

# Lighting Designer Roundtable on Solid-State Lighting

Chicago, Illinois

March 19, 2008

Hosted by:

*U.S. Department of Energy*

*International Association of Lighting Designers (IALD)*

*Illuminating Engineering Society of North America (IESNA)*

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*Prepared for the U.S. Department of Energy by Akoya*

SOLID-STATE LIGHTING

# Roundtable

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## COMMENTS

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## **Introduction**

On March 19, 2008, the U. S. Department of Energy, along with the International Association of Lighting Designers (IALD) and the Illuminating Engineering Society of North America (IESNA), hosted an invited group of lighting designers for a Roundtable meeting in Chicago. The focus of the one-day gathering was to examine solid-state lighting (SSL) market and technology issues and to encourage a discussion of the designers' experiences, ideas, and recommendations regarding SSL and the SSL industry.

Sixteen lighting designers attended the one-day meeting, along with representatives from DOE. DOE's James Brodrick welcomed the Roundtable participants, emphasizing that the lighting design community is a critical part of the complex process of getting SSL into the marketplace. He noted DOE's intention to share designer feedback from this meeting with researchers, manufacturers, and product designers.

Brodrick stated that the transition to SSL requires industry-wide solutions, calling for unprecedented coordination, collaboration, and information exchange among government, industry, manufacturers, standards groups, designers, specifiers, and end-users. With designers' input, DOE can better address technical issues and improvements in SSL products through its R&D program, as well as strengthen its work with industry to assure higher product quality, develop informational materials, and support effective educational programs.

To set the context for the day, several presentations were given at the outset to provide background information and material for reflection. These presentations are summarized below. The heart of the day involved interactive discussion about what needs to be done to achieve viable products and widespread applications for SSL technology. Highlights of the Roundtable discussion and breakout sessions are summarized later in this document, with a synopsis of the issues identified and recommendations discussed.

## **Summary of Presentations**

### **IALD — The Designer's Vision for SSL**

Jeffrey Miller, IALD board president, thanked DOE and acknowledged the presence of some of the best lighting designers in the world and a number of past and present IALD board members. Miller observed that nothing seems to ignite the industry right now like SSL, adding that clients are telling designers they want to use LEDs, but much is still not known about lifetime and other performance variables. He cautioned against a single platform or "Windows"-type dominance, noting that multiple viable SSL platforms would broaden design and financial choices.

Miller also encouraged development of industry standards that make sense. "CALiPER has been doing a great job in testing light fixtures to see if they meet manufacturers' claims," he stated. He urged IESNA and the American National Standards Institute (ANSI) to establish benchmarks that designers can use for comparisons. Finally, he recommended that DOE convene similar meetings more frequently, because designers want to be involved and provided with opportunities to share knowledge and understanding – whether with manufacturers, standards-setting groups, or demonstration projects.

## **IESNA — Solid-State Lighting from an Engineering Perspective**

Kevin Dowling chose a quote, “The system is the product,” to set the tone for his take on SSL from an engineer’s point of view. Dowling, who serves as chair of the IESNA sub-committee on solid-state lighting, cited astounding growth throughout the SSL industry, including breakthrough developments in such areas as lumens per watt, color rendering index (CRI), and color quality, all happening much faster than most in the industry anticipated.

Although many manufacturers produce LED fixtures, designers who specify products – and consumers themselves – must be cautious, Dowling advised. New standards are needed, and are gradually coming into place, with the recent release of C78.377-2008 and the imminent release of LM-79 (*editor’s note: LM-79 has been released since the Roundtable was held*) and LM-80 as the first tangible results of an accelerated, collaborative standards development process.<sup>1</sup>

Following a quick overview of some product development aspects of SSL, Dowling observed that manufacturers are looking for the best application-package mix, but a “higher horsepower” attitude is not always the right answer. With SSL, the whole package needs to be re-thought. “Currents drive costs,” Dowling stated, adding that price is still an issue, especially initial costs, but the industry is making headway, particularly through improvements in product life.

## **Overview of DOE Market Introduction Activities for Solid-State Lighting**

James Brodrick next offered a look at the Department of Energy’s SSL-related market introduction activities. He briefly reviewed the “pathways to market”<sup>2</sup> supported by DOE, including testing, demonstrations, design competitions, ENERGY STAR<sup>®</sup>-related efforts, technical support for standards, and technical information channels.

DOE’s CALiPER Program supports testing of commercially available SSL products for the general illumination market. The first four rounds of CALiPER testing are now complete,<sup>3</sup> and results will provide unbiased product performance information, guiding DOE planning for R&D, GATEWAY Demonstration, and ENERGY STAR initiatives, and informing the development of industry standards and test procedures. Test results also serve to discourage low quality products, helping to reduce the risk of buyer dissatisfaction from products that do not perform as claimed.

The intent of DOE’s SSL Technology Demonstration GATEWAY Program<sup>4</sup> Brodrick explained, is to provide a source of independent, third-party data for use in decision-making by lighting users and professionals. Each GATEWAY Demonstration compares one SSL product against the incumbent technology used in an in-the-field application. Through the Roundtable and future interaction, DOE hopes to encourage more lighting designer involvement in demonstration

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<sup>1</sup> For more information on SSL standards, visit: [www.netl.doe.gov/ssl/usingLeds/measurement-series-standards.htm](http://www.netl.doe.gov/ssl/usingLeds/measurement-series-standards.htm).

<sup>2</sup> For DOE’s fact sheet, *Guiding Market Introduction of High Efficiency, High Performance SSL Products*, go to: [www.netl.doe.gov/ssl/PDFs/Materials\\_2008/CommSupp\\_08FS.pdf](http://www.netl.doe.gov/ssl/PDFs/Materials_2008/CommSupp_08FS.pdf).

<sup>3</sup> For CALiPER summary analyses and detailed test reports, visit [www.netl.doe.gov/ssl/comm\\_testing.htm](http://www.netl.doe.gov/ssl/comm_testing.htm).

<sup>4</sup> For more information on DOE SSL GATEWAY demonstrations, visit: [www.netl.doe.gov/ssl/techdemos.htm](http://www.netl.doe.gov/ssl/techdemos.htm).

opportunities. Noting the need for qualitative analyses in GATEWAY demonstrations, Brodrick sought the involvement of IALD and designers in more strongly addressing this aspect.

National design competitions such as *Lighting for Tomorrow*<sup>5</sup> encourage and promote energy-efficient lighting fixture design. Sponsored by DOE, the American Lighting Association, and the Consortium for Energy Efficiency, *Lighting for Tomorrow* recognizes well-designed, energy-efficient residential LED fixtures. In addition, Brodrick previewed the May 2008 launch of the “Next Generation Luminaires” competition, which seeks to recognize and promote commercial LED luminaires.<sup>6</sup>

Another competition that will further heighten awareness of high-performance solid-state lighting products is the “Bright Tomorrow Lighting Prizes” competition. Section 655 of the Energy Independence and Security Act of 2007 includes provisions for significant prizes for new lighting technologies that can serve as replacements for inefficient lighting products that dominate the market today. The legislation challenges industry to develop a 60W incandescent replacement lamp, a PAR-38 halogen replacement lamp, and a 21<sup>st</sup> Century Lamp.

The development of ENERGY STAR criteria for SSL products will accelerate market penetration of better performing, higher efficiency products. Criteria were announced in September 2007, with labeled products expected to be available in October 2008.<sup>7</sup> DOE also supports the development of standards and test procedures, and keeps industry and consumers informed through the DOE SSL web site,<sup>8</sup> regular SSL Updates, SSL technology fact sheets,<sup>9</sup> the SSL Technical Information Network (TINSSL),<sup>10</sup> planned market studies and technical evaluation reports, and annual R&D and Market Introduction workshops.

In closing, Brodrick invited the designers to attend the upcoming *Voices for SSL Efficiency* Market Introduction Workshop. Sponsored by DOE, the Northwest Energy Efficiency Alliance, the Energy Trust of Oregon, and Puget Sound Energy, the workshop will be held in Portland, Oregon, in July 2008.<sup>11</sup>

### **Overview of DOE/IES Design Guide for Solid-State Lighting**

Samantha LaFleur, a lighting designer with AtelierTen in Baltimore, Maryland, joined Eric Richman of Pacific Northwest National Laboratory to update participants on the status of the *DOE/IES Design Guide: Lighting Design with LEDs*. Prior to the Roundtable, a draft of the Guide (see Appendix B) was distributed to participants for review in preparation for the session. The purpose of the Guide is to focus on achievable, marketable products, to create a common vocabulary for specifiers and manufacturers, educate potential users about the possibilities and challenges of SSL, raise good questions for better results, and drive the market to improve

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<sup>5</sup> For more information on *Lighting for Tomorrow*, visit [www.lightingfortomorrow.com](http://www.lightingfortomorrow.com).

<sup>6</sup> Information on the “Next Generation Luminaires” competition will be available soon at [www.netl.doe.gov/ssl](http://www.netl.doe.gov/ssl).

<sup>7</sup> For more information on ENERGY STAR, visit [www.netl.doe.gov/ssl/energy\\_star.html](http://www.netl.doe.gov/ssl/energy_star.html).

<sup>8</sup> To visit the DOE SSL web site, or to register to receive the *SSL Update*, go to [www.netl.doe.gov/ssl](http://www.netl.doe.gov/ssl).

<sup>9</sup> To view the SSL technology fact sheet series, visit [www.netl.doe.gov/ssl/publications/publications-factsheets.htm](http://www.netl.doe.gov/ssl/publications/publications-factsheets.htm).

<sup>10</sup> For more information on TINSSL, visit [www.netl.doe.gov/ssl/technetwork.htm](http://www.netl.doe.gov/ssl/technetwork.htm).

<sup>11</sup> More information on the Portland Market Introduction Workshop will be available soon at [www.netl.doe.gov/ssl](http://www.netl.doe.gov/ssl).

luminaires. The Guide's intended audience includes contractors, specifiers, architects, sales representatives, and those involved in product development.

The Guide features technical information on performance, special characteristics of LEDs, and application challenges, as well as design guidance on specific applications according to space and building types. It examines LED performance in terms of absolute versus relative photometry, performance standards, light output, color quality, correlated color temperature (CCT) and CRI, and color compatibility, in addition to looking at thermal management, product life, and energy efficiency.



Samantha LaFleur discusses the *Design Guide for Solid-State Lighting* with Roundtable participants.

“Why LEDs?” was the question LaFleur kept central during her involvement in preparing the Guide. “If we can make this a document that solves some of our issues, starts a dialogue, and gets some of this information out, we’ll be closer to general market comfort and clarity. One of our goals today is to walk you through and get feedback about how ‘on track’ we are, and what is missing.”

LaFleur spoke of designers’ concerns – such as “specify-ability” – before a project, in the design and specification stages, during construction, and after installation. “What happens when the system fails? We are basically buying a company more than a product, and manufacturers do not always follow through. This increases designers’ risks exponentially in choosing to specify SSL products.”

Feedback from participants included requests to add space types such as theaters, arenas, and healthcare facilities, to talk about quality of light in the “task” section of the Guide, and to address such concerns as “the biggest issue” of liability. Another participant noted the importance of spectral power distribution, pointing out that LEDs are an interrupted spectrum of light. Most current white LEDs are phosphor-converted, which can impact the efficiency of the LED product by changing the spectrum of the original LED diode. Kevin Dowling illustrated this concept in a diagram showing “Stokes shift,” which is included in Appendix C.

In summary, both Richman and LaFleur again encouraged participants to review the Guide, and provide their feedback on issues and concerns, as well as their suggestions for improvement. “Our business is very much about managing risk,” LaFleur observed, “and my hope is that tools like this Guide can support our work and help us manage these risks.” Suggestions and feedback from participants will be incorporated into the final draft version of the Guide, to be forwarded to IESNA by June of 2008.

## Roundtable Discussion with Meeting Participants

Samantha LaFleur and Derry Berrigan, of Derry Berrigan Lighting Design in Rogers, Arkansas, introduced the Roundtable session, drawing on their personal experiences to set the stage for the frank and lively discussion that followed. The session was designed to elicit participants' perspectives on their successes, failures, considerations, and needs in incorporating SSL into lighting designs. Participants were asked to analyze their key concerns, focusing on "What's Going Right" and "What's Not Going Right" in the areas of design, implementation, and performance of SSL.

Comments are summarized in the tables below.



Breakout sessions focused on identifying key actions and next steps for government and industry.

### Lighting Designer Roundtable Feedback SSL – What's Going Right

- Small format allows luminaire design and architectural design flexibility
- Low expected connected load
- Efficiency above similar sources
- Color changing ability – LED systems can be tuned for lighting mood effects
- Low heat (front) – Little heat is radiated towards occupants and objects providing more comfort
- No UV – ideal source for fragile artifacts
- Long lamp life allowing reduced maintenance
- Vibration resistance due to no filament and compact format
- Cold temperature operation without the issues with FL technology
- Direct low-voltage input good for some renewable systems and design flexibility
- Can easily daisy-chain fixtures with low voltage connectors



## **Lighting Designer Roundtable Feedback**

### **SSL – What’s Not Going Right: Issues and Concerns**

#### **Overall**

- Lack of definition of SSL as tool – is it a lamp or a system?

#### **Technology**

- Rapid pace of technology changes
- Immediate performance vs. down the road
- Information flow

#### **Manufacturing/Products**

- Cycle – 2 years
  - 1) Design 2) Spec 3) Install
  - Product might not be around in 2 years
- Truth in advertising is not there: “lasts forever”
- More standardized cut sheets (templates)
  - Among LEDs
  - Among Hg products
- Model specifications
  - Like nutritional guide – standardized form
- Published data must follow some government standard
- Maintenance contract issues
- Potential availability of matching replacement parts
- “Box on a shelf” vs. separate parts
- Lack of modularity
- Want to be able to compare things in my tool box
- Easier if fitting into current model
  - Universal LED socket design could accommodate issues
- Lack of info on product details
- LED uplights
  - Shift to green
  - Back to factory to look at

#### **Cost issues**

- Volume of sales not yet high enough to bring down costs
- Hard to track true price of SSL
- Perception of low cost may not reflect complete luminaire costs

#### **Distribution system – potential for new way to sell and market**

- Start with government contracts?
- Put new products out as direct sales?
- Recommend to owners to buy direct
- Government role to support direct sales

#### **Government**

- Seed money for industry collaborative effort for standards

### **Breakout Discussion – Small Groups**

The final component of the Roundtable session was a breakout into three discussion groups, to identify key actions and needed next steps. Summarized here are the findings of the three groups.

#### **Breakout Group One – Priorities for Action**

1. Accepted standards – need to have standards in place that are acceptable to industry and that provide useful comparative metrics for users.
2. LED replacement availability for LED luminaires – the market will lean in part toward availability of actual replacement LED packages. This idea of “lamp” replacement will be important to address.
3. Cradle-to-grave footprint, compared to other sources – very important to develop and get RIGHT as green is in. But very important to also do for other competing technologies – NOT JUST LED!
4. Color shift over time – not enough seen on this issue and it may become important. The industry needs to feel comfortable that they know what this is, as they do for other technologies.
5. Claims! – misinformed claims are everywhere and need to be counteracted where possible in public arenas. Programs like CALiPER are good but this does not reach the public.
6. Market distribution – industry is interested in a better way to distribute products and there are concerns with compatibility between products that are unlikely to be helped with current systems.
7. Cost – Too high and only slows market down in the beginning. Need ways to connect mass application opportunities to help reduce costs.
8. Power hook-up standardization – potential issue with various connection options DC, AC.

#### **Breakout Group Two – Priorities for Action**

1. Risk
  - Failures – need simple solutions for performance failures and replacement
  - UL requirements
2. Cost
  - No system for efficiency savings to benefit owners in commercial or residential leasing situations.
  - Need simple, effective tax rebate/federal tax credit programs
3. Cut sheets – need consistent cut sheets for easier comparisons
4. Product showcases – sponsor product showcases in areas with higher concentrations of designers and specifiers

### **Breakout Group Three – Priorities for Action**

1. Addressing “misinformation” issues
  - Standardized cut sheets with appropriate application information
  - Standardized reporting
  - Quality stamp?
2. Creating false expectations
  - DOE and utilities should avoid over-promotion
  - Continue CALiPER testing program
3. Promoting modularity
  - Planning for “end of life” needed
  - Ease of replacement – how do you “change the bulb”?
  - Lighting competitions should require modular design or explicit end of life plan
  - CALiPER should also take this into account
4. Continuing links with designers
  - Seek input into lighting competitions/incentive programs – both specs and winners
  - Include input on light quality and usefulness

### **Session Wrap-Up**

James Brodrick concluded the gathering by expressing his appreciation to all the lighting designers who came and contributed throughout the day. He stated that, as a result of the insights and input designers had provided, he anticipated DOE program fine-tuning, most notably in the GATEWAY and CALiPER programs. “Better-quality communication between links in the chain is essential,” he noted, “and we will look closely at that need to identify areas where DOE might be of assistance.”

“I anticipate that DOE will be coming back to you with at least one proposal that will essentially capture what you’ve told us today,” he continued. “And, we will be asking you to sign on – to offer us your continuing experiences and recommendations. Taking action will be next. Please feel free to contact us, as this is just the start. Attend a workshop, give us your feedback. Thanks to each of you for your part in making this an excellent meeting.”

## Appendix A

### List of Participants

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## **Appendix B**

### ***Draft* DOE/IES Design Guide: Lighting Design with LEDs**

If I can

**DG – XXX (IESNA)**

**Lighting Design with Light-Emitting  
Diode (LED) Technology**



**IESNA Committee Review (Membership)**

- A
- B
- C
- D
- E
- F
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- H

Copyright Statement.....

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DRAFT

# IESNA Guide to Lighting Design Using Light-emitting Diode (LED) Technology

## Forward

This design guide is an introduction to using light-emitting diode (LED) technology in interior general illumination lighting design. LEDs are frequently used to provide color accents and color-changing effects in both interior and exterior applications but these are outside the scope of this document. The design guide includes sections describing the current state of LED technology with regard to lighting performance, key differences in measurement methods for LEDs compared to traditional sources, special LED attributes that may provide advantages over traditional light sources in some applications, and LED application challenges that must be evaluated to avoid bad design decisions and future dissatisfaction. This guide also provides application guidance for specific design tasks, common space types and buildings where the advantages and technology strengths of LED technology can be applied.

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## 1 Introduction

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Rapid progress in solid-state lighting research and development has resulted in the advent of general illumination LEDs that are approaching and in some cases surpassing the performance of traditional light sources.

Because LEDs are a new light source that differs in important ways from existing light sources it's important for designers to understand how LEDs perform and their advantages as well as important challenges for specific design applications.

### 1.1 Background

LEDs have been used since the early 1960s for a variety of color signal and indicator

applications (red, blue, green, amber). In the past few years LEDs have made serious inroads into the general "white light" illumination market by refining the white light LED source, and incorporating these sources into general illumination luminaires.

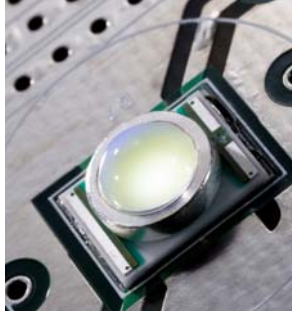
Some of the current products perform very well, but the quality and energy efficiency of LED products still varies widely, for several reasons:

- LED technology continues to change and evolve very quickly. New generations of LED devices become available approximately every 4 to 6 months.
- Lighting fixture manufacturers face a learning curve in applying LEDs. Because they are sensitive to thermal and electrical conditions, LEDs must be carefully integrated into lighting fixtures. Few lighting fixture manufacturers are equipped to do this well today.
- Important differences in LED technology compared to other light sources have created a gap in the industry standards and test procedures that underpin all product comparisons and ratings. Appropriate standards, test procedures, and ENERGY STAR criteria are currently available or coming soon. However, because these comparison aides and rating systems are new and testing and evaluation of products takes time, useful information on all products may not be readily available. In their absence, accurate comparison can be difficult but is a critical part of the successful design process.

### 1.2 LED Technology Basics

LEDs are fully electronic semiconductor devices, while incandescent, fluorescent, and high-intensity discharge (HID) technologies are all based on glass enclosures containing a filament or exposed electrodes, with fill gases and coatings of various types.

LED lighting starts with a tiny diode (most commonly about 1 mm<sup>2</sup>) comprising layers of semi-conducting material. LED packages contain just one diode or multiple diodes, mounted on heat-conducting material and usually enclosed in a lens or encapsulant. The resulting device, typically around 7 to 9 mm on a side, can produce 30 to 150 lumens, and can be used separately or in arrays. LED devices are commonly mounted on a circuit board and attached to a lighting fixture, architectural structure, or even a “light bulb” package.



## 2 LED Performance

To understand how general illumination LEDs perform it's important to consider the illuminance levels, color quality, energy efficiency, thermal management and product life of the LED luminaire.

### 2.1 Measuring LED Performance

For all light sources, there is a difference between rated luminous flux of the lamp and actual performance in a luminaire. However, the performance of traditional light sources in a wide range of luminaire types is well documented and understood. Traditional light sources installed in luminaires operate relatively predictably because the lamp characteristics that relate to light output and life are either not affected by the luminaire structure (as with incandescent sources) or are managed by maintaining optimal ambient temperatures (as with linear fluorescent). Further, traditional light sources are able to dissipate wasted energy (heat) in the form of infrared (IR) radiated into the space. LED technology however, does not emit any appreciable radiated energy. Instead, the wasted energy that is generated must be removed from the LED die via conduction or convection. LED performance is very sensitive to heat and optical design, which increases the

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relative importance of luminaire design and its importance as a heat dissipation tool. This relative importance of luminaire design necessitates the treatment of LED lighting products on a complete luminaire basis rather than a traditional lamp + fixture. LED technology is also at a far earlier stage of development, so experience and documentation of performance within luminaires is less well known.

Luminaire efficacy is a measure of the net light output from the luminaire (as a whole) divided by power into the system (e.g., at the wall socket). For LED fixtures this measurement takes into account the LED, its thermal management system, the efficiency of its driver and any losses inherent in the final luminaire design, as illustrated below. Luminaire efficacy combines both the light system efficacy and luminaire efficiency, allowing for a true comparison of a luminaire regardless of the light source.



#### 2.1.1 Absolute vs. Relative Photometry

With the wide variety of lighting applications, luminaire configurations, and replacement lamps on the market, photometric measurement practices and standards have developed over time that are useful for design. Traditionally, photometric measurement techniques have developed around the general concept of lighting ‘systems’ that are based on a light fixture (housing) into which a lamp (light source, or ‘bulb’) is mounted. Different ‘lamps’ can be installed in a fixture as long as they have the appropriate socket—like an Edison socket—and the appropriate size to fit in a fixture, and do not exceed fixture wattage limitations. Various lamps when installed in a variety of fixtures will shed varying amounts and patterns of light depending on the nature of the fixture (e.g., whether it shades the light, has a more or less opaque sheath, lens type etc.).

From this context and the fact that lamps are easier to test on their own, practices of measurement based on relative photometry emerged: that is, lamps are measured and rated on one side, while fixture efficiencies and

distributions are evaluated using reference lamps on the other side. Relative photometry is the measurement of the photometric qualities of multiple objects relative to each other or relative to a known source.

Using relative photometry to evaluate fixtures separately from lamps breaks down when it comes to LEDs. There are no standard LED “lamp” packages and no standardized lamp ratings. Also, LED performance depends heavily on the thermal, electrical, and optical design of the system or luminaire. So, each LED product must be tested as a whole: using absolute photometry to evaluate luminaire performance characteristics such as total luminaire output and luminaire efficacy.

### 2.1.2 Performance Standards

New measurement protocols and test procedures are available or currently being developed for LEDs. Methods to measure total luminous flux, luminous intensity, color temperature, color rendering, lumen depreciation, and electrical characteristics are all under development or revision to accommodate specific attributes of LEDs that differ from other lighting technologies.

## 2.2 Light Output

Creating LEDs with sufficient light output to compare with traditional light sources has been a considerable challenge for LED manufacturers. To approach the total light output of a typical incandescent or CFL or linear FL, a number of LEDs must be grouped together. Even the “high-brightness” white LEDs typically come in just 1-watt to 3-watt sizes. This can make bringing enough light to a given application a challenge for LEDs.

However, for some applications, LEDs can provide enough light on the task, even though the total light output is lower than comparable incandescent or fluorescent sources. This is because the light emitted from an LED is directional in nature, and in some applications, less light is lost in the fixture than with traditional light sources. Still, it is helpful to know how much total light the LED product provides and

compare it to competing products using traditional light sources.

The light output of a traditional recessed downlight, for example, is a function of the lumens produced by the lamp and the luminaire (fixture) efficiency. Reflector-style lamps are specially shaped and coated to emit light in a defined cone, while “A” style incandescent lamps and CFLs emit light in all directions, leading to significant light loss unless the luminaire is designed with appropriate internal reflectors. Downlights using non-reflector lamps are typically only 50% to 60% efficient, meaning about half the light produced by the lamp is wasted inside the fixture. Recently, LED downlights have come on the market. The table below provides examples of performance data for recessed downlights using several different light sources, including a LED product. These data should not be used to generalize the performance of fixture types, but are provided as examples.

Recessed Downlight Lamping Options			
	65W BR-30 Flood	13W 4-pin Spiral CFL	LED 2
Luminaire light output, initial (lumens)	570	514	730
Luminaire wattage (W)	65	12	12
Luminaire efficacy (lm/W)	9	42	60
CCT (Kelvin)	2700 K	2700 K	2700 K
CRI	100	82	95
Center beam candlepower (candela)	510 cd	154 cd	280 cd
Beam angle (degrees)	55°	120°	105°
Average luminance at 45° (cd/sq meter)	27267	13479	16439
Dimmable	Y	N	Y

## 2.3 Color Quality

Color quality has been one of the key challenges facing LEDs as a general light source. Unlike incandescent and fluorescent lamps, LEDs are not inherently white light sources. Instead, LEDs

emit light in a very narrow range of wavelengths in the visible spectrum, resulting in nearly monochromatic light. White light can be generated in two primary ways: 1) phosphor conversion, in which a blue, violet, or ultraviolet (UV) LED is used in combination with phosphors; or 2) RGB, in which the light from red, green, and blue LEDs is combined.

### 2.3.1 Correlated Color Temperature (CCT)

Correlated color temperature (CCT) describes the relative color appearance of a white light source, indicating whether it appears more yellow/gold or more blue, in terms of the range of available shades of white. The most efficient high-output white LEDs are phosphor-converted (PC) devices based on blue LEDs, characterized by very high CCTs of 5000K or above. Warmer color temperatures are increasingly available, as improvements continue in LED efficacy, phosphor technology, and phosphor conversion efficiency. Warm white (2700K to 3000K) devices are now available at efficacies similar to CFL efficacy.

### 2.3.2 Color Rendering Index (CRI)

The Color Rendering Index (CRI) is a measure of the ability of a light source to render colors, relative to a reference light source. CRI has been found to be inaccurate for LEDs, especially RGB (red, green, blue) systems, but also for phosphor-converted (PC) white LEDs. Other potentially more useful metrics are being developed, but in the meantime, CRI is the only available metric.

When using the current CRI system, it's important to remember:

- CRI may be compared only for light sources of equal CCT. This applies to all light sources, not only to LEDs. Also, differences in CRI values of less than five points are not significant, e.g., light sources with 80 and 84 CRI are essentially the same.
- If color appearance is more important than color fidelity, do not exclude white light LEDs solely on the basis of relatively low CRI values. Some LED products with CRIs as

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low as 25 still produce visually pleasing white light.

- Evaluate LED systems in person and, if possible, on-site when color fidelity or color appearance are important issues.

### 2.3.3 Color Compatibility

LED color compatibility with fluorescents and incandescents makes them useful in environments with mixed light sources. The current ANSI specification for white light LEDs provides color ranges that match the typical color offerings for CFL and linear fluorescent products. Some LED luminaires are available with selectable color temperature within a range, such as between 3000K and 6500K, which makes them useful for entertainment, color changing applications, and for tuning of the white light tones to decorative effect.

## 2.4 Energy Efficiency

Energy efficacy of light sources is typically measured in lumens per watt (lm/W), meaning the amount of light produced for each watt of electricity consumed. This is known as luminous efficacy. The best white LEDs are advancing in efficacy beyond that of fluorescent sources. However, most currently available white LED luminaires and replacement lamps, while more efficient than incandescent sources, are not as efficient as luminaires using fluorescent or HID sources.

It's important to remember that LED products use only a small amount of energy, and therefore may appear energy efficient, but many have very low light output. True energy efficiency means using the most efficient light source or system that is capable of providing the amount and quality of light needed.

### 2.4.1 Measured LED Luminaire Performance

In order to evaluate the effectiveness of various light sources for specific applications, comparisons between LED products and luminaires using other light sources need to look

at overall luminaire performance, rather than lamp ratings or fixture efficiencies. Overall luminaire performance of traditional light products can be measured through similar absolute photometry at the fixture level, or estimated based on more traditional relative data (lamp ratings, fixture efficiencies...). Standardized measurement methods similar to those used for LEDs allow for absolute testing of luminaires using incandescent, fluorescent, or any other light source. Values for luminaire efficacy, luminaire output, and intensity distributions obtained from absolute testing will provide the most accurate points of comparison, but they will be specific to the lamp, ballast, and luminaire combination that was tested.

Rough Estimate of Luminaire Efficacy	
Lamp source rated output	900 lm
Lamp rated power	15 W
Fixture efficiency	40%
Driver or ballast efficiency	85%
Luminaire output = 900 lm * (40%) = 360 lm	
Luminaire Efficacy = 360 lm / (15W/85%) = 20 lm/W	

**2.4.2 Calculating Luminaire Performance for Comparing LEDs to Traditional Sources**

If absolute photometry for comparable fixtures is not available, the luminaire output and efficacy can be estimated using relative photometry provided by the fixture manufacturer and lamp ratings, as shown below. Essentially, luminaire output can be estimated starting with the output of the lamp, and discounting that output for fixture losses. The luminaire efficacy can be estimated by dividing the estimated luminaire output by the estimated power input to the luminaire. When estimating luminaire performance in this way, a few caveats and rules of thumb apply. First, take care that the geometry and dimensions of the lamp to be used are similar to that of the lamp used to obtain the tested fixture efficiency. For example, fixture losses will be much higher for a traditional incandescent lamp in a downlight than with a directional lamp such as a reflector lamp. Second, check that ballast factor or driver losses are applied correctly to obtain luminaire input power. Third, ensure that losses from fixture optics such as lenses are included in fixture efficiency, or apply a separate loss factor for additional optics if need be. Also, apply an appropriate thermal loss factor as needed depending on the type of lamp source and luminaire environment. Finally, be wary of implicit implications of lamp rating values: whether you are using 'initial' lumens, 'mean' lumens, or 'typical' lumens can make a large difference.

**2.4.3 Comparing LED Energy Efficiency to Traditional Light Sources**

For a rough comparison, the range of luminous efficacies for traditional and LED sources, including ballast and driver losses as applicable, are shown below.

Light Source	Typical Luminous Efficacy Range in lm/W
	(varies depending on wattage and lamp type)
Incandescent (no ballast)	10-18
Halogen (no ballast)	15-20
Compact fluorescent (CFL) (incl. ballast)	35-60
Linear fluorescent (incl. ballast)	50-100
Metal halide (incl. ballast)	50-90
Cool white LED 5000K (incl. driver)	47-64*
Warm white LED 3300K (incl. driver)	25-44*

\* As of October 2007.

**2.4.4 Relating Energy Efficiency to LED Color Characteristics**

Standard incandescent A-lamps provide about 15 lumens per watt (lm/W), with CCT of around 2700 K and CRI close to 100. ENERGY STAR-

qualified compact fluorescent lamps (CFLs) produce about 50 lm/W at 2700-3000 K with a CRI of at least 80. Typical efficacies of currently available LED devices from the leading manufacturers are shown below. Improvements are announced by the industry regularly. Please note the efficacies listed below do not include driver or thermal losses.

CCT	CRI	70-79	80-89	90+
2600-3500 K		23-43 lm/W		25 lm/W
3500-5000 K		36-73 lm/W	36-54 lm/W	
> 5000 K		54-87 lm/W	38 lm/W	

Sources: Manufacturer datasheets including Cree XLamp XR-E, Philips Lumileds Rebel, Philips Lumileds K2.

## 2.5 Thermal Management

LEDs won't burn your hand when you grab the illuminated surface like some light sources, but they do produce heat. The difference is that more traditional light sources radiate the heat away from the lamp but LEDs do not. Thermal management is one of the most important aspect of successful LED luminaire design and should be considered in lighting design and application as well.

Excess heat directly affects both short-term and long-term LED performance. The short-term (reversible) effects are color shift and reduced light output while the long-term effect is accelerated lumen depreciation and thus shortened useful life.

For general illumination applications, heat sinks are often incorporated into the functional and aesthetic design of the luminaire, effectively using the luminaire chassis as a heat management device. The design process can help with thermal issues by avoiding the application of LED luminaires where excessive heat buildup might be likely.



All light sources convert electric power into radiant energy and heat in various proportions. Incandescent lamps emit primarily infrared (IR), with a small amount of visible light. Fluorescent and metal halide sources convert a higher proportion of the energy into visible light, but also emit IR, ultraviolet (UV), and heat. LEDs generate little or no IR or UV, but convert 15%-25% of the power into visible light (similar to other light sources); the remainder (unlike traditional sources that radiate most wasted heat away from the lamp) is converted to heat that must be conducted from the LED die to the underlying circuit board and heat sinks, housings, or luminaire frame elements. The table below shows the approximate proportions in which each watt of input power is converted to heat and radiant energy (including visible light) for various white light sources.

	Incandescent† (60W)	Fluorescent† (Typical linear CW)	Metal Halide†	LED*
Visible Light	8%	21%	27%	15-25%
IR	73%	37%	17%	~0%
UV	0%	0%	19%	0%
Total Radiant Energy	81%	58%	63%	15-25%
Heat (Conduction + Convection)	19%	42%	37%	75-85%
Total	100%	100%	100%	100%

## 2.6 Product Life

With proper thermal control, LEDs are projected to produce a very long service life. Realistic application based projections of life are in the 20,000 to 50,000 hour range. The LED itself is a stable non-filament light source that can theoretically continue to function indefinitely. However, the light output of the technology like all other technologies continues to degrade over

time. Unlike incandescents and fluorescents that have filaments or electrodes that fail long before the light output degrades drastically, LEDs just continue to operate but fade in output as well. This long life makes hard-to-reach and difficult maintenance applications ideal for LEDs. However, the level of light output over its long life must be considered carefully in design considerations.

Light Source	Range of Typical Rated Life (hours)* (varies by specific lamp type)	Estimated Useful Life (L <sub>70</sub> )
Incandescent	750-2,000	
Halogen incandescent	3,000-4,000	
Compact fluorescent (CFL)	8,000-10,000	
Metal halide	7,500-20,000	
Linear fluorescent	20,000-30,000	
High-Power White LED		35,000-50,000

Because of the importance of thermal design issues, consider asking the following questions when evaluating the projected lifetime of LED products.

- Does the replacement lamp design have any special features for heat sinking/thermal management?
- Does the luminaire manufacturer have test data supporting life claims?
- What life rating methodology was used?
- What warranty is offered by the manufacturer?

### 3 LED Special Characteristics

LEDs possess a number of unique attributes which may make them the right choice for a number of applications. The special characteristics covered in this design guide include:

- Controllability
- Directionality
- Size
- Durability
- Cold temperature operation
- Instant on/ Rapid cycling
- No IR or UV emissions
- Environmental impact

#### 3.1 Controllability

LEDs are easily integrated into electronic control systems making it easy to control color balance and intensity independent of each other while maintaining color rendering accuracy. This is not possible with traditional light sources. For general illumination, LEDs have the ability to dim from 0 – 100% with little effect on color output or lifetime.

Traditional, efficient light sources (fluorescent and HID) present a number of challenges with regard to lighting controls. Dimming of commercial fluorescent systems is readily available and effective, although at a substantial price premium. For CFLs used in residential applications, dimming is more problematic. Unlike incandescent lamps, which are universally dimmable with inexpensive controls, only CFLs with a dimming ballast may be operated on a dimming circuit. Further, CFLs usually do not have a continuous (0% to 100% light output) dimming range like incandescents. CFLs will commonly dim down to only about 30% of full light output.

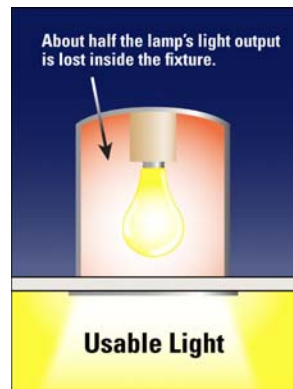
LEDs may offer potential benefits in terms of controlling light levels (dimming) and color appearance. However, not all LED devices are compatible with all dimmers, so manufacturer guidelines should be followed. As LED driver and control technology continues to evolve, this is expected to be an area of great innovation in



lighting. Dimming, color control, and integration with occupancy and photoelectric controls offer potential for increased energy efficiency and user satisfaction.

### 3.2 Directionality

Due to the directional nature of their light emission, LEDs potentially have higher application efficiency than other light sources in certain lighting applications. Fluorescent and standard “bulb” shaped incandescent lamps emit light in all directions. Much of the light produced by the lamp is lost within the fixture, reabsorbed by the lamp, or escapes from the fixture in a direction that is not useful for the intended application.



For many fixture types, including recessed down lights, overhead general light fixtures, and under cabinet fixtures, it is not uncommon for 40-50% of the total light output of the lamp(s) to be lost before it exits the fixture. LEDs emit light in a specific direction, reducing the need for reflectors and diffusers that can trap light. Therefore, well-designed fixtures and systems using LEDs can potentially deliver light more efficiently to the intended location.

### 3.3 Size

A single LED is very small and produces little light overall but this characteristic is both a weakness and a strength. This small size allows fixture designers to make light sources into shapes and sizes suited for most any application. Light distribution can also be controlled by the LED's epoxy lens making LED architectural construction simpler. Because of the small size, most LED luminaires incorporate multiple point sources. This can provide better sparkle for multifaceted surfaces/products (i.e. jewelry) but can produce multiple shadows for near field objects. Incorporating multiple LEDs also presents heat sinking issues which require careful design.

For directed light applications with lower luminous flux requirements, the low profile benefit of LEDs can be exploited with excellent results. Under-, over-, and in-cabinet LED lighting can be very low-profile, in some cases little more than the LED devices on a circuit board attached unobtrusively to the cabinetry.

### 3.4 Durability

LEDs are highly rugged. They feature no filament that can be damaged due to shock and vibrations. LED devices mounted on a circuit board are connected with soldered leads that may be vulnerable to direct impact, but no more so than cell phones and other electronic devices.

LED light fixtures may be especially appropriate in applications with a high likelihood of lamp breakage, such as sports facilities or where vandalism is likely. LED durability may provide added value in applications where broken lamps present a hazard to occupants, such as children's rooms, assisted living facilities, or food preparation industries.

### 3.5 Cold Temperature Operation

LED performance inherently increases as operating temperatures drop making LEDs a natural fit for grocery store refrigerated and freezer cases, cold storage facilities, and outdoor applications.



The performance of fluorescent lamps, in contrast, decreases as temperatures decrease. At low temperatures, higher voltage is required to start fluorescent lamps, and luminous flux is decreased. A non-amalgam CFL, for example, will drop to 50% of full light output at 0°C. The use of amalgam (an alloy of mercury and other

metals, used to stabilize and control mercury pressure in the lamp) in fluorescent technology largely addresses this problem, allowing the lamp to maintain light output over a wide temperature range (-17°C to 65°C). The trade-off is that amalgam lamps have a noticeably longer “run-up” time to full brightness, compared to non-amalgam lamps.

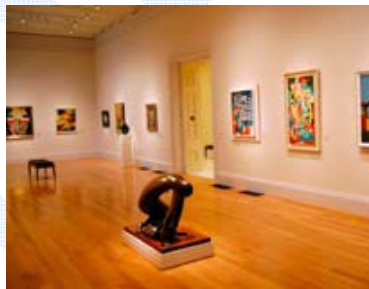
### 3.6 Instant on/ Rapid Cycling

LEDs, unlike other traditional light sources such as fluorescent and HID lamps, come on at full brightness almost instantly, with no re-strike delay. In general illumination applications, instant on can be desirable for both safety and convenience.

LED life and lumen maintenance is unaffected by rapid cycling unlike traditional light sources. This rapid cycling capability makes LEDs well-suited to use with all types of on-off controls such as occupancy or daylight sensors. LED technology is inherently dimmable from 0 to 100% with little effect on life or color shift.

### 3.7 No UV Emissions/Little Infrared

LEDs produce essentially no ultraviolet and very little infrared radiation. While LEDs produce heat, the heat is not radiated with the light but remains at the light production point (the back of the diode itself). This, in part, allows the LED lens material to be integrated into the LED chip itself making for more effective direction of the light. The lack of radiated heat by LEDs makes them a good application for fragile goods and displays which are sensitive to heat. The lack of UV light also makes them a suitable for choice to illuminating objects such as works of art as well as any materials subject to irradiated heat degradation.



## 3.8 Environmental Impact

LEDs reduce environmental impacts in several areas. Longer lamp life means that fewer resources are required for the lifetime of the fixture given the reduced lamp replacement. They also use no mercury and fewer phosphors than fluorescent alternatives and require little energy to manufacture. These facts combined with the increased energy efficiency, make LEDs a smart choice in reducing the footprint on the environment.

## 4 LED Application Challenges

While LED technology provides many potential design advantages, it also presents several challenges that must be examined for lighting design considerations. The following LED issues will be covered in this design guide:

- Glare
- Flicker
- Color Consistency
- Product Cost
- Product Claims

### 4.1 Glare

Because of the small concentrated source and directional nature of LEDs, glare is an important consideration when using them for general illumination. Using louvers, shielding trim, or deeper recessing of the light source can alleviate glare, but these measures can also reduce the light levels provided and the efficacy of the luminaire.

### 4.2 Flicker

LED sources are driven at high frequencies therefore typically don't have flicker issues like some older low frequency driven technologies like T12s or magnetic ballast CFLs. However, the dimming of LEDs interior variable frequency that can create potential for flicker.

Most LED drivers use pulse width modulation (PWM) to regulate the amount of power to the LEDs. This technique turns the LEDs on and off at high frequency, varying the total on time to achieve perceived dimming. Driver output frequency should be at least 120 Hertz (Hz) to avoid perceptible flicker under typical circumstances.

LED light fixtures may appear to flicker at the lowest settings, but only when the dimmer control is moved. This is due to the finite “resolution” of the digital electronics. Good-quality electronic drivers feature 12-bit or greater resolution to obtain flicker-free operation throughout their dimming range.

### 4.3 Color Consistency

Color variations in LED arrays are an important consideration, especially for side-by-side applications like wall washing. LED manufacturers use color binning (sorting by color appearance) as a cost effective way to produce white light arrays with consistent color. An ANSI specification on LED white light color<sup>1</sup> is available to specify the variability that could reasonably be tolerated and still provide reasonable white light. The amount of acceptable color variation for different LED applications is dependent on many factors that the designer must consider. Because of the greater potential variability of color options with LED technology, the designer must be sure to consider the specification of LEDs for color as well as other characteristics.

### 4.4 Product Cost

Most white-light LEDs currently cost significantly more than traditional light sources. This fact forces designers to use caution in specifying LEDs for many lighting applications at this time. With rapidly increasing performance and price reductions, increasing numbers of LED products will soon become cost effective choices especially when maintenance costs, energy efficiency and other special characteristics as discussed in this guide are taken into account.

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1 ANSI C78.377

## 4.5 Product Claims

With LED technology changing rapidly, it's becoming increasingly difficult to keep up with the newest performance specifications and to separate product hype from genuine technology breakthroughs.

When specifying LED luminaires, it's important to remember to:

- Check manufacturer claims. All performance claims should be considered carefully and should be verified. Look for independent, verifiable testing that includes driver and power loss factors and thermal losses.
- Avoid economy grade products. LEDs are advanced technology and not currently cheap. If a product is too inexpensive, it is potentially using lower quality production methods, lower end components, or has limited capability or performance.
- Be careful when considering retrofit products as variables in fixture design and installed environment are not always predictable.
- Learn as much as you can.
- Stay skeptical, if it sounds too good to be true, it probably is.

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## 5 Design Recommendations by Application

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LED products for general white light illumination are entering the market and currently available for an increasing number of important applications in commercial lighting design. LED replacement lamps are available to replace incandescent and compact fluorescent technology in some existing luminaires. Dedicated LED technology luminaires are also being produced with some potential advantages

over conventional technology. Because the technology is relatively new to the general white light market and exhibits different advantages and challenges, LED-based luminaires are not currently suitable for all applications or space types.

Detailed light output calculations and performance characteristics of LED-based luminaires are not offered as a part of this guide as the technology is rapidly changing. The standards and procedures needed to produce reliable and meaningful performance testing of LED luminaires is emerging. As the LED market continues to grow, sufficient information in the form of test and photometric reports for comparable LED luminaires will become more readily available. It remains incumbent on the specifier to study an LED option carefully and assess the likely performance of that luminaire in each application.

Specific design guidance and application information is provided in the following sections for various applications, space types and building categories. The appropriateness and availability of LED luminaires for typical lighting needs are addressed in each section. Applications, spaces, and building categories do overlap and it is suggested that the designer consult all applicable sections. Not all possible applications are included but those that currently represent good or cautious opportunities for LED application are discussed. For building or space types not listed, consider the specific visual task to be performed in the spaces of interest and look for guidance within related space type sections.

## **5.1 General Illumination Applications**

### **5.1.1 Downlights**

With the popularity of downlights in both residential and commercial applications, the creation of products powered by LEDs is a deserving goal from both energy efficiency and design flexibility perspectives.

As LED downlights continue to emerge in the market, their performance and variety will improve. However, because of the high surface

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brightness of LEDs, visual comfort can be a problem. The typical and efficient application of LEDs near the outer edge of the downlight can create a glare condition. The glare can be reduced by means of a suitable diffusing lens and/or increasing the recess depth of the LEDs into the housing but this can often reduce the light output to a point no longer sufficient or acceptably compared to a halogen or CFL source.

The first applications to consider replacing compact fluorescent and incandescent-powered downlights with LED-based options are those used in spaces with low ambient brightness or with multiple layers of light. Additionally, spaces with intermittent occupancy, such as corridors, restrooms and storage rooms, could be considered for LED downlights.

In such spaces, the current compact fluorescent lamping would be using 9, 13, 18 or 26 watt lamps in single or double lamp profiles. Incandescent sources are likely 60 or 100 watt standard A-lamps. These fixtures can easily be powered with LED replacement lamps and deliver equivalent light output. As the market grows, dedicated LED luminaires will become increasingly available as replacements for existing CFL and incandescent driven products. These LED specific products will likely offer additional efficiency, and lifetime benefits because the luminaire is designed around the important characteristics of the LED technology.

It is important, as with all newer technologies, to ensure that the light output characteristics are understood for the application and that the luminaire is reviewed for glare control prior to specification. Potential glare should be more carefully considered in extended occupancy spaces where the glare may cause fatigue or discomfort to the occupants.

### **5.1.2 Overhead Lighting – Direct/Indirect**

Overhead direct and indirect lighting is the largest indoor application for lighting and has the potential for large energy savings from the application of newer more efficient technologies such as LEDs. As the lighting and research industries continue to develop LED technology, appropriate overhead products will become a common reality.

Currently, there are limited products aimed at general overhead illumination and no effective replacement of the standard direct or indirect luminaire is yet available. When such luminaires are introduced, careful study of the direct component for possible glare is suggested, as will the successful blending of the indirect light from the individual LEDs.

## 5.2 Decorative Applications

White-light LEDs can directly replace incandescent lamps and low wattage compact fluorescents in decorative task luminaires, offering improved energy efficiency and reduced maintenance through the life of the luminaire.

### 5.2.1 Decorative Luminaires

Decorative luminaires such as sconces, pendants, table and standing lamps utilizing low wattage CFLs are becoming more common and provide an incremental efficiency and maintenance improvement from the original incandescent products. LEDs can now offer a further step toward improved efficiency and maintenance, in addition to offering greater design flexibility for smaller fixtures. In many instances, incandescent and CFL-based decorative fixtures rely upon a diffuse lens to obscure direct view of the lamp and to create the overall impression of an even glow behind the lens or shade. This same design aesthetic can be achieved using LED-based lamps behind similar lenses or shades. In the future, more decorative fixtures and LED-based 'lamps' will be introduced to further replace the use of incandescents and low wattage CFLs in these luminaires.

### 5.2.2 Concealed Architectural Lighting

Concealed architectural lighting is another opportunity for replacing traditional sources such as low-wattage compact fluorescent lamps with LED luminaires. Indirect lighting integrated with architectural elements, especially in areas adjacent to daylight apertures, can provide smooth, glare-free illumination for the perception of a bright, large space. LED luminaires, which are readily available in segments as short as 6

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inches, are ideal sources for cove or concealed lighting where a curve needs to be followed. The small size also allows for the design of even smaller architectural enclosures than current design alternatives which may also result in lower material and installation costs.

The use of LEDs in concealed architectural applications can save energy and create longer maintenance cycles for additional cost savings. For dimming applications, they can also reduce costs by eliminating the need for extra dimming hardware required by compact fluorescent solutions.

## 5.3 Task Applications

Task applications are ideally suited for illumination by LED sources. The compact form of the LED in linear or cluster form affords opportunities for bringing the light source into close proximity to a task surface. This close proximity requires less than the full light output otherwise required from ambient luminaires located at greater distances from the task plane. More of the light distributed from the fixture reaches the task, thus less is required from the fixture itself.

As specifiers move away from providing one uniform high level of light for a space to providing layers of light tuned to the functions of a space, the improvement of task lighting is a natural direction for progress. Task / ambient lighting has become a virtually standard for office lighting design and is being used increasingly in other visual-task-specific spaces, such as lobbies with reception desks, workrooms, classrooms, pantries, and restrooms.

### 5.3.1 Adjustable Arm Desk Task Lighting

Options in work area task lighting have been limited in the past. Original incandescent-based task luminaires, featured one or two adjustable arms ranging in length from 9 to 12" that allow



extension and light output directional control over up to 2 ft in range. These characteristics offer ideal flexibility for a workstation, but the heat output, short lamp life, and energy consumption are undesirable. The next generation of adjustable task fixtures, using the compact fluorescent lamp is now widely used although challenges exist to successfully integrate the ballast into the fixture gracefully. The lower wattage compact fluorescent lamps offer an improvement in lamp life from the incandescent and halogen sources, but an LED source would be an even greater improvement.

Task lights using LEDs are an ideal pairing of technology with function as the LEDs offer small form factor, long life, and low heat output (towards the work surface) They can provide sufficient brightness close to the work plane but this needs to be verified to ensure the output is adequate. The use of LED-based adjustable task lights is an ideal direct replacement when the cost difference can be accepted.

### 5.3.2 Linear Desk Task Lighting

Undercabinet-mounted task lighting is commonly integrated with office furniture. Typically using two or three foot T8 or T5 lamps, these fixtures offer light levels that are typically in excess of the actual recommended light levels for traditional office visual tasks. This can cause veiling reflections on monitors and papers on the work surface while using unnecessary energy. Some specifiers recommend reduced output ballasts to tune the light output to more comfortable levels, but this is a detail often overlooked in subsequent years of maintenance.

LED-powered undercabinet style task luminaires offer a shallow format that can be easily integrated with furniture. This application



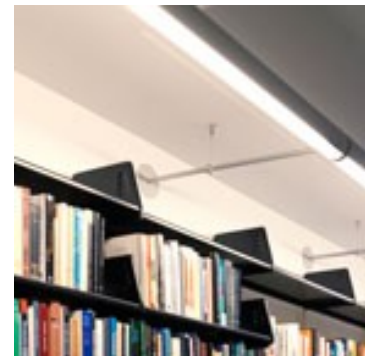
offers shielded, moderate light output to increase light levels by 20-25 footcandles at the desk surface for appropriate task illuminance.

This type of luminaire is also recommended as a direct replacement for linear fluorescent options for display cabinets, kitchens, pantries and any similar undershelf or undercabinet application. This LED application can also offer dimming of the light output eliminating the need for and the cost of special dimming ballasts required with fluorescent technology.

### 5.3.3 Vertical Task Lighting

Vertical tasks include library stacks, displays, signage, art, bulletin boards, and other vertical elements of interest. These task zones benefit from supplemental light located in close proximity to the surface. LED-based fixtures are ideal for such applications in the form of a recessed, asymmetric luminaire designed to wash a vertical surface or as a linear wall-mounted luminaire with an asymmetric reflector. LEDs are well-suited for these applications as they allow for small profile fixtures, fewer power feeds, and a greater variety of light output options than linear fluorescent.

In spaces with daylight, target light levels for the vertical surfaces may shift from day to night as the ambient light level changes. For example, in a daylighted library, the daytime ambient light level may be between 30 and 75 footcandles at the reading plane. The



vertical light level target to provide for comfortable reading of the book titles would be approximately 50 footcandles to the bottom shelf of the stacks. At night, the ambient light level, now provided simply by the electric lighting, may be between 30 and 40 footcandles. At these levels, the vertical light level target for the stacks can be tuned to 35 footcandles. With a standard linear fluorescent solution for the vertical element, the cost of additional control equipment would make a dimming scenario less likely. However, LED fixtures require nominal additional expense to enable dimming and a light level tuning option with associated energy savings would be more easily implemented.

## 5.4 Specific Space Applications

### 5.4.1 Circulation Spaces

In typical circulation zones within most buildings, there are a number of spaces that require average, maintained light levels in the range of 5 to 15 footcandles at the floor. Many of these spaces represent zones in a building where occupants are passing without performing visually strenuous tasks. These spaces include corridors, stairs, and other circulation zones, which historically may have been over-



lighted. As compliance with energy codes becomes a more important part of specifiers' projects, recalibrating the light levels in these spaces becomes a source for energy reduction.

LED-powered luminaires offer specifiers' another option when struggling with the basic problem of light output and energy consumption in limited increments with standard technologies. LED products are typically available in more segments and increments and therefore smaller wattage increments for more flexibility in design and associated potential for energy savings.

For example, for a typical corridor that is 6 ft wide, 50 ft long, with an 8 foot ceiling height, the ASHRAE / IESNA 90.1-2004 standard requires a connected load maximum of 0.6 watts per square foot. That equals 180 watts of allowable connected load. Using standard 18-watt compact fluorescent downlights [drawing 20 input watts], only 9 fixtures can be used, using a total of 10,800 initial lumens. Using LED-based 10 to 12-watt downlights, 15 fixtures may be used with a total of 9750 lumens. By increasing the number of fixtures with only a slight reduction in total light output, the light level can be maintained at approximately the same level, but with a smoother uniformity, which may be desirable for that project.

Another advantage to LEDs as a solution for ambient lighting in moderate light level spaces is the choice of the light output distribution as a cluster or in a linear format. Traditional downlights, using halogen or compact fluorescent sources, are most closely replaced by a cluster of LEDs installed within a downlight housing. However, LEDs may also be installed in linear housings with linear light distribution, enabling the light from the luminaire to cover a broader horizontal or vertical area than a compact fluorescent lamp could cover from its compact format. Linear fluorescent-powered luminaires are often not a successful choice for such applications as the light output from T5 or T8 linear fluorescent lamps may result in light levels in excess of IESNA recommendations.

Specification tip for LEDs to be used as emergency egress fixtures: Since LEDs slowly lose light output over their life, dipping below 50% of light output at some time, their service as emergency egress fixtures is a cause for concern. Life safety codes require that egress lighting systems provide a guaranteed light level. Specify LED controllers with auto-shutoff at 50% light output for LED luminaires intended to serve as emergency egress luminaires. This will cause the LED to be replaced at the appropriate time to ensure that the light level of the space will not fall below 50%.

The use of linear-distributed LEDs spreads the energy consumption more thinly over an area which can reduce overall energy consumption. Many linear LED luminaires offer the specifier options for how many LEDs to include per linear foot, allowing the specifier to tune the light level requirement with the connected load carefully.

### 5.4.2 Stairways

Thanks to their core characteristics, LED luminaires seem well-suited for use in such traditionally difficult-to-maintain spaces as stairwells. However, a critical specification issue must be understood and specified accurately to



prevent a serious liability exposure to the specifier, engineer and contractor for the project: Since LEDs do not shut off but rather produce less and less light through their lifespan, the minimum average illumination guarantee that is required for compliance with NFPA 101, 2007, of 10 footcandles minimum on walking surfaces cannot be met using a traditional LED luminaire (it may well dip below this level without failing). If a manufacturer can provide a cut-off at a specific light output point for the stair luminaires, then the minimum can be designed and calculated.

### 5.4.3 Display Areas

For enclosed and open displays in museum and retail environments, LED luminaires are increasingly becoming good solutions. The advantages of low forward heat emission, no UV output, long lamp life, and small fixture dimensions make LEDs desirable for concealing within casework for object highlighting. Increasing light output and color temperatures more closely resembling halogen sources are making LEDs even more appropriate. For objects with sparkle elements such as crystal, silver, cool gadgetry, and jewelry, the available cooler color temperature LEDs are ideal for highlighting the best features of these products.

LEDs are appropriate for display lighting for UV sensitive materials, such as fragile textiles and papers as they give off no UV and very little infrared light.

Many retail display areas feature indirect illumination for their ambient lighting scheme, paired with localized accent fixtures at the displays. For such applications, LEDs are a recommended source for both the ambient and accent lighting.

The greatest obstacle to the wider application of LED luminaires in retail facility display areas is likely the first cost of the product. Many retail spaces are intended to be refurbished in relatively short spans of time – typically 5 to 7 years to maintain optimum merchandising capability. This may not be enough time to realize the benefit of the extended life of LEDs.

Long Life LEDs are good for luminaire locations that are inaccessible, in high ceilings, behind decorative elements, built into

casework/cabinetry, exterior fixtures, wall and floor-recessed housings.

## 5.5 Building Type Considerations

### 5.5.1 Industrial Facilities

The relatively high light level needs and typical high ceiling spaces in industrial applications make the effective application of LED luminaires difficult and are not currently recommended for general illumination. Within industrial facilities, there may be certain tasks that would be well-served by an LED luminaire. See the task application section of this guide for more information.

### 5.5.2 Athletic Facilities

Given the required higher light levels, typically high ceilings, and extreme sensitivity to glare within the occupants' visual fields, LED luminaires are not currently recommended for general illumination for athletic facilities. One exception to this would be indirect lighting strategies, although the amount of wattage required may be prohibitive given energy standards. In the future, more development of lenses that reduce the apparent glare would create more opportunities. The long-life and minimal maintenance requirements of LEDs do make them attractive technically for athletic facilities which often feature inaccessible mounting locations. At this time, it is the visual quality and high light level requirement issues that remain unresolved.

### 5.5.3 Ecclesiastical Buildings

Environments for worship are often spaces with moderate light levels and a strong reliance on decorative fixtures. LED-powered decorative luminaires are highly recommended to take advantage of their low maintenance and small profile allowing concealment within diffuse decorative elements. Care must be taken to properly anticipate and manage the heat within any decorative luminaire using LEDs.

A key visual task within houses of worship is reading and horizontal lighting should be provided throughout the space that is sufficient to permit worshipers of any age to read small text easily. LED luminaires, concealed at pews



or similarly integrated with the furniture or architecture, would be an ideal solution. This notion is far simpler with LEDs than with other lamp sources as the smaller LED luminaire profile can be more easily integrated.

#### 5.5.4 Libraries

A significant portion of a typical library includes circulation, stacks and reading areas. As recommended in other sections, LEDs are ideal lamp sources for various lighting strategies for circulation zones. Stacks are a classic vertical display design challenge for which linear LED luminaires, cantilevered from the upper edge of the stacks to provide an asymmetric wash of local lighting, are perfectly suited. Reading areas are often a combination of decorative fixtures, which can easily incorporate LEDs, along with supplemental downlighting to provide added zones of brightness. Currently available LED products already provide solutions for many of the visual challenges within libraries.

#### 5.5.5 Restaurants/Kitchens

Traditional restaurant lighting relies upon multiple levels of illumination. A decorative element, in the form of pendants, sconces, or table-top could easily be powered via LEDs. The small profile and onboard dimming controls of many options increase design freedom in sometimes restricted spaces and restaurants that operate during daytime and nighttime hours that need dimming to define separate moods.

An architectural layer of dramatic spotlights, wall spots or accents may be powered by LEDs, although the current products likely will not offer sufficient punch relative to a halogen source.

The task layer, from a table-top accent, to casework displays, bar illumination and waiting stations, can easily be provided by LEDs. Already, LEDs in faux candles are taking over for open flames on table-tops. Translucent bar surfaces and rear walls can be easily backlit with LEDs with great success.

#### 5.5.6 Signage

LEDs entered the architectural market through this segment. Their integration into exit signs has become the basis for various energy conservation codes and standards.

Future developments of LED-based emergency fixtures would be an ideal direction for product development. Architectural designers have struggled for years to prevent the installation of large emergency 'bug eye' fixtures. LED-based versions would likely be much smaller and less intrusive into environments.

The small profile of LEDs serves well for room and floor-based signage illumination.

#### 5.5.7 Academic Buildings

Spaces within typical academic buildings vary widely in the specific visual tasks to be performed. Certainly, general circulation and accent lighting could be considered for LED strategies. LED luminaires are not currently recommended for classroom ambient lighting systems.

### 5.6 Exterior Lighting

The exterior lighted environment is by definition a low ambient light level space. The full moon provides approximately 0.01 footcandles\* of illumination at the ground and this is sufficient for the human eye to see effectively enough for general navigation through a space. Uniformity is a key element to successful nighttime illumination as the human eye adapts rather slowly to changes in low levels of illumination.

An exterior illumination concept centered on the use of LEDs would allow for careful tuning of the light levels and uniformity with the least energy consumed. The moderate light output of an LED, combined with its small form factor, compatibility with low operating temperatures, and long lamp life make it ideal for exterior luminaire applications.

Furthermore, the common 12 or 24 volt DC input requirement for a majority of LED luminaires makes connection with on-site renewable power generation systems relatively easy. This application can realize even better system efficiency compared to metal halide or compact fluorescent sources that are designed for higher voltages. The required conversion of typical renewable power generation systems from direct current (DC) to alternating current (AC) to power

standard lighting technologies incorporates additional conversion energy losses. A luminaire-mounted PV array powering an LED cluster is a simple way to provide off-grid exterior pathway or plaza lighting.

Ideal exterior luminaires utilizing LEDs include bollards, step lights, pathway accent fixtures, exterior downlights, exterior wall washers, ground-mounted accent lights for facades and landscaping, even pole fixtures (see below for limitations).

Applications well-suited for such luminaires include “pedestrian scale” zones of the exterior illuminated environment: walkways, canopies, steps, plazas, signage, building entries, and

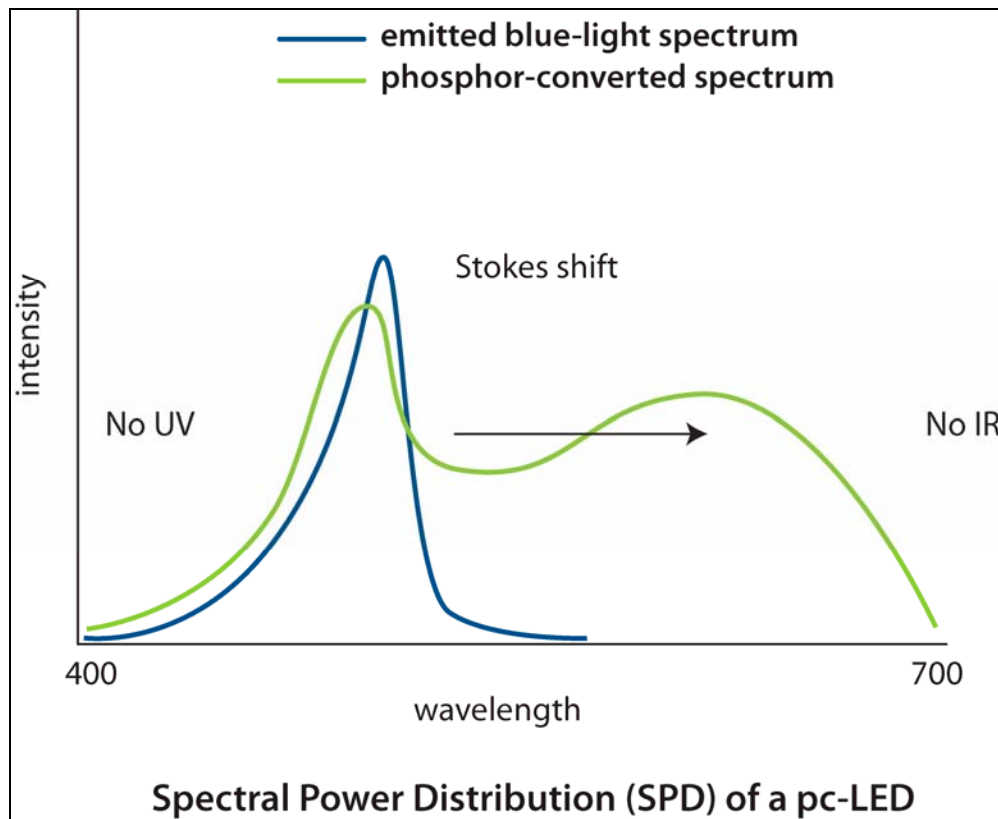
façade washing. Exterior applications not well-suited to LEDs at this time are high-pole applications on streets and in parking lots as the surface brightness from LED-powered versions can be excessive and high power LED products are not readily available. Of these options, the most successful are those paired with shielded optics and mounted to the lowest poles acceptable. In this application, more fixtures will be required than for a metal halide or compact fluorescent lamping strategy to deliver acceptable uniformity.



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## Appendix C

### Stokes Shift



In most white LEDs on the market today, a blue LED excites a phosphor to convert the narrow-spectrum blue light into a broader emission that appears white to the eye. White light can also be created by a combination of red/green/blue/(amber) colors or individual colors can be combined with a phosphor-converting (pc) LED to improve that spectrum. Although in principle more efficient, these approaches are presently more complex and expensive than the pc-LED alone. Early white pc-LEDs had a harsh bluish appearance due to the challenges in creating phosphors that could efficiently convert blue to longer wavelength reds, in particular, but many improvements have been made in recent years.

In the phosphor-conversion process, light of shorter (blue) wavelength is absorbed by the phosphor and re-emitted at longer wavelengths. Since the longer wavelength photons are of lower energy than the short wavelength of the exciting photons, there is a consequent loss of power efficiency. The difference between the input and output wavelengths of emitted and absorbed light, known as the Stokes shift, is usually measured as the difference between the wavelengths of maximum intensity in the excitation and emission spectra. Efficiency losses in converting from one part of the spectrum to another are thus often termed 'Stokes shift losses.' Phosphors applied to LED products continue to improve with different chemical combinations and researchers now see more efficient warm-white LED sources that have successfully reduced these Stokes shift losses through a different mix of wavelength shift.