DEPARTMENT OF VETERANS AFFAIRS

OFFICE OF CONSTRUCTION AND FACILITIES MANAGEMENT

LED & CONVENTIONAL LIGHTING SYSTEMS COMPARISON STUDY

MAY 1, 2014

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1 EXECUTIVE SUMMARY

This study compares LED lighting to conventional fluorescent and high-intensity discharge (HID) lighting within the VA healthcare environment. It calculates the luminous performance and installation and maintenance life cycle costs of these lighting systems.

Lighting calculations were performed in typical VA functional areas which account for the majority of the luminaires used in healthcare construction: office and exam rooms, corridors, nurse stations, parking lots and garages, and warehouses and energy centers. The calculations are based on readily-available lighting systems and technologies from multiple manufacturers, and underlying assumptions for hours of use, color temperature, energy cost, optic types, etc., were made such that the calculations were performed to enable direct performance comparison.

- Conventional lighting systems have lower initial cost.

- LED luminaires are suited for all interior applications on a life-cycle cost basis, particularly any application that requires long hours of operation or has mounting heights such that maintenance access is costly.

- The same quantities of LED fixtures can be used to achieve the luminous and life cycle cost performance demonstrated by conventional lighting.

- Exterior LED luminaires are superior to conventional sources for all examined applications.

- LED luminous efficacy is improving rapidly. Fluorescent and HID luminous efficacies appear to have reached a plateau. Although lamp manufacturers are listing longer life ratings for linear fluorescent and compact fluorescent lamps.

- The largest challenge currently faced by LED lighting technology is the management of produced heat. Between 60% and 80% of the energy supplied to an LED light source is dissipated as heat.

- Conventional lighting systems generally demonstrate compatibility of lamps and ballasts between various luminaire manufacturers. LED lighting does not yet show a similar level of component interchangeability. Conventional lighting is most easily maintainable due to component interchangeability.

- Longest-lifespan linear fluorescent systems require matched ballast and lamp combinations, similar to the matched drivers and engines of LED lighting systems.

- While fluorescent and HID lighting technologies are mature, LED lighting technology is developing quickly. The information and conclusions regarding LED lighting in this study will be out of date within 12 months following this publication.

2 INTRODUCTION

2.0 Acknowledgments

This study was performed by GLHN Architects & Engineers, Inc. for the National Institute of Building Sciences and the Department of Veterans Affairs, Office of Construction and Facilities Management.

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2.1 Study Scope

The goal of this study was to calculate, examine, and compare the luminous performance, life cycle cost, maintainability, and component compatibility of LED and conventional (linear fluorescent, compact fluorescent, and high-intensity discharge) lighting systems in the context of the most common luminaire uses in the VA healthcare environment.

2.2 Study Conditions

The luminaire types examined in this study account for the majority of the luminaires used in VA medical facilities:

- Troffers
- Downlight Cans
- Exterior Egress Lights
- High-Bays
- Parking Lot Pole Lights
- Parking Garage Lights

These luminaire types, with LED and conventional sources, were applied in the spaces that account for the majority of the space program in VA medical facilities:

- Offices
- Exam Rooms
- Procedure Rooms
- Corridors
- Exterior Egress
- Reception Areas, Waiting Rooms, and Television Lounges
- Nurse stations
- Warehouses
- Energy Centers
- Parking Lots and Garages
- Surgery Rooms
- Research Laboratories

This study uses a common set of calculation assumptions for lamp color temperature, length of luminaire ‘on’ time, energy costs, etc., in order that the most realistic comparison is obtained. For example, it was found that the underlying assumptions commonly used by luminaire manufacturers to obtain rated lamp life were chosen to most advantageously present the lighting technology used, i.e. 3 hours of ‘on’ time per start for linear fluorescent, and 10 hours of ‘on’ time per start for HID, and 12 hours of on time per start for LED. As much as possible, this study uses a normalized set of assumptions.

The luminaires selected for this study are typical application products for use in typical environments.

Each space was lit in calculation, using manufacturer’s photometry, to the light levels specified in the VA Electrical Design Manual. Sufficient LED and conventional luminaires were used to achieve the specified light level. The luminaire counts thus obtained were carried to the life cycle cost comparison, where the luminaire first cost, cost of energy, and cost of maintenance were compared over a 15-year life cycle.

The final goal of this study was to make recommendations on the most advantageous lighting technologies for VA use.

3 METHOD OF APPROACH

3.0 Selection of Spaces

This study compares LED and conventional lighting technologies in the following spaces:

- Offices
- Exam Rooms
- Procedure Rooms
- Corridors
- Exterior Egress
- Reception Areas, Waiting Rooms, and Television Lounges
- Nurse stations
- Warehouses
- Energy Centers
- Parking Lots and Garages
- Surgery Rooms
- Research Laboratories

These spaces are typically illuminated with what, on a set of construction documents, are termed ‘commodity’ luminaires for general illumination: those that account for the majority of the luminaires used, and therefore those that account for the largest share of the lighting budget on a construction project. These spaces account for much of the floor plate area in a wide cross-section of VA facilities: hospitals, ambulatory care centers, and administrative, support, utility, and parking areas.

Spaces that use more specialized luminaire applications – for example, patient bed wards, radiology, etc. – are not examined in this study.

The results obtained for the spaces selected for this study can easily be extended to similar spaces with similar illumination criteria. There are many additional VA spaces, for example, that use the ubiquitous ceiling troffer luminaire: pharmacies, SPD, research, dietetics, etc.

3.1 Selection of Luminaire Manufacturers

The luminaires used in this study's calculations were chosen with the following criteria:

- Produced by manufacturers with a minimum of three years lighting manufacturing experience.
- Produced by manufacturers having an above average reputation for manufacturing quality, product reliability, and ongoing research and development.
- Compliance with the Buy American Act (BAA).
- Conformance with national and international standards for light sources.

3.2 Lighting Calculations Assumptions

The study uses a common set of assumptions to perform lighting calculations.

- **Light Levels**: As required by the VA Electrical Design Manual.
- **Photometry**: Relative Photometry IES files are acceptable for conventional sources because they have standardized lamps. For LED sources, Absolute Photometry IES files are necessary because of LED lighting systems variability, per IESNA LM-79.
- **Light Loss Factors**: Includes dirt depreciation, lumen depreciation, and ballast factor. Refer to Section 5, Results for the light loss factors used.
- **Color Rendering Index (CRI)**: All sources used in this have CRI values between 80 and 90, assuring appropriate color quality of light. The current VA standard is for sources with a CRI >70.
- **Color Temperature**: Sources with a color temperature of 3500K were used for interior applications, and 4000K sources were used for exterior applications. Note that LEDs are most efficient at 5000-6000K; however, this is not a desirable color temperature for most applications.
- **Luminaire 'On' Time per Start**: 12 hours per start was used for fluorescent and LED sources, and 10 hours per start for HID sources, per manufacturers published data.

Note that T5HO lamps were not evaluated despite their high lumen output and performance in high bay applications. T5HO lamps are not listed as an acceptable lamp in the VA Master Electrical Specifications (Section 26 51 00) or the VA Electrical Design Manual.

3.3 Life Cycle Calculation Assumptions

The following life cycle costing assumptions were used:

- **Energy Cost, Escalation, and Discount Rate**: Refer to the Life Cycle Analysis.
- **Time**: 15 years was used for the useful lifespan of a luminaire. This encompasses the lifecycle of one LED and driver system, and is a common assumed lifespan of a building space before renovation that will affect the lighting system.

4 DEFINITIONS & BACKGROUND

4.0 Definitions

Absolute Photometry: Involves luminous measurements made with detectors calibrated to provide direct assessment in absolute units. Used for conventional lamps and luminaires with solid-state light sources (in which the source and luminaire are inseparable), produces light intensity values for a given luminaire under specific conditions (time, location, temperature, etc.) *See Relative Photometry.*

Color Rendering Index (CRI): Expressed as a rating from 0 to 100 on the Color Rendering Index, the CRI describes how a light source makes the color of an object appear to human eyes. The higher the CRI rating, the better its color rendering ability. The International Commission on Illumination (CIE) does not recommend its use with white light LEDs. A new metric for white light LEDs is under development.

Correlated Color Temperature: A specification of the apparent color of a light source relative to the color appearance of an ideal incandescent source held at a particular temperature and measured on the Kelvin (K) scale. The color temperature of a light source is a general indication of the warmth or coolness of its appearance.

Driver: The power supply that provides constant current and constant voltage to the light-emitting diode in order to maintain a constant luminous output.

Fluorescent: A gas-discharge lamp that uses electricity to produce visible light by exciting mercury vapor within a phosphor-lined tube.

High-Intensity Discharge: A gas-discharge lamp that uses electricity to produce visible light by an electric arc inside a tube filled with gas and metal salts.

Light-Emitting Diode (LED): Diodes that emit visible light when electricity is applied.

Luminous Efficacy: A measure of light produced per unit of power, expressed in lumens/watt.

Relative Photometry: Provides an intensity distribution on a per unit basis. The basis is an assumed total lumen output of the lamp or lamps usually used in the luminaire. Equivalent luminous intensities are determined from measurements made with detectors that are not absolutely calibrated. This system relies on standardized light sources and is not appropriate for LEDs.

4.1 Background

This section contains additional technical material of interest in the comparison between LED and conventional lighting technologies.

Compliance with Buy American Act: The cutsheets for luminaires used in this study usually do not indicate country of manufacturing origin. The manufacturers are reputable and typically US-based.

Dimming: Until national standards are in place to measure dimming performance, dimming LEDs is generally not recommended. However, dimming technology for fluorescents sources is more mature.

Electromagnetic and Radio Frequency Interference (EMI/RFI): In general, LED drivers and controls and conventional ballasts produced by reputable manufacturers will exhibit similar levels of EMI/RFI. These levels are typically acceptable in most power distribution environments.

Environmental Impact: Fluorescent and HID sources contain mercury, and are generally classified as hazardous waste. Although LED lighting systems typically contain no mercury, they have their own environmental impacts, which are governed by the 2006 RoHS directive in the European Economic Community, which restricts six hazardous substances in the manufacture of electronic equipment. It is anticipated that RoHS compliance will become an increasingly important criterion for specifying LED lighting.

Organic LED (OLED): Organic LEDs are an emerging technology, for which standard luminaires do not yet exist. OLED sources are physically flexible and very thin, but luminous efficacies are currently much lower than silicon-based LEDs. This study does not consider OLED technology.

Performance Testing for LED Technology: The US Department of Energy is a recommended resource for the evaluation of LED lighting technology, under the CALiPER program (http://www1.eere.energy.gov/buildings/ssl/index.html).

Photometry: Conventional lighting products are tested using relative photometry, where actual test data is adjusted to the light output of a standardized lamp. This is not possible with LED products, so absolute photometry is used, reflecting actual light from the test source without adjustment. The calculations performed in this study use IES files with absolute photometry for all LED products in accordance with IESNA LM-79 recommendations.

Warranty: LED luminaires typically carry a five year warranty. Conventional lighting system warranties vary, with one year for the fixtures and three to five years for the lamp & ballast combination being typical.

5 RESULTS

5.0 Lighting Calculations & Drawings

The 22 pages of lighting calculations that follow were performed with Lithonia Visual.

The input data and assumptions, and the calculation results, are on each drawing.

The result of the calculations is the quantity of luminaires necessary to achieve similar luminous performance in a given space with a specified light level and uniformity. The quantity of luminaires is a data input for the life cycle cost analysis.

Drawings pages 13 through 35

5.1 Life Cycle Analysis

The following table compares the life cycle cost of LED and conventional lighting systems when applied to the given spaces under the stated assumptions. Refer to Appendix A for cutsheets of the luminaires used, and to Section 3, METHOD OF APPROACH, for more information on underlying assumptions of these calculations, and to the table of assumptions following the life cycle cost analysis.

Space (Illumination Level); Technology	Luminaire Type	Luminaire Description	LED type	Drawing	Luminaires to Meet Specified Illumination level	Luminaire Price	Lamps per Luminaire	Lamp price	System Input Watts per Luminaire	System Luminous Efficacy, lumens per watt	Lamp life @ 10-12 hr starts	Weekly Hours of Operation	Annual kWh	Hours of Operation/15 yrs	kWh in 15 yrs	Number of lamp changes in 15 yrs	INITIAL COSTS: Luminaires	INITIAL COSTS: Installation	OPERATION COSTS: Lamp Replacement Cost (present value)	OPERATION COSTS: Ballast Replacement Cost (present value)	OPERATION COSTS: Energy Cost (present value)	OPERATION COSTS: Lamp Disposal Cost (present value)	15 YR TOTAL COST (net present value, calculation not shown)
Exam/Treatment Room (50 fc) - Conventional	SFA	2x4 Fluorescent Troffer	n/a	5.1.1	1	$81.84	2	$3.65	58	100	36,000	40	121	31,200	1,810	0	$82	$86	$0	$115	$188	$0.80	$1,008
Exam/Treatment Room (50 fc) - Conventional	SFB	2x4 Fluorescent Troffer	n/a	5.1.1	1	$96.00	3	$3.65	88	98	36,000	40	183	31,200	2,746	0	$96	$86		$115	$286	$1.20	$1,008
Exam/Treatment Room (50 fc) - LED	SLA	2x4 LED Troffer		5.1.1	1	$169.95	1	$84.98	102.1	102	50,000	40	212	31,200	3,186	0	$170	$86 $0	$0	n/a	$331	$0.00	$609
Exam/Treatment Room (50 fc) - LED	SLB	2x4 LED Troffer		5.1.1	1	$232.49		$84.98	84.3	88	50,000	40	175	31,200	2,630	0	$170	$86	$0	n/a	$274	$0.00	$609
Procedure Room (100 fc) - Conventional	SFB	2x4 Fluorescent Troffer	n/a	5.1.2	3	$96.00 1	3	$3.65	88	98	36,000	40	549	31,200	8,237		$288	$257	$0	$345	$857	$3.60	$1,690
Procedure Room (100 fc) - LED	SLB	2x4 LED Troffer		5.1.2	3	$232.49		$116.25	50.5	69	50,000	40	315	31,200	4,727	0	$697	$257	$0	n/a	$492	$0.00	$1,478
Corridors (20 fc) - Conventional	VFA	2x4 Fluorescent Troffer	n/a	5.1.3,5.1.4	3	$131.87 1	2	$3.65	54.8	108	36,000	126	1,077	98,280	16,157	2	$396	$257	$115			$2.40	$2,752
Corridors (20 fc) - Conventional (ext. life T8)	VFA	2x4 Fluorescent Troffer	n/a	5.1.3, 5.1.4	3	$131.87	2	$3.65	54.8	111	46,000		1,077	98,280		2	$396	$257	$115	$345	$1,680	$2.40	$2,752
Corridors (20 fc) - LED	VLA	2x4 LED Troffer		5.1.3, 5.1.4	3	$300.33	1	$150.17	50	91	50,000 126	126	983	98,280 16,157	14,742	1	$901	$257	$462 $345	n/a $1,680	$1,533	$0.00	$2,793
Nurse Station (50 fc) - Conventional	VFA	2x4 Fluorescent Troffer	n/a	5.1.5	3	$131.87	2	$3.65	54.8	108	36,000	126	1,077	98,280	16,157	2	$396	$257	$115	$345	$1,680	$2.40	$2,752
Nurse Station (50 fc) - LED	VLA	2x4 LED Troffer		5.1.5	3	$300.33	1	$150.17	50	91	50,000	126	983	98,280	14,742	1	$901	$257	$462	n/a	$1,533	$0.00	$2,793
Reception (50 fc) - Conventional	VFA	2x4 Fluorescent Troffer	n/a	5.1.6	2	$131.87	2	$3.65	54.8	108	36,000	84	479	65,520	7,181	1		$171	$38	$230	$747	$1.60	$7,623
Reception (50 fc) - Conventional	DFA	Downlight Compact Fluorescent Can	n/a	5.1.6	5	$150.41	1	$4.25	28.6	63	16,000	84	625	65,520	9,369	4 $264	$752	$535	$324			$3.75	$7,623
Reception (50 fc) - LED	VLA	2x4 LED Troffer		5.1.6	2	$300.33	1	$150.17	50	91	50,000	84	437	65,520	6,552	1	$601	$171	$312	n/a	$681	$0.00	$4,571
Reception (50 fc) - LED	DLA	Downlight LED Can		5.1.6	5	$260.49		$130.25	15.6	74	60,000	84	341	65,520	5,111	1	$1,302	$535	$663 $575	n/a $974	$531	$0.00	$4,571
Waiting Rooms (30 fc) - Conventional	DFB	Downlight Compact Fluorescent Can	n/a	5.1.7	6	$199.64 1	1	$9.45	36	67	16,000	84	943	65,520	14,152	4	$1,198	$642	$513	$690	$1,472	$4.50	$8,008
Waiting Rooms (30 fc) - LED	DLB	Downlight LED Can		5.1.7	6	$263.63	1	$131.81	21.4	75	60,000	84	561	65,520	8,413	1	$1,582	$642	$803	n/a	$875	$0.00	$3,690
Television Lounge (30 fc) Dimmed - Conventional	DFD	Downlight Compact Fluorescent Can	n/a	5.1.8	6	$199.64	1	$9.45	36	67	16,000	84	943	65,520	14,152	4	$1,198	$642	$513	$690	$1,472	$4.50	$7,984
Television Lounge (30 fc) Dimmed - LED	DLD	Downlight LED Can		5.1.8	6	$263.63	1	$131.81	21.4	75	60,000	84	561	65,520	8,413	1	$1,582	$642	$803	n/a	$875	$0.00	$3,690
Warehouse Storage (20 fc) - Conventional	HMA	HID High Bay	n/a	5.1.9a	12	$228.69	1	$56.00	458	92	20,000	70	20,005	54,600	300,082	2	$2,744	$2,556	$5,424	$3,720	$31,208	$30.00	$52,443
Warehouse Storage (20 fc) - LED	HLA	LED High Bay		5.1.9b	15	$446.47	1	$223.24	286.5	78	100,000	70	15,643	54,600	234,644	0	$6,697	$3,195	$0	n/a	$24,403	$0.00	$35,922
Energy Center (30 fc) - Conventional	HMA	HID High Bay	n/a	5.1.10	15	$228.69	1	$56.00	458	92	20,000	168	60,016	131,040	900,245	6	$3,430	$3,195	$20,340	$4,650	$93,625	$37.50	$227,484
Energy Center (30 fc) - LED	HLA	LED High Bay		5.1.10b	18	$446.47	1	$223.24	286.5	78	100,000	168	45,052	131,040	675,773	1	$8,036	$3,834	$4,188	n/a	$70,280	$0.00	$93,084
Exterior Egress Exit (10 fc) - Conventional	WFA	Compact Fluorescent Wall Pack	n/a	none	1	$295.50	1	$9.45	36	67	16,000	96	180	74,880	2,696	4	$296	$107	$86	$115	$280	$0.75	$1,668
Exterior Egress Exit (10 fc) - LED	WLA	LED Wall Pack		none	1	$520.50	1	$260.25	27	66	100,000	96	135	74,880	2,022	0	$521	$107	$0	n/a	$210	$0.00	$852
Parking Garage (2 fc) - Conventional	GFA	Fluorescent Vapor-Tight	n/a	5.1.11a	10	$115.69	2	$3.65	55	107	36,000	134	3,832	104,520	57,486	2	$1,157	$1,330	$385	$1,150	$5,979	$8.00	$12,434
Parking Garage (2 fc) - Conventional	GHB	HID Garage Lighter	n/a	5.1.11b	8	$298.44	2	$9.45	80	75	20,000	134	4,460	104,520	66,893	5	$2,388	$1,064	$1,233	$1,712		$40.00	$22,062
Parking Garage (2 fc) - LED	GLB	LED Garage Lighter		5.1.11c	8	$298.60	1	$149.30	53.4	83	100,000	134	2,977	104,520	44,651	1	$2,389	$1,064	$1,206	n/a	$6,957 $4,644	$0.00	$9,182
Parking Lot (1 fc) - Conventional	PHA	HID Pole Light (Pole not included)	n/a	5.1.12a	24	$505.40	1	$36.50	129	53	20,000	96	15,455	74,880	231,828	3	$12,130	$5,112	$14,868	$5,136	$24,110	$60.00	$89,888
Parking Lot (1 fc) - LED	PLA	LED Pole Light (Pole not included)		5.1.12b	24	$977.53	1	$488.77	86	83	100,000	96	10,303	74,880	154,552	0	$23,461	$5,112	$0	n/a	$16,073	$0.00	$45,718
General Operating Room (200 fc) - Conventional	OFA	2x4 Supplemental Surgical Light, Fl.	n/a	5.1.13a	16	$692.30	6	$3.65	157	70	36,000	40	5,225	31,200	78,374	0	$11,077	$1,368	$0	$1,840	$8,151	$38.40	$89,888
General Operating Room (200 fc) - LED	OLA	2x4 Supplemental Surgical Light, LED		5.1.13b	16	$923.06	1	$461.53	314	63	60,000	40	10,450	31,200	156,749	0	$14,769	$1,368	$0	n/a	$16,302	$6.40	$33,526
Double Module Lab (150 fc) - Conventional	SFA	2x4 Fluorescent Troffer	n/a	5.1.14a	20	$81.84	2	$3.65	58	100	36,000	40	2,413	31,200	36,192	0	$1,637	$1,710	$0	$2,300	$3,764	$16.00	$8,913
Double Module Lab (150 fc) - LED Panel	SLP	2x4 LED Troffer (panel type LED)	panel	5.1.14b	20	$244.67	1	$122.33	50	92	50,000	40	2,080	31,200	31,200	0	$4,893	$1,710	$0	n/a	$3,245	$0.00	$9,415
Double Module Lab (150 fc) - LED Strip	SLA	2x4 LED Troffer (strip type LED)	strip	5.1.14c	20	$169.95	1	$84.98	40	102	50,000	40	1,664	31,200	24,960	0	$3,399	$1,710	$0	n/a	$2,596	$0.00	$7,878

Assumptions			Source
General			
Energy Cost	$0.104	per kWh	US Energy Information Administration; ww.eia.gov
System Life	15	years	assumed; no data available
Discount Rate	3.2%		
Financing Period (Years)	15		
% yearly increase for electricity	3.2%		per US Energy Information Administration; www.eia.gov
Installation	Average	Cost	
Troffer, fluorescent & LED	$85.50	each	per 2014 RS Means Electrical Cost Data
Vaportight linear fluorescent	$133.00	each	per 2014 RS Means Electrical Cost Data
Pole	$213.00	each	per 2014 RS Means Electrical Cost Data
High bay	$186.00	each	per 2014 RS Means Electrical Cost Data
Garage Lighter (low bay)	$133.00	each	per 2014 RS Means Electrical Cost Data
Can, wall pack, CFL & LED	$107.00	each	per 2014 RS Means Electrical Cost Data
Downlight, fluorescent & LED	$53.50	each	per 2014 RS Means Electrical Cost Data
Supplemental Surgical Light	$128.25	each	per 2014 RS Means Electrical Cost Data (accounts for higher installation cost in surgery ceiling system)
Disposal Cost	Average	Cost	
4' fluorescent	$0.40	each	per Environment, Health and Safety Online; www.ehso.com/fluoresc.php
CFL	$0.75	each	per Environment, Health and Safety Online; www.ehso.com/fluoresc.php
HID	$2.50	each	per Environment, Health and Safety Online; www.ehso.com/fluoresc.php
LED	$0.00	each	per Environment, Health and Safety Online; www.ehso.com/fluoresc.php
Lamp Cost	Average	Cost	
4' T8 835	$3.65	each	per 2014 RS Means Electrical Cost Data
400W pulse start metal halide	$56.00	each	per 2014 RS Means Electrical Cost Data
100W ceramic metal halide	$36.50	each	per 2014 RS Means Electrical Cost Data
70W ceramic metal halide	$32.82	each	per 2014 RS Means Electrical Cost Data
32W compact fluorescent	$9.45	each	per 2014 RS Means Electrical Cost Data
26W compact fluorescent	$4.25	each	per 2014 RS Means Electrical Cost Data
LED assembly - panel	50%	of luminaire	assumed; no data available
LED assembly - strip	50%	of luminaire	assumed; no data available
Lamp Replacement Labor Cost			
	Average	Cost	
Troffers, Downlight, garage	$11.93	per luminaire	per 2014 RS Means Electrical Cost Data
High Bay, pole	$170.00	Per luminaire	per Lighting Reseach Center, Parking Lot Luminaire Calculator
Ballast Replacement Cost, Material & Labor			
	Average	Cost	
Fluorescent	$115.00	each	per 2014 RS Means Electrical Cost Data
400W HID	$310.00	each	per 2014 RS Means Electrical Cost Data
100W ceramic metal halide	$214.00	each	per 2014 RS Means Electrical Cost Data
70W ceramic metal halide	$214.00	each	per 2014 RS Means Electrical Cost Data
32W compact fluorescent	$115.00	each	per 2014 RS Means Electrical Cost Data
26W compact fluorescent	$115.00	each	per 2014 RS Means Electrical Cost Data
Compact fluorescent wallpack	$115.00	each	per 2014 RS Means Electrical Cost Data

Notes:

1. Pole Lights costs do not include pole, base, and excavation.
2. HVAC loads added by luminaires are assumed to be equal, and are not included in the calculations.

5.2 Maintenance & Replacement Compatibility

Fluorescent and HID lighting systems typically have interchangeable components – lamps and ballasts are often interchangeable between original equipment manufacturers, or with aftermarket components. Note, however, that the longer lifespans suggested for some linear fluorescent systems are only achieved using the manufacturer's suggested lamp and ballast combinations.

LED lighting does not yet exhibit the level of interchangeability displayed by conventional sources. Component interchangeability is a stated goal of the International Zhaga Consortium (Zhaga), a non-mandatory consensus body which is promulgating interface specifications for component interchangeability. The number of products that carry a Zhaga compliance label or Zhaga compatible components is small but increasing.

Note that the long lifespan of LED luminaires, and the rapid changes in LED technology, make it likely that entire fixtures will be replaced rather than individual components.

5.3 Power Quality

IEEE published a 2011 study that models and compares the effect of LED and compact fluorescent power quality on a power distribution system (Comparison of CFL and LED Lamp – Harmonic Disturbances, Economics (Cost and Power Quality) and Maximum Possible Loading in a Power System, 2011). LED is superior to compact fluorescent in its lessened power quality impact. A similar study comparing LED to linear fluorescent or HID sources was not found. All LED, fluorescent, and HID lighting are non-linear systems.

5.4 Life Span

Typical life span ratings are based on lamp life for conventional sources. Ballasts typically last 2.5 times longer than lamps. An exception is the new extended-life linear fluorescent lamp & ballast systems.

LED system life spans are based on the useful life of the LED modules expressed a aL70 rating. Currently the LED the drivers have a twice the life rating of the LED modules.

6 CONCLUSIONS

6.0 Luminous Performance

- Interior LED luminaires are best suited for any applications that require long hours of operation or have mounting heights such that maintenance access is costly.

- The same quantities of LED fixtures can be utilized to achieve the luminous and life cycle cost performance demonstrated by conventional lighting.

- Exterior LED luminaires are currently suited for parking lots and garages, and exterior egress lighting.

- LED luminous efficacy is improving rapidly. Fluorescent and HID luminous efficacy appears to have reached a plateau.

- The largest challenge currently faced by LED lighting technology is the management of produced heat. Between 60% and 80% of the energy supplied to an LED light source is dissipated as heat.

- While fluorescent and HID lighting technologies are mature, LED lighting technology is developing quickly. The information and conclusions regarding LED lighting in this study will be out of date within 12 months following publication.

- LED sources are most efficient at cooler color temperatures, e.g. 6000K, which is inappropriate for most applications. This study used 3500 - 4500K sources to balance energy efficiency with color rendering needs.

6.1 Life Cycle Performance

The life cycle analysis shows that the comparison between LED and conventional lighting systems is most sensitive to the differences in first cost between systems, and least sensitive to the cost of energy. In between is the cost of maintenance; and it is to be noted that the labor costs of maintenance outweigh the material cost of replacement lamps, ballasts, or LED modules.

6.2 Future Trends

- LED luminous efficacy is improving rapidly. Fluorescent and HID luminous efficacies appear to have reached a plateau.
- Rated lamp life for conventional lighting technologies is increasing.
- The single largest challenge faced by LED lighting technology is the management of produced heat, which affects LED life and luminous efficacy.
- While fluorescent and HID lighting technologies are mature, LED lighting technology is relatively new and is developing quickly. The information and conclusions regarding LED lighting in this study will be out of date within 12 months following publication.
- Testing, manufacturing, safety, controls, and measurements standards for conventional light sources have been established for many years. Similar standards for LED lighting are relatively new or still under development, and are likely to change as the technology develops.
- At the current time, dimming of LED luminaires requires very careful component matching and slow fade rates for the LED module, the dimming driver, and the dimming controls. This technology is expected to improve.
- It is hoped that the LED modules will become easily replaceable, and will be electrically, physically, and optically interchangeable between manufacturers, similar to the interchangeability displayed by many conventional lighting systems.
- If the recent trend of limited availability and steep cost increases for phosphors continues, the price difference between fluorescent and LED lighting systems will diminish rapidly. Both technologies use phosphors, but fluorescents lamps use a higher quality of phosphors, and in greater quantities than LED.
- LED lighting shows less power quality problems than compact fluorescent, per an IEEE study (Comparison of CFL and LED Lamp – Harmonic Disturbances, Economics (Cost and Power Quality) and Maximum Possible Loading in a Power System, 2011). A formal study comparing the power quality impact of LED vs. linear fluorescent or HID sources was not found.

7 RECOMMENDATIONS

Based on the results of this study, the following recommendations are made:

- LED lighting is recommended for all building interior spaces examined in this study. Only Surgery Rooms are advantageously lit with conventional sources, due to limits on color temperature and color rendering for some manufacturers of LED sources. We believe these issues will be resolved in the near future.
- Steady increases in LED luminous efficacy, color rendering, and at all color temperatures have made LED sources the preferred source for most applications on a 15-year life-cycle basis.
- LED technology is currently recommended for general-illumination areas, including those requiring high light levels with high color rendering, such as medical diagnostics. LED technology can equal or exceed the luminous and life cycle cost performance of fluorescent lighting in these applications.
- When relamping linear fluorescent luminaires, use extended-life lamps. The life of such lamps can be rated as high as 46,000 hours, based on a 12-hour start.
- T8 to LED retrofits (changing lamp/ballast for LED/driver) are not recommended. DOE CALiPER testing has shown that LED retrofits have low lumen outputs compared to the fluorescent lamps they replace. For any LED retrofit product, it is recommended that end users refer to CALiPER product test results.

APPENDIX A LUMINAIRE COSTS & CUTSHEETS

Each luminaire cutsheet is keyed to the luminaire type used in the calculations in Section 5, Results.

Up to three cutsheets for each luminaire type are provided, when 'or equal' luminaire types were found. When fewer than three cutsheets are provided for a luminaire type, it indicates that three equivalent luminaires were not available that met the criteria of this study.

Type	Average Cost	RC Lurie*	Arizona Ltg Sales*	Inverse*	LOL AZ*	Alternate RC Lurie*
DFA	$150.41	$199.64	$152.00	$155.00	$95.00	
DFB	$150.41	$199.64	$152.00	$155.00	$95.00	
DFC	$258.72	$307.88	$248.00	$284.00	$195.00	
DLA	$260.49	$236.47		$280.00	$265.00	
DLB	$263.63	$245.88		$280.00	$265.00	
DLD	$263.63	$245.88		$280.00	$265.00	
GFA	$115.69	$108.76	$144.00	$115.00	$95.00	
GHB	$298.44	$276.76	$390.00	$222.00	$305.00	
GLA	$298.60	$329.41	$270.00	$300.00	$295.00	
GLB	$386.16	$456.47	$465.00		$237.00	
HLA	$446.47	$452.94			$440.00	
HMA	$228.69	$261.06		$230.00	$195.00	
SFA	$81.84	$76.35	$90.00	$91.00	$70.00	
SFB	$96.00	$105.99	$114.00	$94.00	$70.00	
SLA	$169.95	$168.06	$158.00	$141.00	$125.00	$257.71
SLP	$244.67	$220.00		$259.00		$255.00
SLB	$232.49	$238.65	$158.00	$259.00	$155.00	$351.82
PHA	$505.40	$370.59	$556.00	$550.00	$545.00	
PLA	$977.53	$901.18	$1,000.00	$1,130.00	$800.00	$1,056.47
VFA	$131.87	$123.47	$124.00	$160.00	$120.00	
VLA	$300.33	$293.00		$283.00	$325.00	
WFA	$295.50	$320.00	$268.00	$265.00	$329.00	
WHB	$332.33	$370.00		$285.00	$342.00	
WLA	$520.50	$485.00	$587.00	$440.00	$570.00	
WLB	$624.96	$825.88		$470.00	$579.00	
OFA	$692.30	$734.90		$692.00	$650.00	
OLA	$923.06	$1,054.12		$792.00		
OFB	$984.28	$887.84		$1,300.00	$765.00	
OLB	$1,294.71	$1,289.41		$1,300.00		

*Name of Distributor.