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Next Generation Luminaire (NGL) Downlight Demonstration Project:

St. Anthony Hospital

May 2015

Prepared for:

Commercial Building Integration
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Next Generation Luminaire (NGL) Downlight Demonstration Project: St. Anthony Hospital, Gig Harbor, WA

Final Report prepared in support of the Commercial Building Integration
NGL Downlight Demonstration Project

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May 2015

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Preface

NGL Downlight Demonstration Project

As of 2012, 700 million downlight luminaires were installed in residential and commercial buildings; light-emitting diode (LED) luminaires represent less than 1% of this installed base according to estimates from the U.S. Department of Energy (DOE). Downlight luminaires using conventional incandescent, halogen, and compact fluorescent lamps have lower efficacies and shorter expected lifetimes than comparable LED systems; however, the lower initial cost of conventional technology combined with the public's uncertainties with new LED technology have limited widespread adoption of LED downlight luminaires. **If LED downlight luminaires were wholly adopted, about 278 trillion British thermal units (tBtu) could be saved annually, equating to an annual energy cost savings of $2.6 billion.**[1]

The U.S. DOE conducts demonstration projects documenting the performance of LED luminaires relative to conventional technologies to increase market adoption of energy-efficient LED systems and to stimulate ongoing product development. These demonstration projects evaluate various aspects of lighting design, purchase, installation, and operation, and they assess the impacts LED technology might have on building owners and users. DOE collaborates with commercial building owners in these demonstrations and evaluates projects based on the general criteria of saving energy, matching or improving lighting quality, and offering cost-effective solutions relative to standard competing light sources.

This report is the third in a series of demonstrations that focus on documenting the implementation of LED downlight luminaires. For these projects, DOE sought projects where the host organization implemented products available from manufacturers who had participated in the DOE Next Generation Luminaires (NGL) competitions. Preference for host organizations was given to members of the DOE's Better Buildings Alliance (BBA), which promotes energy efficiency in U.S. commercial buildings through collaboration with building owners, operators, and managers.

The prior reports featured NGL-recognized LED downlight luminaires in projects that were either new construction (Hilton Columbus Downtown) or a major renovation (Alston & Bird, LLC). But purchasing and installing new luminaires is not always feasible for existing buildings. For this report, the DOE evaluated the use of LED replacement lamps in the existing CFL downlights at St. Anthony Hospital in Gig Harbor, WA.

Acknowledgements

Jason Henricksen, Maintenance Engineer in the Facilities Engineering Department at St. Anthony Hospital, was very generous with his time and with information regarding the hospital and the lighting upgrades taking place. He coordinated and hosted several site visits to the hospital by DOE/Pacific Northwest National Laboratory (PNNL) staff. This project would not have been possible without Mr. Henricksen's full support.

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[1] DOE, *Adoption of Light-Emitting Diodes in Common Lighting Applications*, May 2013, (http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf).

Executive Summary

In U.S. hospitals, lighting comprises 42% of the electricity used. While 90% of U.S. hospitals use CFLs to light 11% of their total building area, only 40% currently use LEDs and those LEDs are only used to light about 2% of the building area.[2] Thus, upgrading CFLs to LEDs represents a significant energy saving opportunity for the nation. When St. Anthony Hospital in Gig Harbor, Washington opened in 2009, CFL luminaires were considered to be state-of-the-art for energy efficient lighting in downlight applications. In 2013, the hospital began investigating energy and cost saving opportunities throughout their facilities and explored LED alternatives for the large number of installed CFL downlights.

After evaluating several options, the facility staff decided to replace their 1,262 CFLs with Lunera® Helen lamps. These LED replacement lamps fit into existing CFL sockets, run on the CFL's electronic ballasts, and are compatible with non-lensed and non-dimming downlights. The 13 W LED product is designed to directly replace a 26 or 32 W CFL, reducing energy by at least 50%. The full installation was completed in November 2014, following small-scale mock-up installations in different areas of the hospital which were evaluated for apparent light output and visual appearance. The hospital's calculated return on investment (ROI) for the retrofit was 26.3%.

PNNL staff visited St. Anthony Hospital on December 10, 2014 to document lighting conditions in a surgery waiting area and a patient changing room area. In the waiting area, the same data were collected with CFLs installed to allow a direct comparison with the LED performance. The 13 W LED replacement lamps produced horizontal illuminance values that exceeded those of the incumbent 32 W CFLs. The success of the LED system relative to the CFL system depended in part on the directional light distribution from the horizontal LED lamp which minimized the loss from the downlight optics.

Although the overall light levels increased with the LED system, the LED replacement lamps changed the distribution of light in the space (Figure ES-1). When lamped with CFLs, the illuminance readings in the rows under the downlights and the row between the downlights were relatively similar. However, when lamped with LEDs, the light levels taken in the rows under the downlights were higher than those in the row between the downlights. This suggested that the LEDs produced a more focused distribution than the original CFL downlights. In this application, the change does not cause any concerns because the overall light levels are above recommended values in all cases and the max:min ratios are within guidelines. But in applications with lower ceilings and/or greater spacing between fixtures, the more focused distribution with the LED replacement lamps could create non-uniform patterns of light with dark areas between the fixtures.

[2] EIA, *Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007*, August 2012, (http://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm).

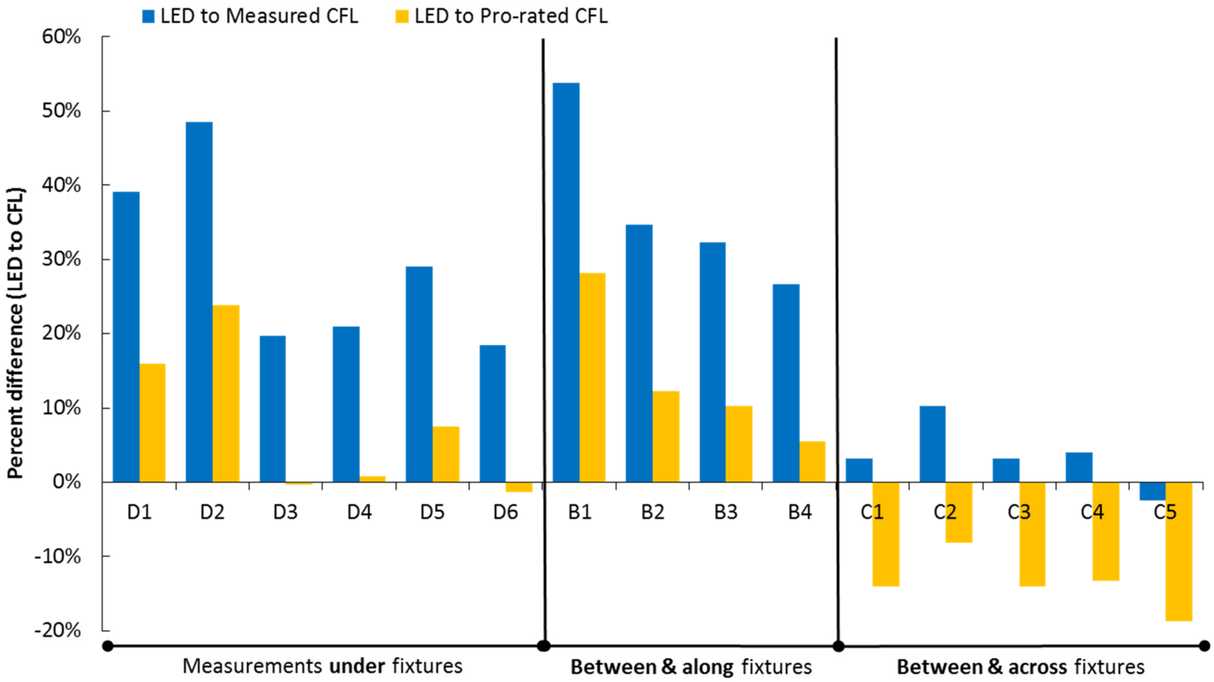

Figure ES-1. Percent difference in LED to CFL horizontal illuminance per measurement point: the blue bar shows the difference in LED to measured CFL; the yellow bar shows the difference in LED to pro-rated CFL (CFL illuminance values were increased by 20% to simulate output from new CFL lamps). The data were grouped by measurement location, with the measurements directly under the fixtures on the left (D1-6), those along the downlight row but between the fixtures in the middle (B1-4), and those between the rows of fixtures (across) on the right (C1-5). Points C1-C5 show the relative drop in light level between the rows of fixtures for the LED replacement lamp measurements.

The color quality of the LEDs was more consistent than the CFLs, with less variance in correlated color temperature (CCT), and the R_9 index (a metric for evaluating the rendering of a saturated red color) was higher for the LEDs than for the CFLs. Additionally, electrical measurements were made on two new LEDs and a sample of the hospital's incumbent CFLs. The power draw of both was within manufacturer ratings and the total harmonic distortion (THD) for the CFLs was 5.8% compared with 18.4% for the LEDs, both meeting ENERGY STAR and DesignLights Consortium (DLC) standards. Although THD as a percentage increased, the LED retrofit reduced the overall power on the circuit.

Table ES-1. Analysis for St. Anthony Hospital comparing the LED installation with the incumbent CFLs. The total annual energy use (kWh) and annual energy cost for the LED system was 59% less than the CFLs. The rated life shown for the CFL lamps is for a 3-hour operating cycle; for the 15-hour cycle typical in the hospital, actual life would be longer.

	Lamp Quantity	Rated Life (hours)	Power (Watts)	Operating hours per year	Total Annual Energy Use (kWh)	Annual energy cost
CFL: Sylvania Dulux T/E 32 W 4-pin	1,262	12,000	32	5,475	221,102	$ 17,555.53
LED: Lunera Helen Lamp	1,262	50,000	13	5,475	89,823	$ 7,131.93
				SAVINGS	**131,279**	**$ 10,423.60**

Although other LED solutions such as new luminaires or retrofit kits that replace the interior components of the luminaire provide some advantages over replacement lamps, the economic arguments for replacements lamps are attractive, mainly due to lower material and labor costs. At St. Anthony Hospital, the lamp replacements were performed by their in-house facilities staff and any additional electrical work, such as re-wiring or swapping out ballasts, was done by the staff's licensed in-house electrician. The total annual energy use and cost (Table ES-1) for the LEDs was 59% less than the CFLs. The estimated annual energy savings are 131,279 kWh and $10,424 for Gig Harbor's electricity rate of $0.0794/kWh. For areas of the country with higher electricity rates, the savings would be even greater.

Based on the information in Table ES-1 and the cost of the LED installation, simple payback will occur in 4.4 years. St. Anthony Hospital received a $13 rebate per lamp from its electric utility, which reduced the simple payback to less than three years. The specifics of the hospital's life-cycle cost analysis are confidential, but their calculated return on investment (ROI) was 26.3%, which included assumed operation and maintenance savings. **The bottom line for St. Anthony Hospital was that for a modest up-front investment, substantial energy savings were realized, with some improvements in lighting color quality and the hope for improved long-term lighting system performance leading to reduced ongoing maintenance costs.**

Roughly six months after the installation, the hospital remains very pleased with the overall results of the project. According to Jason Henricksen in the St. Anthony Hospital Facility Engineering Department, **"We are very happy with the results of the LED retrofits to our CFL downlights. The conversion was easy to implement. We hit a few snags that were easily addressed, and the energy savings were immediate. A rebate from our utility made an already attractive project even better. We easily see this project as a benefit for our facility."**

Acronyms and abbreviations

AFF	above finished floor
AHA	American Hospital Association
ANSI	American National Standards Institute
BBA	Better Buildings Alliance
Btu	British thermal unit
CBECS	Commercial Building Energy Consumption Survey
CBI	Commercial Building Integration
CCT	correlated color temperature
CFL	compact fluorescent lamp
CRI	color rendering index
DLC	DesignLights Consortium
DOE	U.S. Department of Energy
EIA	Energy Information Administration
fc	footcandle
IES	Illuminating Engineering Society
lm	lumen
lx	lux
K	Kelvin
kWh	kilowatt hour
LED	light-emitting diode
PNNL	Pacific Northwest National Laboratory
NGL	Next Generation Luminaires
ROI	return on investment
SPD	spectral power distribution
SSL	solid-state lighting
tBtu	trillion British thermal units
THD	total harmonic distortion
W	watt

Contents

1.0 Introduction

1.1 Overview

St. Anthony Hospital[3] opened in Gig Harbor, Washington in 2009. The hospital provides state-of-the-art medical care to patients, including emergency services, outpatient surgery, cancer care, pharmaceutical services, and other care options. There are currently 80 beds in the hospital, with room for an additional 32 on the unfinished top (5th) floor. While linear fluorescent luminaires are the primary source of lighting for the ground floor and labs, downlights originally lamped with compact fluorescent lamps (CFL) provide direct lighting in the patient rooms, lobbies, and bathrooms (Figure 1).

In 2013, hospital facilities staff initiated an effort to identify energy and maintenance cost savings opportunities for the 1,262 CFL downlights, most of which operate over 5,400 hours per year. Given the downlight luminaires were less than five years old, the hospital chose not to consider replacing them with new LED luminaires and instead investigated a number of upgrade options. Ultimately, an LED product designed as a direct replacement lamp for the incumbent 32 W CFLs was selected: the Lunera® Helen lamp. This option offered attractive economics and ease of installation, since it required no changes to the fixture wiring. The 13 W Helen lamp fits directly into the four-pin CFL socket and operates on the existing CFL electronic ballasts. The conversion of the CFL downlights to LED was completed in 2014, and the DOE evaluated the performance of the converted lighting system in November 2014. This report summarizes that evaluation.

Figure 1. Pendant globe luminaires are lamped with vertically-oriented Lunera® Helen lamps. The diffuse, even light is a characteristic of both the vertical lamp and the luminaire itself. Photo credit: PNNL.

1.2 Hospital lighting

According to the American Hospital Association (AHA), in 2012 there were 5,723 hospitals in the U.S. with over 920,000 staffed beds and at least 36 million annual admissions.[4] The total hospital footprint in the U.S. amounts to 1.96 billion ft^2. The 2007 Commercial Building Energy Consumption Survey (CBECS) showed major fuels

[3] St. Anthony Hospital homepage: http://www.chifranciscan.org/St-Anthony-Hospital/.

[4] American Hospital Association, *Fast Facts on US Hospitals*, 2012, (http://www.aha.org/research/rc/stat-studies/fast-facts.shtml).

(including electricity, natural gas, fuel oil, and district heating) consumed by large hospitals (defined as greater than 200,000 ft^2) amounted to 458 trillion Btu, which was 5.5% of the aggregate delivered energy used by the commercial sector.[5] Of the energy consumed, 194 trillion Btu went towards electricity, representing 7% of the electricity used by all commercial and institutional buildings. The 2003 U.S. Energy Information Administration (EIA) study shows that lighting comprises 42% of the electricity used in hospitals, making lighting upgrades and retrofits a smart solution for energy conservation measures.[6] Also according to the EIA study, while 90% of U.S. hospitals use CFLs to light 11% of their total building area, only 40% currently use LEDs and those LEDs are only used to light about 2% of the building area. These numbers suggest that there is major energy savings potential in upgrading hospital lighting from CFL fixtures to LEDs, and they represent a significant energy saving opportunity for the nation.

1.3 Upgrading the downlights at St. Anthony Hospital

When St. Anthony Hospital first opened in 2009, CFL luminaires were considered to be state-of-the-art for energy efficient lighting in downlight applications; LED technology was relatively new and was just becoming widely available for downlighting. In 2013, the hospital began to investigate energy and cost saving opportunities throughout their facility, and as they considered LED options for other aspects of the hospital's interior and exterior lighting, the facility staff explored LED alternatives for the CFL downlights. The large number of CFL downlights provided an attractive target, in part because of the long operating hours that led to high energy and maintenance costs. In addition to providing energy and maintenance savings, the hospital's sustainability goals were met by using LED lamps which contain no mercury and thus have no special recycling or disposal requirements.

Figure 2. Lunera's Helen lamp – vertical (left) and horizontal (right). © Lunera.

After evaluating several options, the facility staff decided to replace their 1,262 CFLs (794 horizontal lamps and 468 vertical lamps) with Lunera® Helen lamps (Figure 2). These 2-pin or 4-pin LED replacement lamps fit into existing CFL sockets, run on the CFL electronic ballasts, and are compatible with non-lensed and non-dimming downlights. The 900 lumen 13 W product is designed to directly replace a 26 or 32 W CFL, reducing energy by at least 50%. Although there is some variation among ballast brands and series, the Helen lamp generally draws the same ballast power as the original CFL lamp. The lamp specifications are provided in Appendix A. The hospital selected 3,500 K LED replacement lamps, which matched the rated correlated color temperature (CCT) of the CFL lamps. Beginning in December 2013, the facilities department initiated small-scale mock-up

5 EIA, *Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007*, August 2012, (http://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm).

6 EIA, *Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007*, August 2012, (http://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm).

installations of the Helen lamp in different areas of the hospital and evaluated the results for apparent light output and visual appearance. Based on the mock-up evaluations, and the fact that no negative feedback was received from other hospital staff or guests, they proceeded with the full installation, which was completed in November 2014.

Figure 3. The CFL downlights in the restrooms were re-lamped with LED replacement lamps. The photos show the ground floor ladies' restroom after the LED conversion. Photo credit: PNNL.

St. Anthony Hospital usually follows a spot relamping strategy, replacing lamps on a one-for-one basis when they burn out. The original CFLs were Sylvania Dulux T/E 32 W 4-pin lamps (CF32DT/E IN 835) and some have been replaced with other manufacturers' lamps over time. Consequently, the existing CFL system had lamps from different manufacturers operating at various stages of life when they were replaced. The hospital installed LED replacement lamps in all non-dimmable downlights and globe-style pendant fixtures, such as those in the ground floor lobby (Figure 1) and the inside of the ladies' restrooms (Figure 3). Because the LED replacement lamps are not compatible with dimmable ballasts, CFLs remained in areas with dimming systems, such as the chapel and several conference rooms.

Out of over 1,200 installed LED lamps, 5 failed upon initial installation (less than 1% failure rate) and were replaced by the lamp manufacturer. In addition to the small number of initial LED lamp failures, some of the LED replacement lamps initially operated erratically, usually flashing on and off or flickering noticeably. In some cases, this was caused by an incompatibility between the LED lamp and the CFL ballast and in others, the downlight was found to be incorrectly wired. In response, the facility staff had all wiring problems corrected and replaced 25 of the existing CFL ballasts with newer model Philips Advance CFL ballasts. These steps resolved all issues in those luminaires.

2.0 Performance measurements

PNNL staff visited St. Anthony Hospital on December 10, 2014, to document lighting conditions in a surgery waiting area and a patient changing room area. Illuminance levels and color properties of the LED systems were measured in both locations. In the waiting area, the same data were collected with CFLs installed to allow a direct comparison with the LED performance. Results are summarized here and in further detail in Appendix B.

2.1 Surgery waiting area

According to the Illuminating Engineering Society's *Recommended Practice: Lighting for Hospitals and Health Care Facilities* (ANSI/IESNA RP-29-06), a pleasant environment in a hospital waiting room depends on a mixture of indirect lighting for glare control, direct downlighting, and daylighting. The waiting area outside of surgery at St. Anthony Hospital is a large waiting space with couches, tables, and a fireplace. It complies with the former recommendation with wallwash luminaires, downlights, and floor-to-ceiling windows along one wall. The downlights selected for measurements are Spectrum Lighting horizontal lamp CFL downlights with a 4.5" square aperture.

2.1.1 Methods

PNNL collected photometric measurements in the lobby area next to the information desk and elevators to characterize the light distribution of the downlights in an open space (10' ceiling). Six downlights were selected, configured in two rows of three downlights each, spaced 8' apart (center-to-center) between the rows and 6' apart along the rows. Fifteen measurements were taken within a rectangular grid of 5 points along and 3 across.[7] Measurements were taken after dark (at 7:00 PST on December 10, 2014) to eliminate daylight contribution. Window blinds were closed during the measurements to minimize spill light from exterior lighting. The horizontal illuminance measurements were taken at 30" above finished floor (AFF).

Measurements were first taken of the downlights lamped with the installed horizontal LED replacement lamps and then 6 lamps were removed and replaced with CFLs, allowing for at least 30 minutes of stabilization after the change. The CFLs were the same lamps that had been removed by the facilities staff at the time of the LED conversion; therefore, although their operating age was not known, they accurately represent previous lighting conditions at the hospital. Figure 8 and Figure 9 (Appendix B) show the percent difference in LED to CFL performance for each measurement point. On the assumption that the CFL lamps were very near the end of expected lamp life based on visual inspection, the CFL illuminance values were increased by 20% to approximate the light output from new lamps; this assures that the comparisons being made are between new lamp products in both cases. Color measurements were taken directly underneath each downlight at the aperture opening for both the LED and CFLs, with the meter held horizontally about 2" beneath the light source. The recorded color data are in Table 7 (Appendix B).

[7] Across and along designate the measurement direction in relation to the lamp orientation. The lamps were installed horizontally along the row of downlights; therefore measurements along the lamps were in the same row whereas those across the lamps were between rows.

2.1.2 Results

Horizontal illuminance values are tabulated in Table 1—the values ranged from 124 lux to 298 lux for the LEDs, and from 101 lux to 252 lux for the CFLs, with max:min ratios of 2.4 (LED) and 2.5 (CFL).[8] Overall, the LED light output ranged from 2% less to 54% more than the CFLs, with an average of 21% greater illuminance. The IES Handbook's (Table 27.2) recommend illuminance values for hospital patient/visitor lounges are 20, 40, and 80 lux (at the floor) depending on the age of the user (<25, 25 - 65, >65 years, respectively) with a uniformity target of 4:1. Both the LEDs and CFLs met the IES requirements, and any daylight in the space will only add to the light levels. When the CFL measured values were increased by 20% to account for likely lumen depreciation, the LEDs performed similarly to the CFLs, averaging 1% greater illuminance.

Table 1. Horizontal illuminance measurements: the "% Difference (LED to CFL)" column expresses the illuminance from the LED lamps as a percentage difference relative to the CFL illuminances, with positive values indicating an increase in illuminance under the LEDs. The "% Difference (LED to pro-rated CFL)" column compares the data from the LEDs with CFL measurements increased by 20% to account for likely lamp lumen depreciation in the testing lamps.

	LED (lx)	CFL (lx)	% Difference (LED to CFL)	Pro-rated CFL (lx)	% Difference (LED to pro-rated CFL)
Mean	199	164	+21%	197	+1%
Mean (downlight rows)	215	166	+30%	199	+8%
Mean (center row)	166	162	+3%	194	-14%
Max	298	252	+18%	302	-1%
Min	124	101	+22%	122	+2%
Max:Min	2.4	2.5	N/A	2.5	N/A
Range	175	151	+16%	181	-3%

Although the overall light levels were similar between the two systems, the LED replacement lamps changed the distribution of light in the space. When lamped with CFLs, the illuminance readings in the rows under the downlights and the row between the downlights were relatively similar—166 versus 162 lux on average. However, when lamped with LEDs, the light levels taken of the rows under the downlights were higher than those in the row between the downlights—215 versus 166 lux on average (highlighted in Table 1). The difference in illuminance distribution is indicated by the right portion of Figure 4, which shows the data for the measurement points between the luminaire rows. This suggested that the LEDs produced a more focused distribution than the original CFL downlights. In this application, the change does not cause any concerns because the overall light levels are above recommended values in all cases and the max:min ratios are within guidelines. **But in applications with lower ceilings and/or greater spacing between fixtures, the more focused distribution with the LED replacement lamps could create non-uniform patterns of light with dark areas between the fixtures.**

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8 There was additional light from globe fixtures (near the desk) and linear pendant fixtures (near the elevators) that PNNL staff was unable to switch off, which explained the increase in light levels in those areas. The contributions from those fixtures were assumed to be equal for LED and CFL measurements.

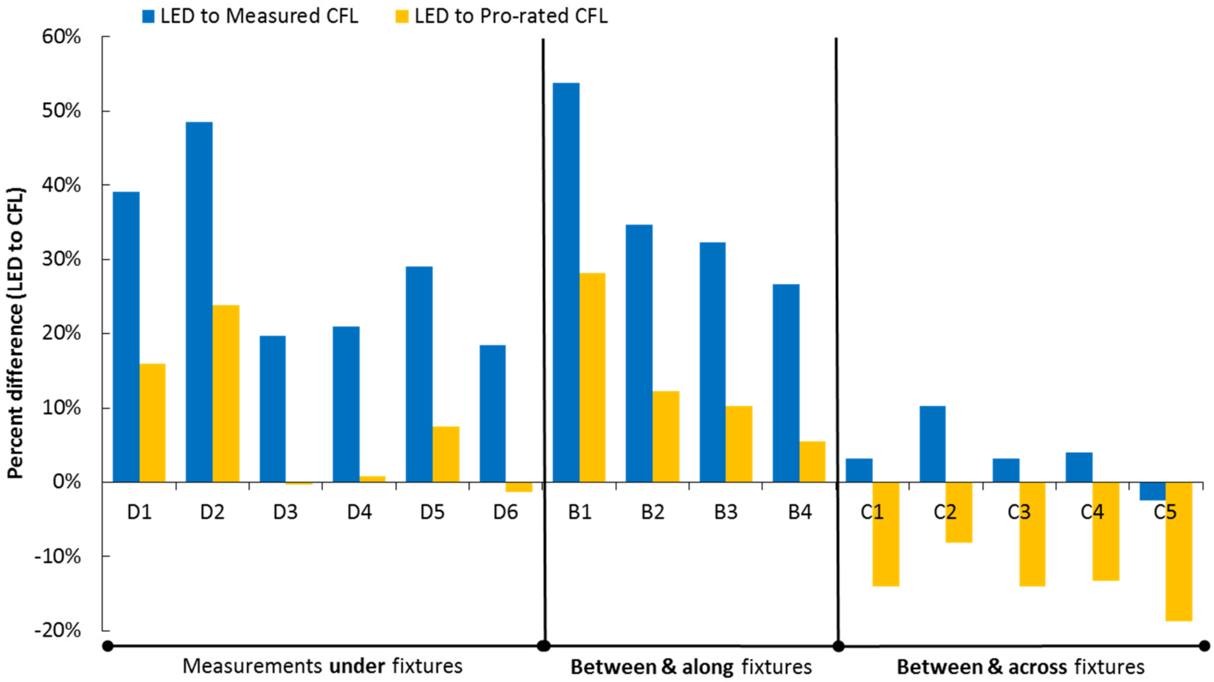

Figure 4. Percent difference in LED to CFL horizontal illuminance per measurement point: the blue bar shows the difference in LED to measured CFL; the yellow bar shows the difference in LED to pro-rated CFL (CFL illuminance values were increased by 20% to simulate output from new CFL lamps). The data were grouped by measurement location (diagramed in Figure 5 below), with the measurements directly under the fixtures on the left (D1-6), those along the downlight row but between the fixtures in the middle (B1-4), and those between the rows of fixtures (across) on the right (C1-5). Points C1-C5 show the relative drop in light level between the rows of fixtures for the LED replacement lamp measurements.

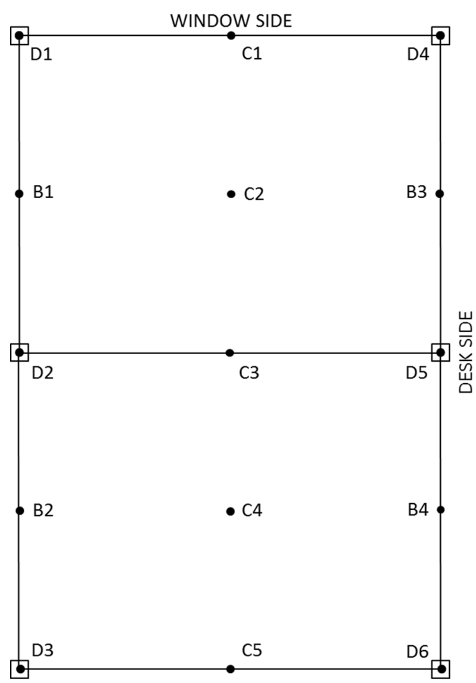

Figure 5. Diagram of measurement locations used in the bar chart above (Figure 4). Measurement points directly under the fixtures are designated D1-D6, those along the downlight row but between the fixtures B1-B4, and those between the rows of fixtures C1-C5.

Regarding color performance (Table 2), the IES Handbook recommends a color rendering index (CRI) of at least 82 for assessment and patient self-esteem. The CFLs and LEDs averaged 83 and 84, respectively. However, the LEDs had a higher R_9[9] value of 25 compared to 2 for the CFLs and thus render red colors better, which may be better for health assessments using skin tones. Representative spectra for both the LED and CFL lamps are depicted in Figure 6 showing the distinct difference in the sources. The LEDs, rated at 3,500 K, had an average measured CCT of 3,329 K with a range of only 24 K (within ANSI tolerances) whereas the CFLs averaged 3,121 K with a range of 109 K.[10,11] For D_{uv}, all lamps were within the ANSI standard, but the LEDs averaged -0.0020 whereas the CFLs averaged 0.0035, making the LEDs slightly pinker and the CFLs slightly greener.[12,13] Although preference is highly individualized, some studies have shown a preference for a negative D_{uv}, along with sources ranging from 3,500 - 5,500 K (but there are negligible differences between sources in that range).[14]

Table 2. Color data for the LED and CFL systems.

	CCT (K)		CRI		R_9		D_{uv}	
	LED	CFL	LED	CFL	LED	CFL	LED	CFL
Mean	3329	3121	84	83	23	2	-0.0020	0.0035
Max	3343	3176	84	83	24	3	-0.0014	0.0045
Min	3319	3067	83	82	22	1	-0.0024	0.0027
Range	24	109	1	1	2	2	0.0010	0.0018

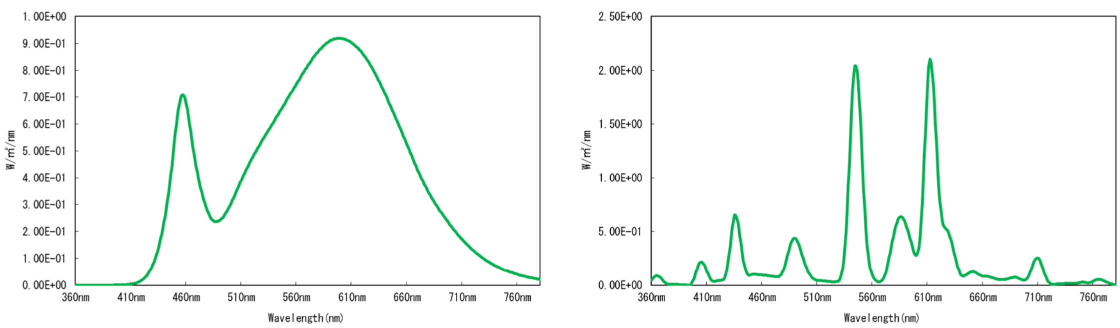

Figure 6. Representative SPD of the LED (left) and CFL (right). Note that the vertical axes have different scales.

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9 R_9 is a metric for evaluating the rendering of a saturated red color.

10 ANSI tolerances for a 3,500 K source are 3,465 +/- 245 K. The LEDs were all within this range.

11 NEMA-American National Standard Lighting Group, ANSI_ANSLG Standard C78.377-2011, *Specifications for the Chromaticity of Solid State Lighting Products*, 2011.

12 The distance from the blackbody locus on the CIE 1960 UCS chromaticity diagram (u, v). A positive value indicates the measured chromaticity is above the locus (appearing slightly green) and a negative value indicates the measured chromaticity is below the locus (appearing slightly pink).

13 D_{uv} target performance for 3,500 K sources is 0.0004 +/- 0.006.

14 Veitch et al., "Preferred Chromaticity of Color-Tunable LED Lighting", *Leukos*, 2013.

2.2 Diagnostic imaging changing rooms

Figure 7. Diagnostic imaging patient preparation area (left) and a typical changing room (right), shown after the LED conversion. Photo credit: PNNL.

The diagnostic imaging changing room area encompassed a hallway with two center-aligned downlights and three changing rooms, two on one side and one on the other (shown in the photo above on the left). Each changing room had one downlight roughly in the middle of the room and one recessed wall uplight on the far wall (shown in Figure 7, right). The luminaires are Spectrum Lighting© vertical downlights with a clear cone, round aperture. When lamped with LEDs, the vertical long Helen lamps were pulled as close to the opening of the fixture as possible to spread the light as wide as possible.

2.2.1 Methods

Photometric measurements were taken in the hallway (6'-5" wide by 16'-6" long) and the changing rooms (ranging from 7'-3" to 8'-5" wide by 4'-5" to 6'-7" long) in order to characterize the light distribution of the LEDs. Both areas had 9' ceilings. The measurement locations are diagramed in Figure 10 (Appendix B): rectangles represent the wall sconces (13" square) mounted at 6' AFF (at the base of the fixture); circles represent the downlights. The measurements were taken at 30" AFF. Light for task visibility was important at counter space and a storage area for hospital staff. Also, patients needed visibility for changing in the rooms. Vertical measurements were also taken along the walls in four places, marked by the red letters (A-D) in Figure 10 (Appendix B). Color was measured directly underneath each downlight at its aperture, with the meter held horizontally about 2" beneath the light source. The recorded data (CCT and CRI) are in Table 8 (Appendix B). Measurements were not taken for the luminaires lamped with CFLs.

2.2.2 Results

Horizontal illuminance values (summarized in Table 3) ranged from 103 lux to 185 lux, with a uniformity ratio (maximum to minimum) of 1.4 or 1.8, depending on the space. In particular, illuminances on the changing room benches and in the middle of the rooms (at task area) ranged from 133 to 184 lux. The IES Handbook recommends for general patient rooms 25, 50, and 100 lux at the floor for different ages (<25, 25 to 65, >65 years, respectively) and a uniformity ratio no greater than 2:1. These illuminances were met or exceeded by the LEDs, and uniformity ratios reduced (i.e., became more uniform).

Table 3. Horizontal illuminance data (lux). The mean value reported does not represent an overall average illuminance for the area; it is the mean of the data points measured. Those data points were selected to characterize the overall distribution and uniformity of light.

	Hallway (lx)	Changing rooms (lx)	Under fixtures (lx)	Between fixtures (lx)
Mean	155	142	157	143
Max	185	184	184	185
Min	129	103	136	103
Max:Min	1.4	1.8	1.4	1.8
Range	56	81	48	82

Vertical illuminance measurements are shown in Table 4. These measurements show increased illuminance on the wall near the ceiling relative to the illuminance lower on the wall. Therefore, there was less visible scallop pattern on the wall so the wall appeared brighter and the space was not cave-like. Some lighting retrofits can alter the luminaire light distribution, concentrating the light in a pool on the floor below it. The cone of light produced may have a sharp cutoff that creates a pronounced scallop pattern and produces very dark upper walls. The measurements here show the retrofit LED lamps provided increased high angle light for the space.

Table 4. Vertical illuminance measurements (lux).

Measurement height	Hallway (lx)	Entrance (lx)	Measurement height	Room 3 (lx)	Room 2 (lx)
8' AFF	34	26	**8' AFF**	85	53
6' AFF	78	29	**5' AFF**	144	132
4' AFF	95	53			
2' AFF	79	60			
Ratio of 2':8'	2.4	2.3	**Ratio of 5':8'**	1.7	2.5

The color performance (Table 5) met all requirements discussed earlier for the waiting area. For all 10 fixtures, the CCT averaged 3,433 K and ranged 62 K (from 3,396 K to 3,458 K); the CRI averaged 84 with a range of 1; R_9 averaged 25 with a range from 23 to 28; and D_{uv} averaged -0.0020 and ranged from -0.0026 to -0.0013.

Table 5. Color data for LEDs – meter held no more than 2” from light source.

	CCT (K)	CRI	R_9	D_{uv}
Mean	3433	84	25	-0.0020
Max	3458	85	28	-0.0013
Min	3396	84	23	-0.0026
Range	62	1	5	0.0013

2.3 Summary of measurements

In the surgery waiting area the 13 W LED replacement lamps produced horizontal illuminance values that exceeded those of the incumbent 32 W CFLs. This result is surprising, given that the LED replacement lamps are rated for 900 lumens compared to 2,330 lumens for the CFLs, and that the manufacturer of the LED lamps claims comparable performance to 26 W CFLs, but not to higher wattage lamps. The success of the LED system relative to the CFL system depended on the low efficiency (only 26%) of the installed CFL downlight, and in part on the directional light distribution from the horizontal LED lamp which minimized the loss from the downlight optics. While the narrower distribution of light from the LED lamps was not a concern in this application, in other applications with different ceiling heights or luminaire spacing the possibility of non-uniform illuminances and dark upper walls should be carefully assessed. The color consistency of the LEDs was tighter than the CFLs (less variance in CCT), the R_9 was superior, and the D_{uv} was (acceptably) negative instead of positive, which is often preferable.

To document the electrical characteristics of the lamps, electrical measurements were conducted on 2 new Helen lamps and on 6 CFL lamps provided by St. Anthony Hospital for the surgery waiting area measurements. The testing was done with the lamps operated by a ballast similar to that used in the hospital and in the same orientation as the downlights in the surgery lobby (horizontally). The power draw of both the LEDs and CFLs were within manufacturer ratings. The total harmonic distortion (THD) for the CFLs was 5.8% compared with 18.4% for the LEDs, both meeting ENERGY STAR and DesignLights Consortium (DLC) standards (less than 20% THD). Although THD increased, the LED retrofit dropped the overall power on the circuit, reducing concern for the majority of applications.

Not all LED retrofits are alike

MGM Resorts relocated their IT department to a new three-story core-and-shell leased building in Las Vegas, NV in April 2014. Although MGM planned to use all LED lighting in the tenant spaces, the core hallway spaces had already been finished with CFL downlights. Instead of replacing the relatively new CFL luminaires, MGM decided to test Lunera® Helen lamps. In June 2014, the LED replacement lamps were installed in many of the CFL downlights. However, around 50% of the LED lamps visibly flickered after the installation, even though all of the existing ballasts were confirmed to be electronic and not dimmable.

Further investigation revealed that the internal fixture wiring connecting the ballast to the lamp sockets was unusual, including the means by which the emergency lighting circuit had been connected to some of the luminaires. Resolving this incompatibility would have required completely re-wiring the existing units, which would have greatly increased the initial cost of the installation and dramatically changed the economic justification for the conversion. As a result, the CFLs were subsequently re-installed, and Lunera developed a next generation Helen lamp with a new circuit design that is expected to address the issues encountered. MGM Resorts remains committed to SSL technology and is working to test this new generation product in their facilities.

3.0 Discussion of energy savings & economics

Although other LED solutions such as new luminaires or retrofit kits that replace the interior components of the luminaire provide some advantages over replacement lamps, the economic arguments for replacements lamps are attractive, mainly due to lower material and labor costs. At St. Anthony Hospital, the lamp replacements were performed by their in-house facilities staff and any additional electrical work, such as re-wiring or swapping out ballasts, was done by the staff's licensed in-house electrician. The large difference in material and labor costs for installing retrofit kits or new luminaires, along with the overall time required for implementation, were important factors in the hospital's decision to install LED replacement lamps.

The 1,262 LED replacement lamps installed at St. Anthony Hospital operate for long hours, with many parts of the facility operating nearly 24 hours per day. Overall, the hospital assumes 15 hours of operation per day for 365 days per year, for a total of 5,475 hours annually. Given the long operating hours of the LED replacement lamps, a wattage reduction of 60% should yield substantial energy savings. Furthermore, ongoing maintenance costs should be greatly reduced for the LED product because the expected life of 50,000 hours is much greater than typical CFL rated life.

The initial calculated cost for the installation was approximately $46,000, including both material and estimated labor costs. The total annual energy use and cost (Table 6) for the LEDs was 59% less than the CFLs, for a total of 59% savings. The estimated annual energy savings are 131,279 kWh and $10,424 for Gig Harbor's electricity rate of $0.0794/kWh. The national average commercial price of electricity to ultimate customers in October 2014 was approximately $0.1087/kWh.[15] For areas of the country with high electricity rates, the savings would be even greater.

Table 6. Analysis for St. Anthony Hospital comparing the LED installation with the incumbent CFLs. The total annual energy use (kWh) and annual energy cost for the LED system was 59% less than the CFLs. The rated life shown for the CFL lamps is for a 3-hour operating cycle; for the 15-hour cycle typical in the hospital, actual life would be longer.

	Lamp Quantity	Rated Life (hours)	Power (Watts)	Operating hours per year	Total Annual Energy Use (kWh)	Annual energy cost
CFL: Sylvania Dulux T/E 32 W 4-pin	1,262	12,000	32	5,475	221,102	$ 17,555.53
LED: Lunera Helen Lamp	1,262	50,000	13	5,475	89,823	$ 7,131.93
				SAVINGS	**131,279**	**$ 10,423.60**

Based on the information in Table 6 and the cost of the LED installation ($46,000), simple payback will occur in 4.4 years. The specifics of the hospital's life-cycle cost analysis are confidential, but their calculated return on investment (ROI) was 26.3%, which included assumed operation and maintenance savings and an assumed $10 rebate per lamp. St. Anthony Hospital actually received a $13 rebate per lamp from its electric utility, which reduced the simple payback to less than three years.

15 Available online at: http://www.eia.gov/cneaf/electricity/epm/chap5.pdf.

4.0 Conclusions

St. Anthony Hospital upgraded more than 1,200 CFL downlights by replacing the 32 W CFLs with 13 W LED replacement lamps. The conversion was easily implemented because the LED lamp fit directly into the four-pin CFL socket and operated on the existing non-dimming CFL electronic ballast. As a result of the conversion, the hospital is saving over $10,000 annually in energy costs. But in any lighting upgrade project, the benefits and drawbacks of retrofit lamp options must be weighed against those of luminaire conversion kits and of replacing the existing luminaires with new luminaires. Why did the LED lamp retrofit make sense for St. Anthony Hospital? Several factors specific to the St. Anthony facility affected the decision to use replacement lamps; they are described below.

- Because the CFL luminaires and ballasts were relatively new and in good condition replacing them with new luminaires was not a cost-effective option.
- The existing CFL ballasts were compatible with the LED retrofit lamps. A small number of the CFL luminaires had dimming ballasts and those luminaires were not converted.
- The incumbent downlight housing was not very efficient when used with omni-directional CFLs, so matching the illuminance levels was possible with a lower light output but directional LED lamp.
- There is little to no risk of the CFLs getting re-installed (snap-back) because the facility staff at the hospital have complete responsibility for the lighting. This can be a concern in other lamp retrofit projects.
- Because the lamp replacements could be completed by in-house facility staff and did not require a licensed electrician, installation labor costs were small, making the economics for the retrofit very attractive.
- The hospital's utility provided a rebate for the conversion that offset more than one-third of the initial costs and reduced the simple payback period to less than three years. Expected maintenance and operational savings due to the longer rated lamp life further strengthen the economics of the retrofit.

While the LED retrofit project at St. Anthony Hospital has been very successful, several concerns remain for the long-term success of the installation and for consideration by other facilities considering similar upgrades.

- The CFL ballasts that now operate the LED retrofit lamps will eventually fail. The ballasts had been operating for about five years before the retrofit, and in normal use will likely last another 5 to 7 years. At that time, the hospital will face further decisions regarding the downlights because replacing the 1,200+ ballasts may be costly or the CFL ballasts may no longer be available. Whether a new CFL ballast is installed or a dedicated driver for the LED lamps is selected, re-wiring of the luminaires seems likely which will result in higher labor costs than those of the initial lamp replacement described in this report. Under these circumstances, the installation of new LED luminaires may be economically attractive relative to ballast replacement, especially since the efficiency of LED luminaires is likely to increase while LED luminaire costs are expected to decrease.
- Like any new technology, the LED replacement lamps used in this project have unknown long-term performance. While the manufacturer's ratings and warranty are encouraging, only field experience from multiple installations can ultimately provide the type of comfort level that most lighting users have with conventional lamps. Very little data exists to evaluate long-term depreciation in light output and/or shifts in color quality for LED retrofit lamps in field installations.
- As reported in Figure 4, the LED replacement lamps changed the distribution of light from the downlight luminaires, reducing the spread of light and focusing the light downward more than the incumbent CFLs

did. In this application, because of the ceiling heights and luminaire spacings, this distribution change did not adversely affect the overall system performance, but in other applications the narrower distribution could create significant concerns. These concerns include possible non-uniform patterns of light across task areas and dark walls (or unusual shadow patterns on walls), which in some rooms can produce perceptions of a gloomy, cave-like environment. Any lighting retrofit project should be assessed not only based on the lumen equivalency of the retrofit product, but also based on the effects on lighting distribution and the corresponding quality of the lighting in the application.

Any lighting upgrade project poses trade-offs to the facility manager and end user, and concerns about first cost, long-term energy and maintenance effects, and impacts on lighting performance and lighting quality must all be addressed. The bottom line for St. Anthony Hospital was that for a modest up-front investment, substantial energy savings were realized, with some improvements in lighting color quality and the hope for improved long-term lighting system performance. Roughly six months after the installation, the hospital remains very pleased with the overall results of the project. According to Jason Henricksen in the St. Anthony Hospital Facility Engineering Department, **"We are very happy with the results of the LED retrofits to our CFL downlights. The conversion was easy to implement. We hit a few snags that were easily addressed, and the energy savings were immediate. A rebate from our utility made an already attractive project even better. We easily see this project as a benefit for our facility."**

Appendix A. Replacement lamp information

LUNERA HELEN LAMP

LED Replacement Lamps for
4-pin/2-pin CFL Downlights

LUNERA®

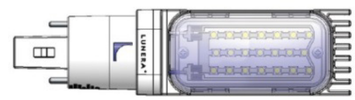
Description

The Helen Lamp from Lunera is a plug-and-play LED replacement for CFL downlights with 4-pin G24q-series (electronic ballast) and 2-pin G24d-series (magnetic ballast) sockets. Simply choose the configuration for Horizontal, Vertical or Vertical Long versions, plug it in like any CFL lamp, and enjoy the superior light quality and energy savings - no need to bypass the CFL ballast.

These beautiful lamps have a Color Rendering Index of 84 and deliver 900 lumens of usable light. The Helen Lamp is available in 2700K, 3000K, 3500K, and 4000K color temperatures.

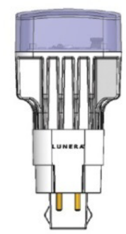
The long lifespan of the Helen Lamp is rated at 50,000 hours, 5x longer than CFLs, and is supported by a five year warranty.

The Helen Lamp offers 50%+ energy savings and is compatible with 26W, 32W, and 42W CFLs, making it easy to save even more energy.



Horizontal

Vertical
Long



Vertical
4-pin

Features

- Directly replaces 26W, 32W, and 42W CFLs (4-pin) or 26W CFLs (2-pin)
- Plug-and-Play installation
- Delivers 900 lumens of usable light
- 84 CRI
- CCT 2700K, 3000K, 3500K and 4000K
- 50,000 Life
- 5-Year Warranty

Ordering Information

Example: HN-V-G24Q-26W-2700-G2

Series	Version	Socket Type	Lamp Wattage Replaced	CCT	Generation
HN Helen Lamp	**V** Vertical **VL*** Vertical Long **H** Horizontal *VL available in 4-pin only	**G24Q** Recessed downlight with G24q series 4-Pin CFL socket **G24D** Recessed downlight with G24d series 2-Pin CFL socket	**26W** 26W, 32W, or 42W CFL	**2700** 2700 Kelvin **3000** 3500 Kelvin **3500** 3500 Kelvin **4000** 4000 Kelvin	**G2** 2nd Generation

PROJECT	CONTACT	MODEL NO.
REFERENCE NO.	QUANTITY	DATE

www.lunera.com **T (650) 241-3875** **F (650) 362-1987**

LUNERA HELEN LAMP

Product Specifications

Illumination

Color Temperatures	2700K, 3000K, 3500K, 4000K
Lumens (4000K@26W)	900 lm
CRI	84
Color Consistency	Lunera TruColor™ Proprietary Process
Lumen Maintenance (L70)	50,000+ hours life

Electrical System

Power Factor	> 90% (determined by installed ballast)
Total Harmonic Distortion	< 20% (determined by installed ballast)
Input Voltage	Driven by CFL Ballast
Power	13W
Lamp Wattage Replaced	26W (32W and 42W compatible)
Dimming	Yes, contact Lunera for details

Physical

Weight	0.25 lbs
Housing and Finish	Aluminum, Painted
Optics	Optical Acrylic Diffusion

Environment

Ambient Operating Temp	-4°F to 100°F (-20°C to 40°C)
Ambient Operating Humidity	20% to 85% RH, non-condensing
Max Heat Sink Temp	221°F (105°C)

Installation

Socket Type (electronic)	G24q series 4-Pin CFL socket
Socket Type (magnetic)	G24d series 2-Pin CFL socket

Certifications & Qualifications

UL	Approved
LM79	Pending
RoHS Compliant	Contains no lead or mercury

Warranty

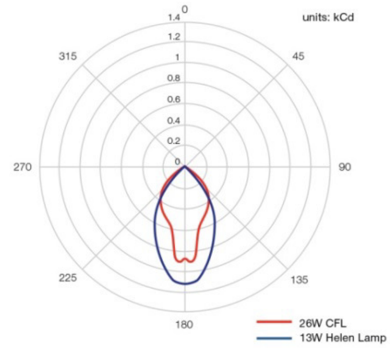
Warranty	5 years

Application Notes

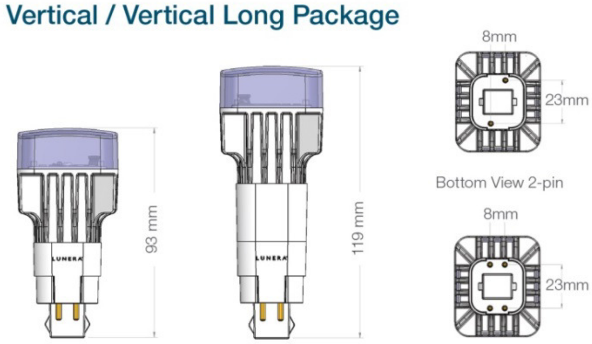
The Helen Lamp may be INCOMPATIBLE with some older ballast models and is not intended for use in lensed downlights. For applications containing dimming ballasts, plese contact Lunera for specific compatibility.

Photometry

The Helen Lamp vs. 26W CFL, compared in the same downlight fixture.

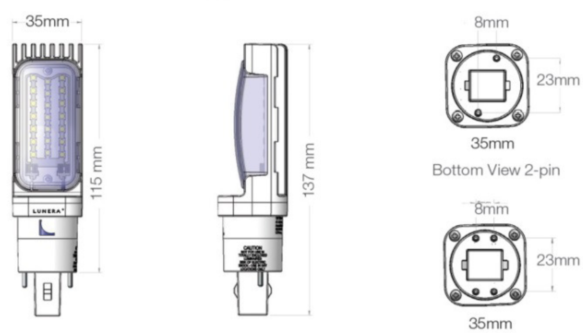


Vertical / Vertical Long Package



Front View　Front View Long　Bottom View 2-pin　Bottom View 4-pin

Horizontal Package



Front View　Side View　Bottom View 2-pin　Bottom View 4-pin

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LUNERA®

Appendix B. Performance measurements

Equipment used

Illuminance readings were measured using a Konica Minolta T-10A meter (serial number 207839, labeled Battelle ESD Metering Lab EM10605) with an attached standard receptor head (serial number 30011584). This meter has rated linearity of ±2%, ±1 digit, rated cosine response within 3%, and rated spectral response within 6% of the CIE spectral luminous efficiency function, V(λ).

Color measurements were made using a Konica Minolta illuminance spectrophotometer CL-500A (serial number 10002008). This meter has rated wavelength precision of ±0.3 nm and rated chromaticity accuracy in xy coordinates of ±0.0015.

Surgery waiting area: photometric performance

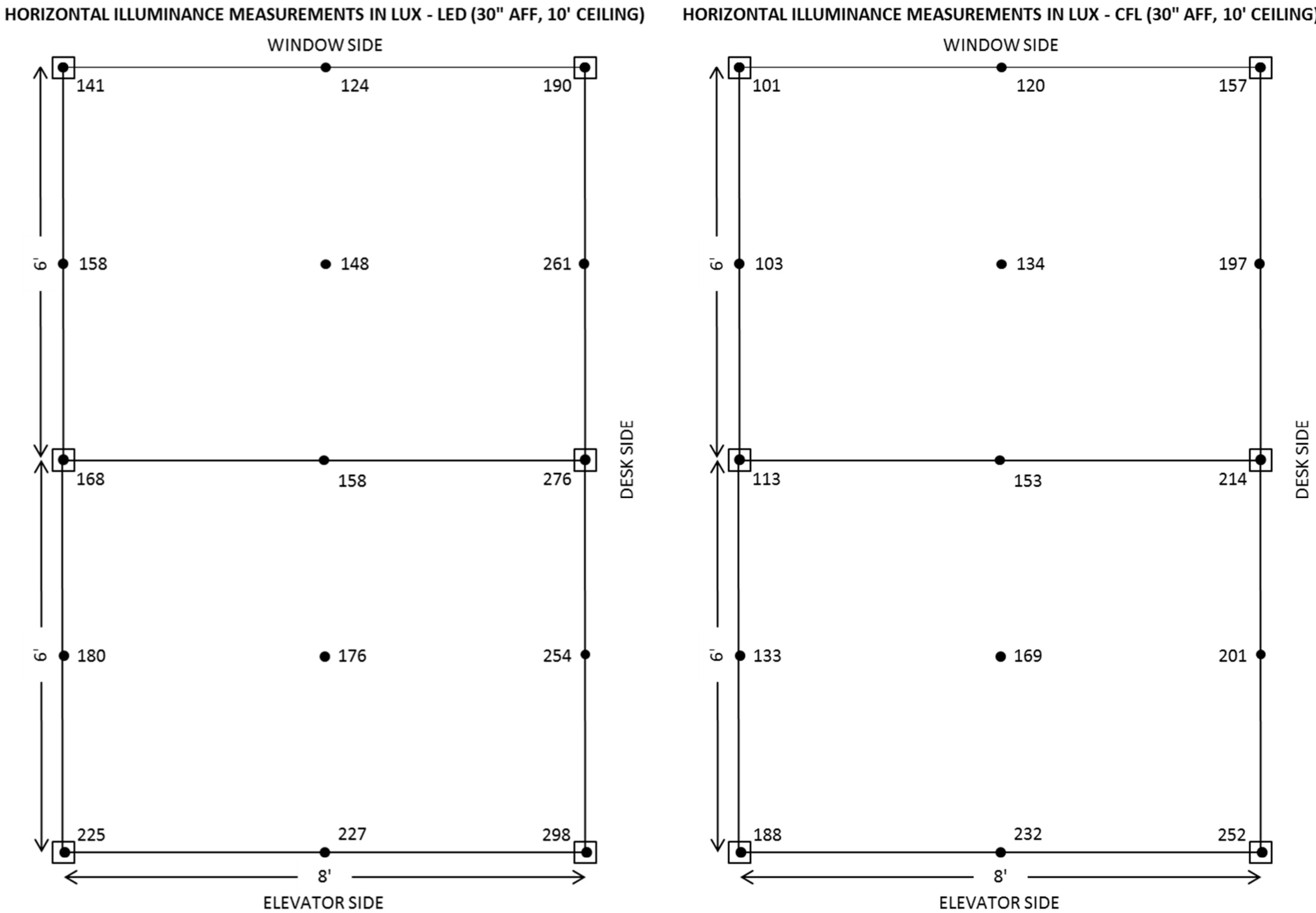

Figure 8. Horizontal illuminance measurements (recorded in lux) for the waiting area outside of surgery: downlights lamped with LEDs (left) compared with the incumbent CFLs (right). The dots indicate the measurement location. The squares indicate the location of the downlights.

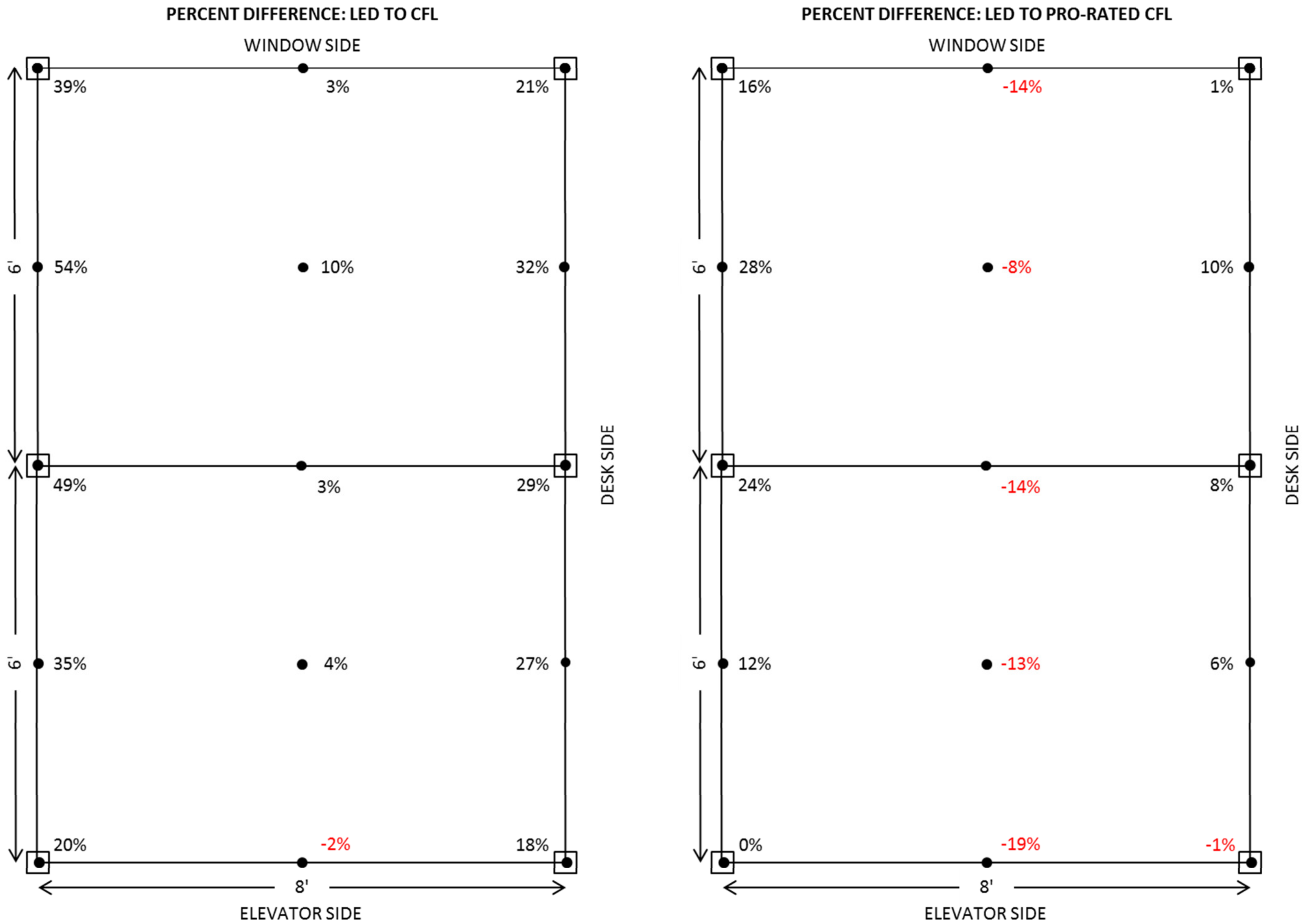

Figure 9. Percent difference in LED horizontal illuminance compared to the measured CFL (on the left) and the pro-rated CFL (on the right). The CFL illuminance values were increased by 20% to simulate new CFL lamp lumen output.

Surgery waiting area: color measurements

Table 7. Color data for the LED lamps compared with the CFLs: CCT, CRI, and D_{uv} were recorded.

	CCT		CRI		D_{uv}	
Measurement location	**LED**	**CFL**	**LED**	**CFL**	**LED**	**CFL**
Downlight	3326	3144	84	83	-0.0023	0.0034
Downlight	3336	3067	84	83	-0.0022	0.0045
Downlight	3320	3176	83	83	-0.0018	0.0030
Downlight	3334	3139	84	83	-0.0018	0.0036
Downlight	3319	3115	84	83	-0.0014	0.0027
Downlight	3328	3123	84	82	-0.0024	0.0037
Downlight	3343	3084	84	83	-0.0021	0.0036
Mean	**3329**	**3121**	**84**	**83**	**-0.0020**	**0.0035**
Max	**3343**	**3176**	**84**	**83**	**-0.0014**	**0.0045**
Min	**3319**	**3067**	**83**	**82**	**-0.0024**	**0.0027**
Range	**24**	**109**	**1**	**1**	**0.0010**	**0.0018**

Diagnostic imaging changing rooms: photometric performance

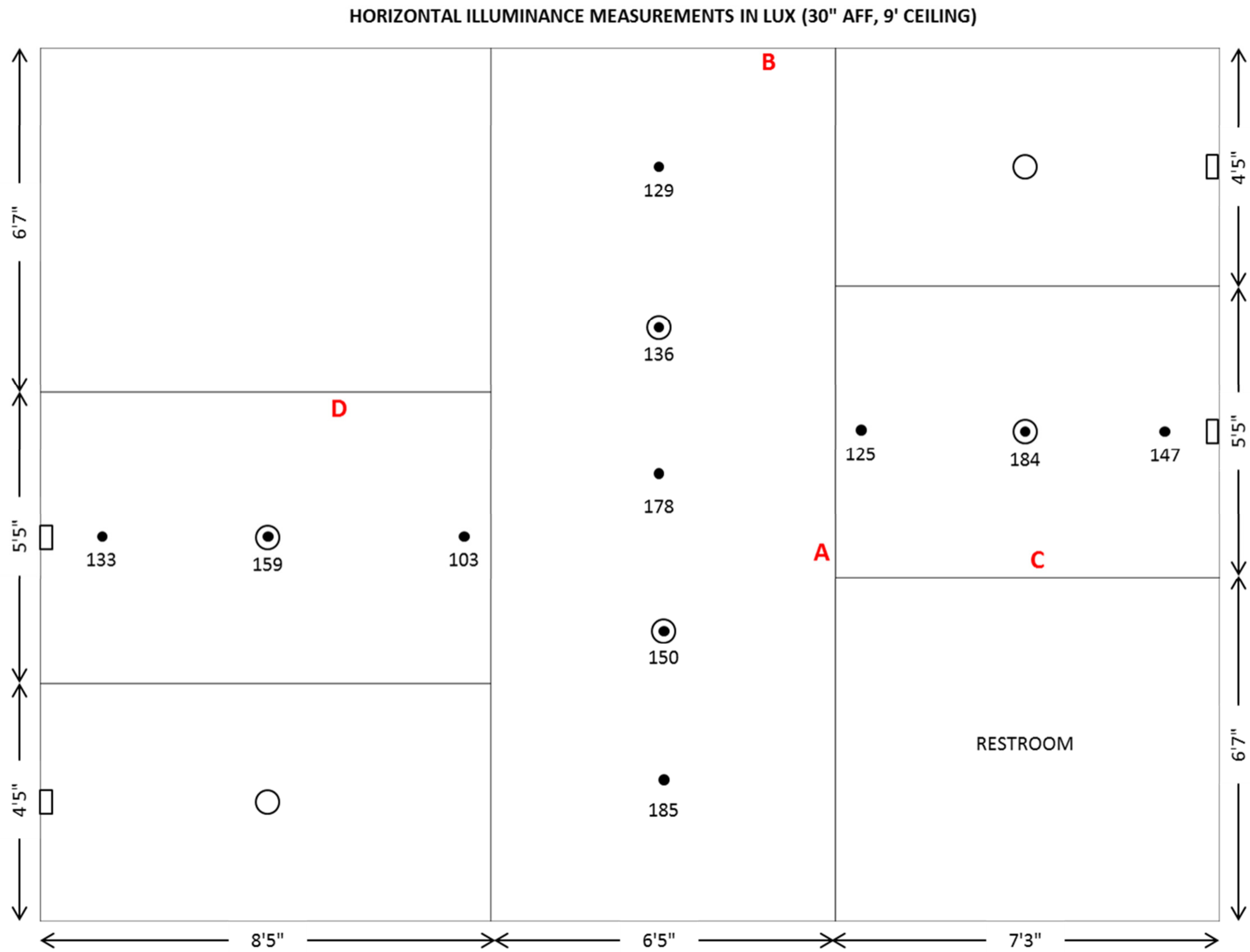

Figure 10. Photometric measurements: horizontal illuminance measurements (recorded in lux) were taken at 30" AFF. The rectangles represent the wall sconces (13" square) mounted at 6' AFF (at the base of the fixture). The circles represent the downlights, also lamped with Helen lamps. The red letters (A-D) indicate where vertical illuminance measurements were taken.

Diagnostic imaging changing rooms: color measurements

Table 8. Color data for the LED lamps: CCT, CRI, and D_{uv} were recorded.

Measurement location	CCT	CRI	D_{uv}
Hallway Downlight	3426.0	84.0	-0.0020
Hallway Downlight	3444.0	84.0	-0.0017
Room Downlight	3428.0	84.0	-0.0021
Room Downlight	3458.0	85.0	-0.0026
Room Downlight	3418.0	84.0	-0.0025
Room Downlight	3436.0	84.0	-0.0020
Room Wall Uplight	3396.0	84.0	-0.0013
Room Wall Uplight	3422.0	84.0	-0.0020
Room Wall Uplight	3455.0	84.0	-0.0020
Room Wall Uplight	3442.0	84.0	-0.0017
Mean	**3432.5**	**84.1**	**-0.0020**
Max	**3458.0**	**85.0**	**-0.0013**
Min	**3396.0**	**84.0**	**-0.0026**
Range	**62.0**	**1.0**	**0.0013**

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