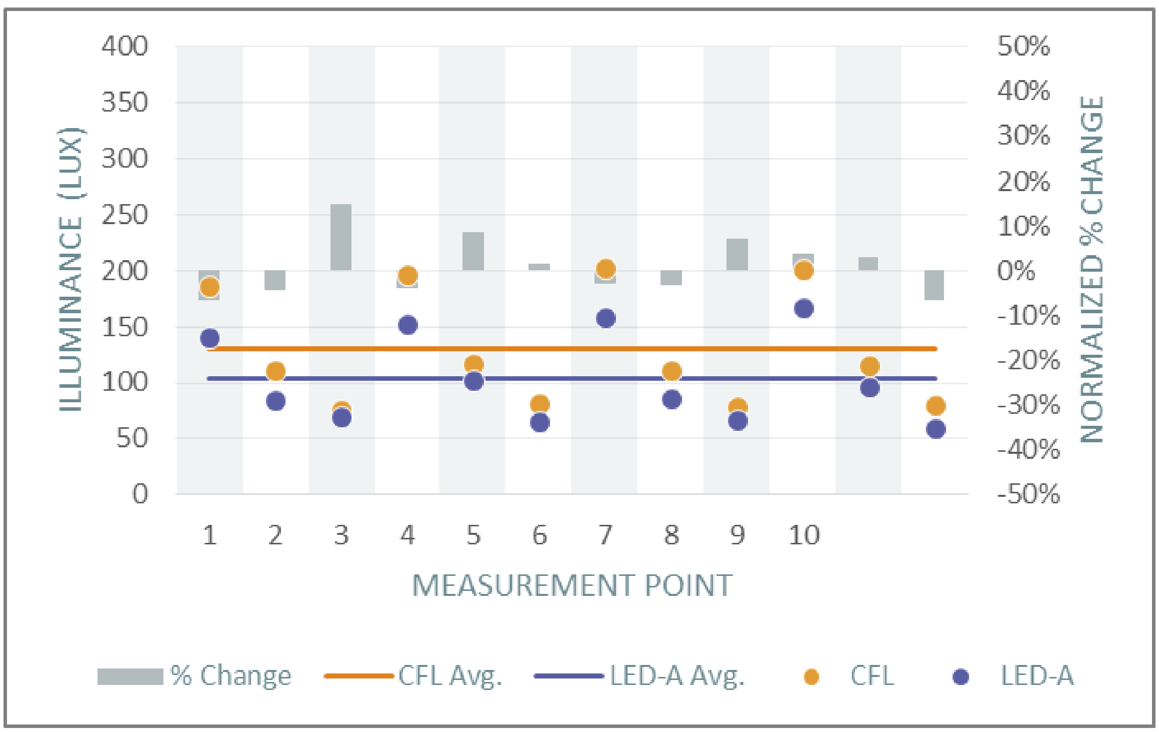


Figure 13: Auburn Dining Area Vertical Illuminance and Normalized Percent Change

B. LIGHTING INTENSITY COMPARISONS (GLARE POTENTIAL)

Luminous intensity is a measure of brightness when viewing an object such as a lighting fixture. This intensity can be related to various forms of glare and it is important to assess if and how there may be increased glare issues with any new technology. As part of this project, data were collected to help evaluate the potential for problematic glare for various fixtures and technologies.

The chart in Figure 14 provides a relative comparison of the brightness the human eye may see when looking directly at a typical downlight fixture. These values can be very high when looking up at a fixture from directly below it or at steep angles. However, occupants typically view fixtures in spaces at a much shallower angle, such as lobby and corridor areas where downlights are commonly used.

A set of brightness data was taken in the areas where LED-A retrofits were completed. Figure 14 shows the intensity of the view of the lighting fixture from the viewpoint of an occupant starting at approximately 8 feet away to as far as 20 feet away. Typical viewing distances from fixtures in a lobby or corridor environment are expected to be much greater than 8 feet. This data shows that at all expected viewing angles, the LED product shows lower intensity and, therefore, is likely to have no glare issues above those that existed using the CFL product.

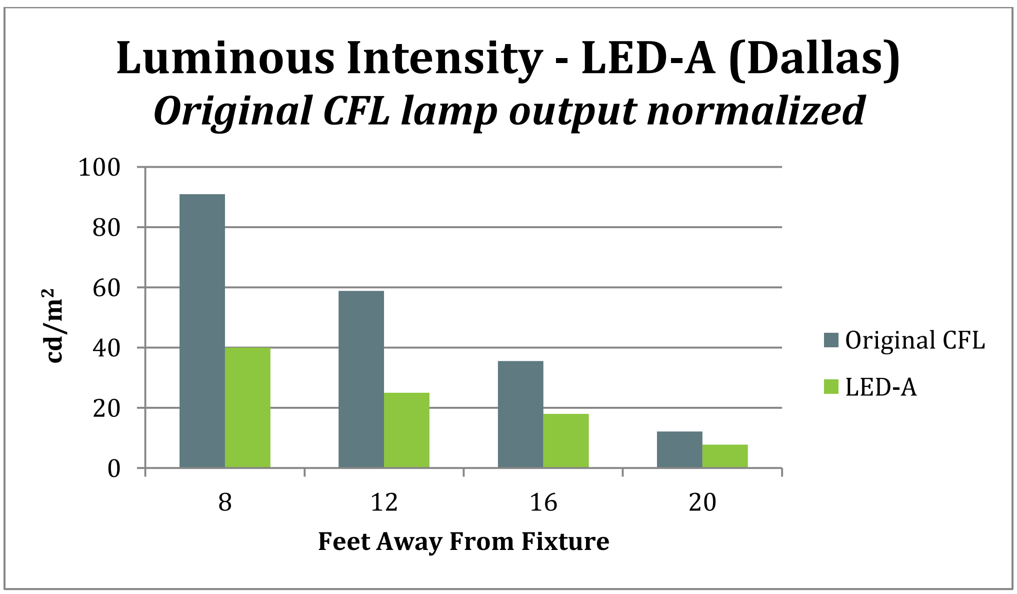


Figure 14: Dallas Site Luminous Intensity at varied views of a downlight fixture

A. ELECTRICAL POWER AND POWER QUALITY COMPARISONS

POWER MEASUREMENTS

The data collected on-site by the installer crews was requested to provide electrical characteristics for both the existing and retrofitted LED lighting systems to help confirm estimates of potential energy savings. This data, received only from the Auburn and Dallas installation crews, is shown in the Figures 15 and 16, below. (Pre-and post -retrofit data was not provided by Philadelphia installation crews.)

Figure 15: Pre- and Post-Retrofit Lighting Electrical Characteristics for Downlights - Auburn

Auburn	Pre-Retrofit				Post-Retrofit		
	Downlight 1	Downlight 2	Downlight 3		Downlight Retrofit (Lunera) 1	Downlight Retrofit (Lunera) 2	Downlight Retrofit (Lunera) 3
Amps (A)	0.013	0.0064	0.0059		0.01	0.0043	0.0042
Volts (VAC)	277	277	278		277	277	277
Lamps	2	2	2		2	2	2

Figure 16: Pre- and Post-Retrofit Lighting Electrical Characteristics for Downlights - Dallas

Dallas	Pre-Retrofit				Post-Retrofit		
	Downlight 1	Downlight 2	Downlight 3		Downlight Retrofit (Lunera) 1	Downlight Retrofit (Lunera) 2	Downlight Retrofit (Lunera) 3
Amps (A)	0.15	0.15	0.15		0.09	0.09	0.09
Volts (VAC)	277	277	277		277	277	277
Lamps	2	2	2		2	2	2

It is important to note that each application of new technology, such as LED lighting, will provide different energy savings depending on the lighting system that it replaces and any other changes to the space, such as light levels, controls, or operations.

It is also important that data be collected in a consistent manner over a sufficient period of time. In reviewing the Auburn data, inconsistencies or a conversion error of some kind were discovered. However, multiple samples were taken and the data was recorded consistently, so the relative percentage change is considered useful.

The results of this data show that the LED-A potential savings from LED replacement of existing 4-pin CFL products is approximately 33%; savings range from 27% to 40%, depending on the wattage of the existing CFL being replaced.

POWER FACTOR

Power factor (PF) is a measure of the efficiency of electrical devices. For lighting ballasts or drivers, this is the ratio of the power actually made available to the lamp and the energy input to the ballast or driver. For electrical devices, if the current draw is in-phase with the voltage, the power utilization is maximized, but when the two are out of phase, part of the input power cannot be converted to produce light. Low PF registered at a building's electrical service may be a characteristic of a building's power signature, which may result in additional charges by a servicing utility. However, individual electrical products with low PFs are only individual contributors to a buildings PF rating. High PF products are considered to have PF values greater than 0.9. Some rating or listing systems have limits for PF for products that relate a measure of quality for those products. This does not necessarily mean that products with lower PF values are inferior or are detrimental to a lighting system or building. Like many product or system characteristics, the PF is a relative value that must be considered along with other factors when choosing equipment. For reference, the current Design Lights Consortium (DLC) threshold for PF is 0.9, which is considered an industry standard level representing quality and a level that should not affect building PF levels and, therefore, not affect utility billing charges.

The test data collected indicated that the PF of the LED downlights was 0.88, which is effectively at the 0.9 threshold set by DLC and should be considered reasonable for most applications. As noted, The PF at the building electrical service point is the potential issue and the individual product PF values do not directly equate to the PF for a building. For reference, a separate GSA study from December 2011[14] involved the replacement of over 90% of a fluorescent lighting system with LED products. The chosen LED products had relatively poor PF values of around 0.61. However, analysis of the average 15-minute measured PF from the utility billing data for June through July, both before and after the retrofit, shows effectively no change in the overall building PF (2010 = 0.8614, 2011 = 0.8603).

TOTAL HARMONIC DISTORTION

Total harmonic distortion (THD) is a measure of the distortion of the input current expressed as a percentage of the fundamental frequency current of 60 Hz. Significant harmonics can be introduced back onto electrical lines from lighting ballasts and LED drivers if the electrical product load type is not linear. Total THD on an electrical circuit or system can be an important consideration when looking at detrimental effects on other electrical equipment or electrical safety.

The actual effect that THD from lighting products can have on an electrical system depends on many factors. For instance, THD is path dependent (*i.e.*, it does not necessarily affect the entire system); it does not adversely affect all equipment or systems; and it depends on the percentage of total load that lighting or other equipment represents in a building. The test data collected as part of this evaluation found the THD value for the downlight LED product to be only 18%, which is below the industry-accepted and regulation standards of 20% or lower at full load.

C. ECONOMIC ANALYSIS

The decision process for energy conservation measures (ECMs) requires a thorough understanding of the existing condition (base case), costs of energy, maintenance and replacement, and must factor in the time value of money for the evaluation period. To that end, LCC is used to account for the cash flows over the evaluation period and to calculate present (or net present) values for competing ECMs. In the federal sector, it is common practice to use a software package called Building Life-Cycle Cost (BLCC), which was developed by the National Institute of Standards and Technology (NIST).

[14] General Services Administration (GSA) (December 2011), Aberdeen Federal Building Lighting Retrofit Evaluation, PNNL-21070, Pacific Northwest National Laboratory, Richland, WA.

Below are the assumptions used in the BLCC models developed for the project:

- Energy rates: $0.06 - $0.24 kWh, plus $0.1062 kWh (national commercial average for February 2015)
- Energy inputs into the models
- Base case 26W CFL = 28W and 112 kWh/yr (includes ballast losses)
- LED = 13W and 52 kWh
- No demand or PF charges
- No heating, ventilation, and air-conditioning (HVAC) impact, *i.e.*, reduced cooling, increased heating
- Annual operating hours: 4000
- Life-cycle period: 12 years, 6 months selected for the following reasons:
    - Manufacturer-stated LED product life: 50,000 hours
    - Typical rated life for modern electronic ballasts: 50,000 hours (rated life for a magnetic CFL ballast will likely be less)
    - Long enough to account for at least four CFL replacements for LED maintenance savings
- Models include the manufacturer-provided cost of $22 for the LED product. Installation costs are based on RSMeans Data[15] with specific application of GSA procurement lists. The table in Section C of the Appendix provides a breakdown of the material, labor, profit, and overhead costs used in the analysis.
- "Base case" for downlights: 1 × 26W PL w/1 generic electronic ballast operating at 28W. Lamp replacements at 12,000, 24,000, 36,000, and 48,000 hours (3, 6, 9 and 12 years) with estimates of yearly energy use of 240 kWh and lamp replacement cost of $21.46. For purposes of comparative economic analysis, it is assumed the base-case and associated costs are installed at time = 0.
- Nominal discount rate: 3.1%.

Figures 17 and 18 show the results of Savings-to-Investment Ratio (SIR), Simple Payback (SPB), Present Value (PV), and Net Present Value (NPV) over a range of electricity rates.

[15] The Gordian Group, "RS Means Construction Cost Data Book," 2015

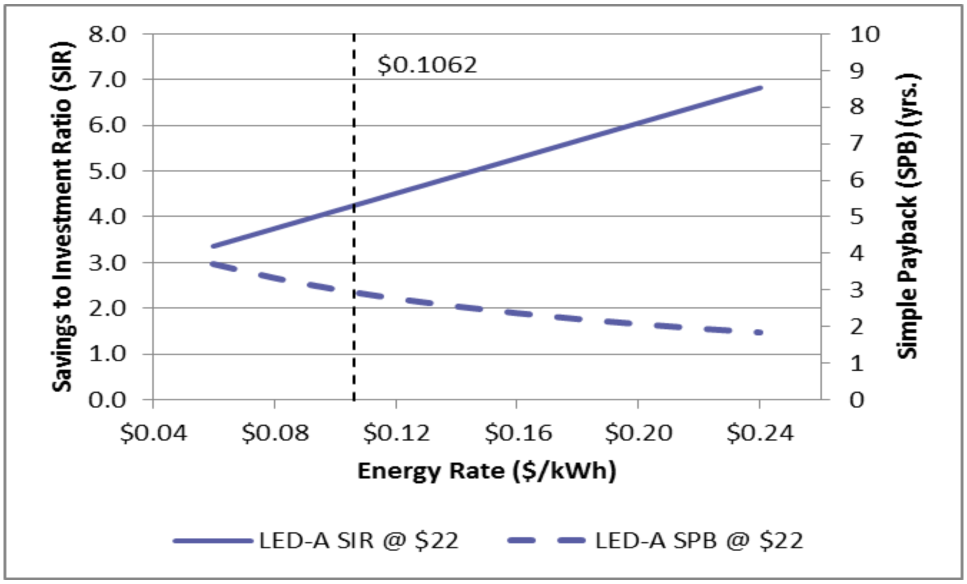


Figure 17: LED-A Savings-to-Investment-Ratio and Simple Payback Results

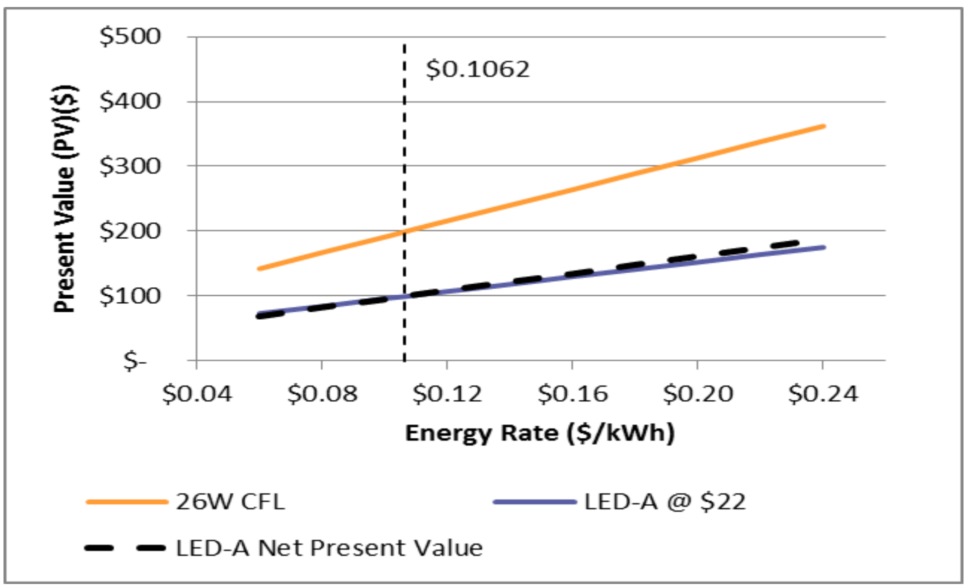


Figure 18: LED-A Net Present Value Results

PRESENT VALUE (PV) AND NET PRESENT (NPV)

When evaluating results, the alternative with the lowest PV is generally considered the most cost-effective. In Figure 16, above, the base case CFL is listed in orange with the competing LED-A solution below in purple. The NPV, the difference between the present values, is black. The results indicate that LED-A is cost-effective at all energy costs. While energy savings are important, the most significant contribution to the PV/NPV calculation is labor savings. Labor costs in implementing new systems and performing future O&M, especially in federal facilities, are quite high. The energy and O&M cost reductions are the differential between the LED-A solution and the base case at each energy cost. The LED-A solution has a low installation cost and avoids four lamp replacement cycles during the study period.

SAVINGS-TO-INVESTMENT RATIO (SIR)

For the LED-A technology, investigated the SIR is greater than 1.0.

ADJUSTED INTERNAL RATE OF RETURN (AIRR)

AIRR is usually compared to the discount rate used in the LCC analysis (3.1%). Higher values equal greater cost-effectiveness. The LED-A technology is shown to be cost-effective.

SIMPLE PAYBACK (SPB)

In this study we have included SPB and it is expected to be well under three years for most energy rates.

D. OCCUPANT SURVEY RESULTS

Occupant surveys administered at the three evaluation sites provide information about the relative satisfaction of the occupants with both the existing fluorescent lighting and the newly installed LED lighting. The following observations are based on a statistical significance analysis of the various responses and provide some general indication of the differences noticed between the pre- and post-retrofit systems.

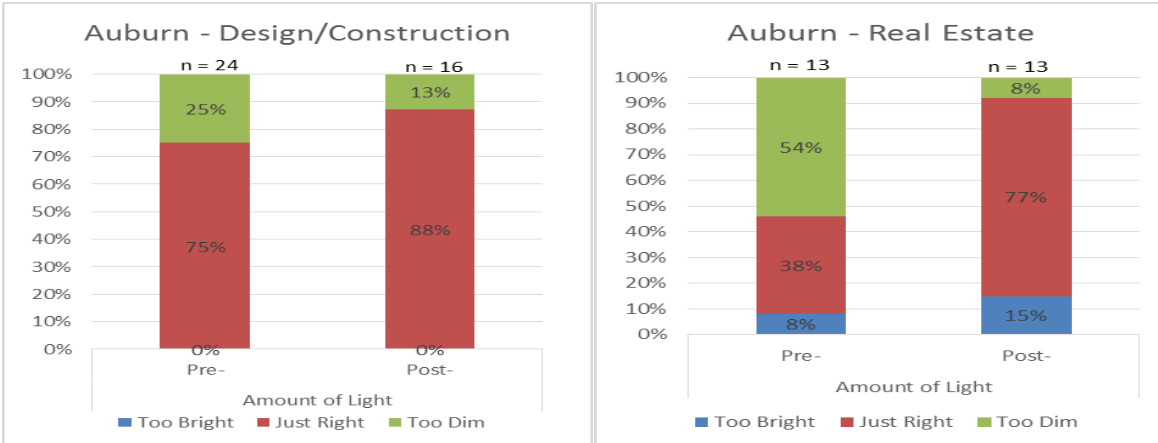
The primary focus of the analysis was to determine if there were any specific issues with either the existing fluorescent or retrofit LED systems and if there were any significant differences with the change to LED technology.

In general, the occupants' responses to the pre-retrofit survey at all three sites indicated that the existing fluorescent system was acceptable. This result was expected because the occupants have been accustomed to working under these systems and any significant issues would likely have been addressed.

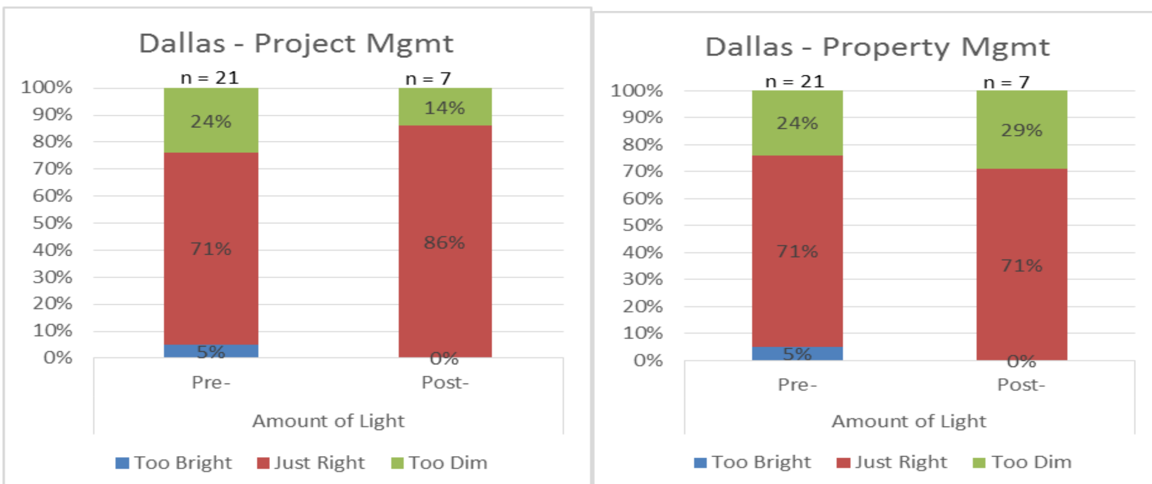
In analyzing the data for significant responses that showed differences between the fluorescent and new LED systems, the following results are noted related to light levels:

- At the Auburn site, the occupants thought the original fluorescent lighting in the common hallway areas was too dim and it improved with installation of the LED downlights. This result can be attributed simply to the higher light levels that resulted from the higher output of the LED downlights that were installed and not necessarily anything specific to LED technology.
- At the Dallas site, the occupants thought the common hallway areas with downlights were a little too dim with both the fluorescent and LED systems. This result can again be attributed simply to the light levels of both the original and retrofit systems and not necessarily anything specific to LED or fluorescent technology.
- At the Philadelphia site, the occupants thought the common hallway areas with downlights were slightly dimmer with the LED technology.

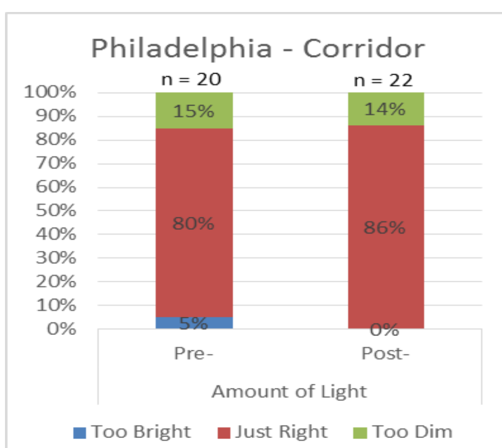
These differences were found, on average, to be slight and no major issues were identified. However, there can always be individual issues with specific occupants.



Pre- and Post-Retrofit Occupant Survey Results in Common Spaces – Auburn



Pre- and Post-Retrofit Occupant Survey Results in Common Spaces – Dallas



Pre- and Post-Retrofit Occupant Survey Results in Common Spaces – Philadelphia

E. INSTALLER SURVEY RESULTS

In addition to occupant surveys, specific questions were also asked of those performing the installation of the new LED technology. This was done to determine if any potential characteristics of the system need to be addressed when considering a project application. Survey responses were only received from the Dallas and Philadelphia sites and only the second question was answered differently by the two sites. In this one case, the response could be related to either part of the question. However, the overall results show clearly that this technology was easy to install with no issues. This was expected because the technology is installed similarly to a simple incandescent lamp retrofit.

Technologies installed	Philadelphia	Dallas
LED-A Lamp		
Was it clear from the product or package how or where the product was to be installed?	Yes	Yes
Were instructions needed to complete the installation? If so, were they complete and effective?	No	Yes
Were there any potential safety issues identified with this lamp or the process for installing it? Please describe.	No	No
Was there any difference in time or effort involved in installing this new LED lamp compared to the standard CFL replacement lamp? Please describe.	No	No
Do you see anything about this product or its installation that would affect future maintenance costs or process? Please describe.	No	No
Anything else you would like to note about this product or the process for installing it?	No	Easy Install

VI. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

ENERGY SAVINGS

- The LED-A technology, when installed in a 26W CFL downlight system, saves 60 kWh/yr, or 50% of the energy.

PHOTOMETRIC PERFORMANCE

- The uniformity with the LED downlight product (LED-A) shows some additional variability. This can be the result of several factors, including lamp orientation (angle) within the fixture or the directional nature of LEDs, or both; however, the difference (typically around 100 lux) is not typically considered noticeable to the human eye.
- Light levels with the new LED downlight product are generally higher than the existing fluorescent system based simply on the availability and choice of wattage.

OCCUPANT SATISFACTION

In general, little change was noticed between the existing fluorescent and replacement LED technology.

- The occupants thought the fluorescent and LED lighting in the common hallway areas was generally too dim, but somewhat better with the LED system in Auburn and Dallas and slightly dimmer with the LED technology in Philadelphia.
- In some areas at all three sites, the occupants felt that the LED-A technology provided more capacity to produce glare on surfaces, but none noticed any severe issues.

These differences were found, on average, to be slight and no major issues were identified.

COST-EFFECTIVENESS

- At $0.1062/kWh (the national commercial building energy rate average for February 2015) LED-A saves $6.37 in energy costs per year over a typical compact fluorescent system and has a:
  - 2.9 year simple payback, assuming the material cost is $22[16].
- Over the economic study period, the greatest contribution to cost-effectiveness is labor savings due to avoided lamp replacement (four for compact fluorescent).
- Based on the findings from this evaluation study for the product evaluated at the three demonstration sites, it is estimated GSA could save 5.7 GWh of electricity per year (over $600,000 per year at the U.S. national average electricity rate) with deployment of SSL in the estimated 95,000 CFL downlights in the GSA building portfolio.

PRODUCT ISSUES

The final installed product has performed well with no performance issues. Soon after the installation of the initial LED-A products in the Dallas site, some lamps exhibited poor performance and failures. The manufacturer identified a manufacturing problem and replaced all lamps and resolved the problem.

B. LIGHTING RETROFIT IMPACTS ON HEATING/COOLING SYSTEMS

Lighting energy introduced into a building equates to heating load, which affects HVAC operation and, therefore, building energy use. When lighting energy is reduced, heating load is also reduced and cooling systems in a building can generally use less energy. However, when lighting energy is reduced, additional heating in colder climates may be required to compensate. To determine the net effects that lighting energy reduction can have on a project, the total kilowatt-hour savings of the lighting project along with cooling and heating season fractions described in an ASHRAE Journal paper (Runquist et al. 1993) can be used.

[16] The manufacturer noted just prior to publication that the product cost had been reduced to $15 which will make the economics even more desireable.

In most climates within the United States, the loss of inadvertent heat to a building from replacing older technologies with more efficacious LEDs does not typically cause additional heating energy to negate lighting energy savings. However, in severe cold climates, such as Alaska, this should be considered.

C. BEST PRACTICE APPLICATION GUIDANCE

This section provides information about the various options available for re-lamping or retrofitting CFL downlights in commercial buildings. It also offers guidance on the issues to consider when evaluating the best option for particular applications. Many options exist for this type of retrofit; each has its own advantages and challenges described in detail below.

PROJECT APPLICATION PROCESS

1. **Target Facilities** – Given GSA's expansive portfolio (in terms of age, volume, and location), wide range of technologies serving similar space-type applications, and variations in the cost of energy, it is recommended GSA adopt a targeted approach to systematic installation. In general, older facilities tend to be over-lit relative to current IES illuminance recommendations. These facilities also tend to use older technologies, such as incandescent and magnetically ballasted downlights. The cost of energy and, thus, operating cost should also be a significant factor in the decision process because return on investment will be maximized.
2. **Select LED Option** – Multiple product offerings are available to the end-user; each has its strengths and weaknesses from a performance, ease of installation, cost, maintenance, risk, and segue for controls, standpoint. No one solution will meet the needs of all buildings and all users.

Therefore, a diligent evaluation of available options that sets priorities for near-term, as well as long-term, objectives is necessary. For each application, more than one option may be viable. For 4-pin (and 2-pin) CFL downlights, more than one product may meet the requirements. The section below describes basic retrofit options for pin-based CFL downlights.

3. **Apply "Above Code" Performance Criteria and Approved Product Lists** – As a federal agency, GSA is required by statute to procure products that meet ENERGY STAR® criteria, where applicable, and downlights would fall into an ENERGY STAR category.
4. **Apply Additional GSA Criteria** – At this stage, GSA may wish to apply its own specifications/criteria (see section on Basic Product Specification in Section E) not addressed in the prior step. Here, GSA should also apply any baseline and High Performance Tier requirements from its P-100 standard.
5. **Develop Performance-Based Specification for Intended Application** – The final step in the process is to develop a specific performance-based specification for the space type(s) or facilities in question and require the manufacturers to demonstrate that their solutions, when installed in the defined GSA application, will meet the requirement, thereby effectively shifting the burden of performance onto the manufacturer.

LED REPLACEMENT OPTIONS FOR CFL DOWNLIGHTS

Category	Dimming	Controls	Attributes	Unknowns	Useful Application Where:
1. LED-A Lamp using existing CFL pin socket and ballast	Unlikely	Shut-off only (switch or occupancy sensor)	LED or FL option, no electrician, matches lens configuration, does not alleviate need for future ballast replacement	Performance on various ballasts and over time	Cost is critical, existing FL ballasts are healthy, and advanced control is not useful
2. LED-A Kit using proprietary power supply	Yes, with matching 0-10V system	Yes, with matching driver/control	Allows for light source relocation/re-alignment within fixture	Product availability and performance over time	Advanced control may be useful
3. New LED Downlight Fixture using proprietary power supply	Yes, with matching 0-10V system	Yes, with matching driver/control	Likely best efficacy and performance and potential for relocation	Performance over time	Space is under major retrofit

1. LED-A Lamp using the existing fluorescent socket and ballast

This option involves directly replacing the existing CFL with a similar form factor LED lamp product and does not require any fixture rewiring. The replacement LED is designed to operate on the existing compact fluorescent ballast. These replacement LED lamp products are currently available from several manufacturers.

Advantages of this type of lamp replacement include:

- Ease of installation – no electrician required
- Lamp only – no need to purchase ballasts, drivers, or other accessories and, therefore, relatively low cost

Disadvantages may include:

- It may not work on all existing ballasts.
- It does not address potentially limited remaining ballast life or actual performance on all ballast types.
- All driver electronics are within the lamp in proximity to the heat-generating LEDs, potentially affecting LED lumen maintenance and system life, particularly when used in enclosed downlight fixtures. Products rated for enclosed fixtures should be chosen in these applications.

2. LED-A kit (hardwire) using alternative mounting hardware.

These kits can be designed in any shape that could be accommodated by a downlight housing. This option often involves the removal of the compact fluorescent ballast and will require direct wiring to the power source. The fixture manufacturer will provide some method of attaching the light kit to the fixture housing, such as self-tapping screws. Using these types of products provides a potentially easier and less costly option compared with a new LED fixture. The system performance characteristics, such as light output, distribution, and application effectiveness, should be considered. Advantages of this option include:

- Potential energy savings compared to CFL.
- Less costly than new LED downlight fixture.
- Dimming capability

Potential disadvantages include:

- Performance may not be optimal depending on the varying optics and lensing of downlight fixtures. LED retrofit kits that come with their own optics may offer an advantage.
- Self-tapping screws (if needed) could cause electrical problems when being installed in fixtures-in-place if they penetrate existing wiring in the building.
- Higher cost than simple lamp replacement using fluorescent ballast.
- Need to penetrate plenum or ceiling, which may trigger code/permitting requirements.

3. New LED downlight fixture

A new fixture will eliminate any issues with UL listing and decreases in optical efficiency and can provide the same or better light for the space and its tasks. Advantages of this option include:

- Likely better expected energy savings compared to retrofit kits.
- New clean install avoiding most socket and wiring issues.
- Dimming capability.

Potential disadvantages include:

- New fixture and installation cost.
- The fixture may not have replaceable LED arrays (lamps), therefore requiring a new fixture when the LED useful life is reached.
- Potentially highest cost of all options.

ISSUES TO CONSIDER WHEN EVALUATING OPTIONS

a Product Efficacy

Product efficacy among LED products varies based on many factors. For simplicity in determining a minimum efficiency for a project, it can be useful to refer to existing program requirements for setting minimum criteria. Commercial recessed downlight products are a bit tricky in that they are not covered under the Design Lights Consortium (DLC) but similar residential-type recessed products are covered under the U.S. Environmental Protection Agency's (EPA's) ENERGY STAR.

Light distribution

Direct LED lamp-for-lamp replacements that can be installed in a downlight are the most variable in terms of consistency of light distribution. For example, typical 2-pin CFL downlight fixtures can be up to 70% efficient, meaning that approximately 70% of the CFL lamp initial lumens will exit the fixture. A typical LED-A replacement for a pin based CFL lamp is directional, meaning that most (90% or more) of the light is typically directed down out of the fixture without relying on any reflection. This means that as long as the LED-A lamp provides 70% of the initial lamp lumens of the CFL that it is replacing, the light levels should not be reduced to unacceptable levels.

If an LED-A kit or new LED downlight is selected as the luminaire upgrade, the optics will be designed based on the directionality of the LEDs, and luminaire losses will not have to be taken into consideration. Whatever the manufacturer states as the lumen output and efficacy should meet or exceed the requirements stated by voluntary programs such as ENERGY STAR.

ENERGY STAR Requirements for Downlights

Luminaire Efficacy (initial)	Luminaire Minimum Light Output (Initial)	Luminaire Zonal Lumen Density Requirement
42 Lumens/Watt	≤ 4.5" aperture: 345 lumens > 4.5" aperture: 575 lumens	Luminaire shall deliver a minimum of 75% of total initial lumens within the 0-60° zone

PRODUCT USEFUL LIFE

LEDs can typically last many times longer than a typical CFL or incandescent lamp. However, LEDs do degrade over time and will eventually degrade past their usefulness for the lighting task. Many LEDs are rated for 35,000 to 50,000 hours at 70% of initial light output compared to the incumbent downlight light sources with common lifetimes of 1,000 (incandescent) to 10,000 (CFL) hours before failure. LEDs can provide a much longer useful life than the lamps they would be replacing in downlight applications. However, each site or project can have different needs and long life may not be a primary requirement and, therefore, should not necessarily drive any cost-effectiveness analysis. If the space has low-lighting use time or may be reconfigured in the near future, then a very long-life product may not be practical or cost-effective.

Lighting Color

LED products are available in the same general color choices as CFL and incandescent directional lamps from warm white (*i.e.*, 2700K) to cool white (*i.e.*, 5000K). Additional color and tuning options are also emerging for LED products. If the current color in the space is appropriate, choose the same color temperature LED lamp. In general, people-occupied spaces are commonly lighted with warmer color temperatures (3000K to 4100K) because of the better treatment of skin tones.

Installation Time and Cost

At current market pricing, direct replacement LED lamps will cost more than replacement CFL lamps, but will have no additional replacement labor costs. New LED luminaires and replacement kits will incur additional electrician wiring and labor costs. Some LED kits, however, can plug directly into downlight sockets and, therefore, allow you to benefit from a negligible labor cost, as well as optics specialized for LEDs. It may be prudent to consult with a contractor with the details of replacement kits and new fixtures in hand to get an estimate of the differences in installation cost, while also considering the amount of light each product is capable of providing.

Installation Compatibility

For replacement LED lamps that operate on existing CFL ballasts, it is important to verify that the product will function on all of the ballast types within the project area being considered. This may be simple to verify if the ballast types are known and consistent throughout a project area or building. However, before committing to purchasing replacement kits, it will be important to verify the compatibility of the product.

If a replacement kit is considered a good option, it will be important to determine that the kit under consideration will fit effectively in the existing downlights. At a minimum, this should be confirmed with the manufacturer. Also useful would be a trial install to verify that the resulting retrofitted fixture is effective and does not present any issues, such as possible glare from the LED source being necessarily lower in the recessed fixture due to limited housing space.

D. BASIC PRODUCT SPECIFICATION

DOWNLIGHT LAMPS

A. General Description: LED lamp replacements for existing 4-pin (G24) CFL
B. Application
   - Luminaire Application
     - Recessed Downlight
     - Surface mount
C. Electrical
   - Operating voltage: 120-277V
   - Power Factor: 0.90 at full light output
   - Total Harmonic Distortion: <20% at full light output
   - Efficacy: 70 lumens/watt at full light output
D. Photometric Performance
   - Light Output: minimum 450 lumens
   - Zonal Lumen Density: >75% of total initial lumens within the 0-60° zone
E. Chromaticity
   - CCT: 3000K, 3500K, 4000K or as specified by site
   - CRI: 80, R9>0
F. Controls
   - As specified by site, which may include integrating occupancy, daylighting, or both.
   - Fixture/lamp products must be verified by manufacturer or separate testing to be compatible with integrated or existing room controls, such as wall/ceiling occupancy sensors.
   - Wired or wireless control systems must not be accessible, networked, or otherwise tied to external systems, unless specified by GSA.
G. Lumen Maintenance: Minimum 70% light output at 36,000 hours derived from LM-80 and TM-21 reportable rating
H. Warranty: Minimum five years
I. Qualifications: UL Classified for U.S. and Canada

VII. Appendices

A. OCCUPANT PRE- AND POST-RETROFIT SURVEY DATA

Occupant Survey Data with Statistical Significance Notations

Auburn, WA – GSA Regional: 1st Floor Design and Construction

Property	**Response**	**Pre-Retrofit** Total Responses	**Pre-Retrofit** Response Percentage	**Post-Retrofit** Total Responses	**Post-Retrofit** Response Percentage
COMMON SPACE	Yes	19.5	81%	14	82%
PUBLIC IMAGE	No	4.5	19%	3	18%
GLARE	Yes	1	4%	5	29%
GLARE	No	24	96%	12	71%
AMOUNT LIGHT[1]	Too Bright	0	0%	0	0%
AMOUNT LIGHT[1]	Just Right	18	75%	14	88%
AMOUNT LIGHT[1]	Too Dim	6	25% [2]	2	13%

[1] Statistical Analysis Performed

[2] Statistical Significance Level 95%

Auburn, WA – GSA Regional: 1st Floor Real Estate

Property	**Response**	**Pre-Retrofit** Total Responses	**Pre-Retrofit** Response Percentage	**Post-Retrofit** Total Responses	**Post-Retrofit** Response Percentage
COMMON SPACE	Yes	3	30%	8	67%
PUBLIC IMAGE	No	7	70%	4	33%
GLARE	Yes	0	0%	3	27%
GLARE	No	12	100%	8	73%
AMOUNT LIGHT[1]	Too Bright	1	8%	2	15%
AMOUNT LIGHT[1]	Just Right	5	38%	10	77%
AMOUNT LIGHT[1]	Too Dim	7	54% [2]	1	8%

[1] Statistical Analysis Performed

[2] Statistical Significance Level 95%

Dallas, TX – GSA Cabell: 7th Floor GSA lobby and adjoining hallways

Property	Response	Pre-Retrofit Total Responses	Pre-Retrofit Response Percentage	Post-Retrofit Total Responses	Post-Retrofit Response Percentage
COMMON SPACE	Yes	4	100%		
PUBLIC IMAGE	No	0	0%		
GLARE	Yes	0	0%		
GLARE	No	4	100%		
AMOUNT LIGHT[1]	Too Bright	0	0%		
AMOUNT LIGHT[1]	Just Right	3	75%		
AMOUNT LIGHT[1]	Too Dim	1	25% [2]		

[1] Statistical Analysis Performed

[2] Statistical Significance Level 90%

Dallas, TX – Project Management-Supervisors (near Jackson street windows)

Property	Response	Pre-Retrofit Total Responses	Pre-Retrofit Response Percentage	Post-Retrofit Total Responses	Post-Retrofit Response Percentage
COMMON SPACE	Yes	17	81%	6	86%
PUBLIC IMAGE	No	4	19%	1	14%
GLARE	Yes	3	14%	0	0%
GLARE	No	18	86%	7	100%
AMOUNT LIGHT[1]	Too Bright	1	5%	0	0%
AMOUNT LIGHT[1]	Just Right	15	71%	6	86%
AMOUNT LIGHT[1]	Too Dim	5	24% [2]	1	14% [2]

[1] Statistical Analysis Performed

[2] Statistical Significance Level 90%

Dallas, TX – GSA Cabell: 7th Floor GSA area(s) behind the GSA lobby = Property MGNT/Contracting No windows

Property	Response	Pre-Retrofit Total Responses	Pre-Retrofit Response Percentage	Post-Retrofit Total Responses	Post-Retrofit Response Percentage
COMMON SPACE	Yes	17	81%	6	86%
PUBLIC IMAGE	No	4	19%	1	14%
GLARE	Yes	3	14%	0	0%
GLARE	No	18	86%	6	100%
AMOUNT LIGHT[1]	Too Bright	1	5%	0	0%
AMOUNT LIGHT[1]	Just Right	15	71%	5	71%
AMOUNT LIGHT[1]	Too Dim	5	24% [2]	2	29% [2]

[1] Statistical Analysis Performed

[2] Statistical Significance Level 90%

Philadelphia, PA – GSA VA: Daycare Center

Property	Response	Pre-Retrofit Total Responses	Pre-Retrofit Response Percentage	Post-Retrofit Total Responses	Post-Retrofit Response Percentage
COMMON SPACE	Yes	18	100%	18	90%
PUBLIC IMAGE	No	0	0%	2	10%
GLARE	Yes	3.5	18%	1	5%
GLARE	No	16.5	83%	20	95%
AMOUNT LIGHT[1]	Too Bright	1	5%	0	0%
AMOUNT LIGHT[1]	Just Right	16	80%	19	86%
AMOUNT LIGHT[1]	Too Dim	3	15%	3	14% [2]

[1] Statistical Analysis Performed

[2] Statistical Significance Level 90%

Installer Survey Responses

Technologies installed	Philadelphia	Auburn	Dallas
Lunera Lamp			
Was it clear from the product or package how or where the product was to be installed?	Yes		Yes
Were instructions needed to complete the installation? If so, were they complete and effective?	No		Yes
Were there any potential safety issues identified with this lamp or the process for installing it? Please describe.	No		No
Was there any difference in time or effort involved in installing this new LED lamp compared to the standard CFL replacement lamp? Please describe.	No		No
Do you see anything about this product or its installation that would affect future maintenance costs or process? Please describe.	No		No
Anything else you would like to note about this product or the process for installing it?	No		Easy Install
NEXT Linear Tube			
Was it clear from the product or package how or where the product was to be installed?	Yes	Yes	Yes
Were instructions needed to complete the installation? If so, were they complete and effective?	Yes	Yes, wish they would have explained better lamps were polarity sensitive	Yes
Were there any potential safety issues identified with this tube/driver product or the process for installing it? Please describe.	No	No	No
Was there any difference in time or effort involved in installing this new LED tube/driver product compared to the standard Fluorescent lamp/ballast replacement? Please describe.	No	No, installed same way as regular ballast and lamp change (Besides polarity)	No
Do you see anything about this product or its installation that would affect future maintenance costs or process? Please describe.	No	No, installed same way as regular ballast and lamp change (Besides polarity)	No
Anything else you would like to note about this product or the process for installing it?	No	Just making sure both lamps are facing same way and that the "+" positive side of lamps are installed on the side where the blue wires come out of tombstones.	No
Cree			
Was it clear from the product or package how or where the product was to be installed?	Yes	Yes	Yes
Were instructions needed to complete the installation? If so, were they complete and effective?	Yes	Yes	Yes
Were there any potential safety issues identified with this system or the process for replacing it? Please describe.	No	Yes, eye protection recommended because you have to drill screws in to metal top of troffer to hold lamps in place	No
Was there any difference in time or effort involved in installing this LED fixture retrofit system compared to the standard Fluorescent lamp/ballast or complete fixture replacement? Please describe.	Yes, Had to take "runny" thing out of fixture to make work	Yes, more time consuming. Need drill with 1/4" nut driver bit to installed brackets that hold lamps in fixture.	No
Do you see anything about this product or its installation that would affect future maintenance costs or process? Please describe.	No	Yes, replacing lamps might be difficult because of plastic clip that holds in the lamp. Brackets might break.	No
Anything else you would like to note about this product or the process for installing it?	I would not use in fixtures that LEDs you can see threw	Less time making up wires because driver has quick connectors that clip in to lamp. But more time consuming installing with screwing in brackets	No

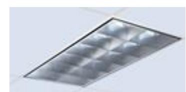
B. EVALUATION SITE FIXTURE SURVEY

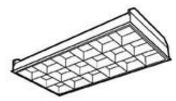
The following site survey was used to identify sites with appropriate facility lighting for the technology evaluations:

Does your facility have significant 2X4 ceiling lighting fixtures? ___YES ___NO

If, YES, please indicate the approximate percentage (%) of each of the 3 major types throughout the facility.

_____% - 2x4 lensed 

_____% - 2x4 (12 cell) parabolic (2 rows of cells) 

_____% - 2x4 (18 cell) parabolic (3 rows of cells) 

_____% - 1X4 or 2x4 ceiling mounted lensed 

_____% - open louver (older)  

_____% - other

Does your facility have significant recessed ceiling lighting fixtures (can lights)? ___YES ___NO

If, YES, please indicate the approximate percentage (%) of each of the 3 major types throughout the facility.

_____% - open 

_____% - lensed 

_____% - louvered  

_____% - Other

C. COSTING ASSUMPTIONS FOR ECONOMIC ANALYSIS

System Description	Freq. (Years)	Crew	Unit of Measure	Labor Hours	Bare Costs				Total In-House	Total w/O&P
					Material	Labor	Equipment	Total		
Replace CFL Ballast	10	1 Elec	Ea.							
Remove indoor fluor., ballast				0.333		$ 18.22		$ 18.22	$ 22.55	$ 27.29
CFL, electronic ballast,				0.667	$ 20.00	$ 36.48		$ 56.48	$ 67.17	$ 79.65
Test fixture				0.018		$ 0.98		$ 0.98	$ 1.22	$ 1.47
Total				**1.018**	**$ 20.00**	**$ 55.68**		**$ 75.68**	**$ 90.94**	**$ 108.42**
Replace CFL (1 lamp), 26W	10	1 Elec	Ea.							
Remove lamp in fixture				0.078		$ 4.27		$ 4.27	$ 5.28	$ 6.39
1x CFL				0.232	$ 4.50	$ 12.69		$ 17.19	$ 20.66	$ 24.64
Total				**0.31**	**$ 4.50**	**$ 16.96**		**$ 21.46**	**$ 25.94**	**$ 31.03**
Lunera "Helen" Lamp	10	1 Elec	Ea.							
Remove lamp in fixture				0.078		$ 4.27		$ 4.27	$ 5.28	$ 6.39
Lunera "Helen Lamp"				0.232	$ 22.00	$ 12.69		$ 34.69	$ 39.91	$ 46.51
Total				**0.31**	**$ 22.00**	**$ 16.96**		**$ 38.96**	**$ 45.19**	**$ 52.90**

D. REFERENCES

If there have been previously published studies that have evaluated the technology, provide them as references, using the following format: Author (Date), Title. Edition, Place: Publisher, Website (if available)

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E. GLOSSARY

Term	Definition
Ballast	A device that regulates the current and voltage supplied to a gaseous discharge lamp or lamps (*e.g.*, a fluorescent lamp).
Daylight Harvesting	A control strategy that reduces electric light levels in the presence of available daylight, "harvesting" the daylight to save electrical lighting energy.
Dimmable Ballast	A ballast that responds to external control signals by adjusting current flowing through the lamp(s), raising and lowering light output.
Life-Cycle Cost (LCC)	The total discounted dollar costs of owning, operating, maintaining, and disposing of a building or its system over the Study Period (see Life-Cycle Cost Analysis).
Life-Cycle Cost Analysis (LCCA)	A method of economic evaluation that sums discounted dollar costs of initial investment (less Resale, Retention, or Salvage Value), replacements, operations (including energy and water usage), and maintenance and repair of a building or building system over the Study Period (see Life-Cycle Cost). Also, as used in this program, LCCA is a general approach to economic evaluation encompassing several related economic evaluation measures, including Life-Cycle Cost (LCC), Net Benefits (NB) or Net Savings (NS), Savings-to-Investment Ratio (SIR), and Adjusted Internal Rate of Return (AIRR), all of which take into account long-term dollar impacts of a project.
Savings-to-Investment Ratio (SIR)	A ratio computed from a numerator of discounted energy, water savings, or both, plus (less) savings (increases) in Nonfuel O&M Costs, and a denominator of increased Investment Costs plus (less) increases (decreased) Replacement Costs, net of Residual Value (all in present-value terms), for an Alternative Building System as compared with a Base Case.
Simple Payback (SPB)	A measure of the length of time required for the cumulative savings from a project to recover the Investment Cost and other accrued costs, without taking into account the Time Value of Money.
Discounted Payback (DPB)	The time required for the cumulative savings from an investment to pay back the total Investment Costs, taking into account the Time Value of Money.
Adjusted Internal Rate of Return (AIRR)	The annual yield from a project over the Study Period, taking into account investment of interim amounts.