LED Lighting in Interior Commercial Applications: Hype or a Real Contributor?

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ABSTRACT

Light emitting diodes (LEDs) are pertinent to "En Route to Zero Energy Building." They are the lighting industry's fastest evolving energy-efficient technology for commercial applications. Manufacturers, along with federal and state governments are dedicating millions of dollars for research to advance LED performance.

LEDs currently offer utilities energy saving opportunities in certain niche markets that can be included in incentive programs. While LEDs are not yet quite ready as a white light source for general ambient lighting applications, as the efficacy of LEDs improves and current barriers are reduced, LEDs will provide opportunities for utility incentive programs.

This paper explains what LEDs are, why they are so promising, and why they are not yet ready for prime time from a designer's perspective. Existing LED lighting successes in other markets and niche lighting applications demonstrate energy saving opportunities and other valuable benefits. Current barriers to market penetration for general illumination, steps needed to overcome the barriers, emerging applications and trends that offer opportunities, and how to know when to incorporate the technology into practice will also be discussed.

The paper discusses product and system life, system performance, color temperature, color rendering, uniformity, standards needs, and economics. The paper aims to debunk the hype about LEDs by taking a pragmatic look at the performance and aesthetic criteria that need to be met before the design community can begin to specify LEDs as a white light source for ambient interior commercial applications and contribute to "zero energy" efforts. This paper is also intended to stimulate the ACEEE community to participate in shaping the LED market.

Introduction

The lighting design community is excited about light emitting diodes (LEDs). Over the last several years, the number of lighting designer trade publications including articles on LEDs has grown. For the first time, *Lighting Design &Application (LD&A)*, the official magazine of the Illuminating Engineering Society of North America, devoted an entire issue to LEDs in November, 2006. Every lighting designer conference and trade show now includes presentations and displays related to this exciting technology. The commercial lighting industry's premier trade show in the U.S., *LightFair*, offers courses, workshops, and seminars on LED lighting along with dozens of LED lighting vendor displays. Designers are exposed to LEDs everywhere they turn and are learning more about the use of LEDs in lighting equipment. Support from the United States Department of Energy's (DOE) Next Generation of Lighting Initiative (NGLI) and the Next Generation of Lighting Industry Alliance (NGLIA) has helped further research and development efforts that have resulted in a rapid increase in the efficacy[1] of this emerging technology. The excitement in the lighting design community is warranted based on the potential energy efficiency of the source and other features such as long life and vibration resistance.

LEDs have already proven themselves in certain colored, monochromatic, and decorative applications. There are, however, issues concerning LEDs as a white light source for ambient illumination and task lighting for interior commercial applications such as office lighting. These issues need to be resolved in order to meet the many needs of designers, specifiers, facility managers, and occupants. This paper addresses some of these issues, such as system performance, standardization, and economics, not on a technical or scientific level, but from the perspective of the lighting design community.

The interests of the design community, consisting of engineers, architects, lighting designers, and specifiers, is important to utilities and energy service providers because until the design community is willing to accept and specify the technology, true market transformation can not can be accomplished.

This paper addresses what barriers need to be overcome in order for designers to begin specifying LEDs for white ambient illumination in interior commercial applications. This information will help utilities evaluate fact from fiction and know what is "hype" and what is not. This is extremely critical with emerging technologies in order to avoid “market spoilage” resulting from bad experiences that could significantly slow market adoption.

Why All the Interest in LEDs?

In 2005, a record number of 17 LED patents were submitted as a result of DOE-funded Solid State Lighting (SSL) research projects. This brings the total number to 31 patents submitted since DOE began funding SSL research projects in 2001. “These patents highlight the value of DOE SSL projects to private companies and notable progress toward commercialization,” (Navigant Consulting 2006, 12).

According to DOE, “The U.S. Department of Energy and its partners are working to accelerate advances in solid-state lighting — a pivotal emerging technology that promises to fundamentally alter lighting in the future. No other lighting technology offers the Department and our nation so much potential to save energy and enhance the quality of our building environments” (DOE web site 2006).

While much of the interest in white LEDs for general illumination can be traced to this potential for energy savings based on efficacy (and the resulting cost savings for end users), the successes in non-lighting applications and successes in monochromatic and colored lighting applications in certain niche markets also have created interest. Although many people focus on the energy savings aspect of LEDs, this is not necessarily the only interest in LEDs, especially for facility managers and the design community. As Bill Ryan, former Product Manager for Philips Lighting pointed out at a recent presentation, depending on the use of the LEDs, the interest can be long life (maintenance savings), durability (maintenance savings), low voltage (safety), low heat and low UV emissions, (safety), small size (new applications), control (digital interface), colors (mood and affect), or other benefits (Ryan 2006).

[1] Efficacy is the metric for a lamp’s efficiency measured in lumens per watt, or lumens of light output per watt of power input. *IESNA Lighting Handbook.*

Monochromatic and colored LEDs have proven themselves in niche market applications such as automotive, electronics, safety and signal lighting, and traffic signal heads (Conroy et al. 2003). The vibration resistance of LEDs was an important feature in these market areas where maintenance cost is a big concern. Similarly, they have proven to be an effective energy-efficient solution in colored commercial lighting applications such as advertising signs (colored LED lamps, digital "motion" displays, and channel letters) and exit signs. These "other market" and "other application" successes have spurred interest in the utility, energy service provider, and design communities.

The DOE's timetable for LED efficacy predicts that white LEDs will produce over 150 lumens per watt by the year 2020 (DOE SSL Timetable 2005). Based on efficacy only, this would put white LEDs ahead of other conventional white light sources such as fluorescent lighting for white general illumination and give LEDs "the potential to revolutionize the lighting market through the introduction of more energy efficient light sources" (Conroy et al. 2003, 44). Current information reported by manufacturers and research labs like the Lighting Research Center suggest that this timetable is very realistic and current technology development may be well ahead of schedule (Narendran 2006).

Why White LEDs Are Not Ready for Prime Time

To understand what designers need and want, it is helpful to understand how designers view LEDs. This is not a technical paper designed to provide detailed scientific explanations of LEDs and how they produce light. However, it is important to understand what LEDs mean to designers and how they are used in lighting applications so energy efficiency programs can make informed decisions of how to effectively incorporate LEDs in program plans.

An LED is a semiconductor device—a diode—that emits photons when it is energized. The radiant output from each LED is limited to fairly narrow bandwidths within the range of ultraviolet to infrared; however, this paper only concerns LEDs that produce wavelengths visible to humans.[2] From a practical lighting design standpoint, an LED lighting system consists of one or more LEDs integrated into an electrical circuit with a power supply (sometimes called a "driver"), a thermal heat sink, and a means of control. LED lighting system controls can be analog or digital and may offer many functions beyond on/off; including timed and sequenced effects, dimming, color selection and blending, and lumen or color point maintenance. Some systems also include housings, reflectors, and/or lenses similar to that of conventional lighting.

Lighting designers take all these system components into account when evaluating lighting options. An individual LED of 50 lumens per watt by itself is a useless metric to a designer. Designers think in terms of how an entire system will perform and how the light produced will affect people and surroundings.

Three major design/specification categories for lighting designers and specifiers are: performance and standardization, flexibility, and economics.

Over coming performance issues is key to the future success of white LEDs becoming part of interior commercial general illumination. Nothing could hurt the rapid progress of LEDs more than pre-mature market adoption. Premature release of substandard products can have a detrimental effect on the market. This is the historical case with compact fluorescent lamps (CFLs). The premature release of that technology by some overly ambitious marketers resulted

[2] Additional technical references are included in the reference section.

in widespread technical and application failures that spoiled the market acceptance. The negative experiences of the end-use market then resulted in the delay of wide spread acceptance by more than a decade. Market players are still forced today to address the negative perceptions of CFLs -- perceptions based on very real negative experiences of substandard CFLs that were released too early. The market did not know how to differentiate between the low-quality and the high-quality products that promised energy savings and superior performance.

The promises of SSL are exciting, but currently there are significant technical and application limitations. Companies promoting various LED products are popping up all over. LightFair 2005 was just one example of how many companies are promoting LEDs, and LightFair 2006 has even a higher percentage (LightFair 2006, 9-10).

The excitement of designers, architects, engineers and even early adopter retailers and consumers for LEDs makes for an easy sales opportunity. However, the end-user market will not know the difference between low-quality premature product and higher-quality products. The market will expect the energy savings and performance benefits as publicized and may not understand the difference between laboratory accomplishments and real world application. It must be remembered that there is a gap in time between laboratory accomplishments and implementation into the commercial market (Ryan 2006).

Furthermore, some of the LED products available today are marketed as "energy-efficient," but actually have very low light output compared to typical light sources. The combination of high price and low light output may actually make them a poor replacement for current technology. (Navigant Consulting 2006)

It is important to compare new LED products to the most efficient conventional technology (such as fluorescent or metal halide) that could be used in a specific application. The performance and specification issues below provide insight into some of the designer's needs and why LEDs are not ready for prime time white light illumination – it is not a matter of just efficacy or just color.

Life expectancy is a critical issue in cost justifying LED sources. The LED industry and the DOE are working hard to set standards and testing methods for LED life expectancy based on lumen depreciation. Further,, the Lighting Research Center and the Alliance for Solid-State Illumination Systems and Technologies (ASSIST) have recommended criteria (ASSIST Recommends 2006). In the meantime, lighting products are being marketed as anywhere from 50,000 to 100,000 hours. Until product manufacturers adapt those standards, it is impossible for designers to determine the true average life expectancy of the products. Also, as with other light sources, designers need to understand how the LEDs will perform within the particular fixture being specified since the fixture temperature can vary significantly from the ambient air temperature or controlled laboratory environment.

Heat directly affects the performance (lumen output) and life of LEDs. Thermal management is important to improving the performance of white LED light sources for ambient illumination and task lighting for interior commercial applications when enclosed in interior fixtures or installed in tight spaces. As an example, when T5-HO fluorescent systems became popular a few years ago many designers got "burned" because they specified T5-HO systems only to find out that at cooler temperatures the lamps did not provide the specified light output. Today, several manufacturers list two different light levels for T5-HO systems, depending on the ambient temperature.

Color temperature is another important element of lighting design. When specifying other light sources, designers can rely on the color temperature to be within a given range. This allows for uniformity of color temperature throughout the lighting project, and designers can blend different lighting sources while maintaining a similar appearance. Similarly, the availability of spectral distribution charts that show the source's strong and weak wavelengths allows the designer to anticipate how the lens of the lighting fixture will appear and how objects, fabrics, and people will look under the light source. One question in the design community is whether designers can rely on LEDs to produce the advertised color temperature based on current production standards (Schwartz 2005). Also, with the various methods of how LEDs produce white light, will reliable spectral distribution charts be available, and will the distribution be consistent? It should also be noted that most of the high efficacy LEDs are being produced in cool color temperatures (over 5000K) and not the warmer color temperatures specified in many office and retail applications.

Color rendering refers to the lamps ability to color objects "correctly." The color rendering index of a source is a general indicator of how colors will appear when illuminated by that particular light source (Rea et al. 2000, G7). While manufacturers list the CRI for lighting sources in their catalogs, this information is not always readily available for LEDs. While there are efforts underway to address issues with CRI as a means for evaluating LEDs (Dowling 2005, 50), this is the method the lighting design community uses for all other sources and the community may be hesitant to adapt an entirely new system just for LEDs.

A standardized reporting method for LED system wattage is needed in the same way it is available for other lighting sources. When evaluating a flood lamp, an MR16, a fluorescent or high intensity discharge luminaire, cove lighting, or other traditional sources designers know the total wattage input of the system based on standardized reporting methods. Many of the LED products marketed today reference only that the product uses "X" number of one watt LEDs, but will fail to report the total wattage consumed by the system including the driver or other electronic components. This information is necessary for designers to calculate power loads, energy efficiency, and energy code compliance based on watts per square foot.

A standard photometric report (Standard IES Photometric File) was developed by the Illuminating Engineering Society of North America (IESNA). This standard system used by lighting manufacturers in testing and reporting allows designers to make easy comparisons of light sources and fixtures (Rea et al. 7-17). Additionally, the electronic versions of these reports, readily found on manufacturer web sites, can be input into lighting software so the designer can anticipate how much light is getting out of the fixture and where it is going. While some White LED lighting product manufacturers have become to supply designers with standard photometric reports, others need to adapt to this same system before their products can be specified by the design community.

A luminaire efficiency rating standard for LED fixtures, which is standard for some other types of general illumination fixtures, would allow designers to better compare products. It is not just the efficacy of the LED that is important, but the efficiency of the complete system. In the case of many commercial, linear fluorescent fixtures this is based on a Luminaire Efficiency Rating (LER). In residential fixtures a more comprehensive energy efficiency and quality standard was set as part of the ENERGY STAR® Program. A similar set of standards for LED lighting products would make it easier for designers to determine if the products are ready for specification and to distinguish poor quality products from good performers.

A lack of standards has led to confusion in the design community, resulting in frustration with LED technology. Many definitions and standards used in the traditional lighting industry may not be applicable to LED technology. However, standard definitions and metrics will have to be adapted for LEDs and LED lighting fixtures before LEDs are specified by the design community for general lighting applications (Narendran 2006, 6).

Designers want flexibility in component specification of the lighting system. Most other light sources allow the designer to mix and match lamps, power supplies, luminaires, and controls to design their own lighting system, but many LED "lamps" and driver systems can not allow substitutes. The result is forced "sole sourcing" which also affects the cost of the project. When working with conventional light sources, designers select a lamp source, a ballast if appropriate (dimming, high ballast factor, low ballast factor, electronic, etc) and the luminaire. Improved component standardization will allow designers flexibility in creating more cost effective solutions.

Economics still remains an issue to be resolved for designer acceptance of white LED light sources for ambient illumination and task lighting for interior commercial applications, even if all of the aforementioned barriers were removed. Great improvements are being made but LEDs still have a very high initial cost compared to other sources. With a first cost of over $64 per kilolumen for white LEDs compared to $0.60 per kilolumen for F32T-8 fluorescent, and $0.30 per kilolumen for incandescent lamps, LEDs first cost are more than 100 times the cost of the incandescent light bulb (Navigant Consulting 2006, 22). The early adoption of many existing LED colored lighting projects for interior use has been in the high end retail market and casinos where budget is not as important an issue. First cost remains an issue for other markets.

The good news is that as performance improves and prices drop over the next few years (or perhaps even sooner based on current market trends), the life cycle cost savings will justify the use of LEDs for general illumination if the other issues are resolved. However, life cycle cost can only be used to sell a project if designers can accurately predict the life of the LEDs within the specified system. It must be remembered that there is a gap in time between laboratory accomplishments and implementation into the commercial market (Ryan 2006).

First cost still remains a barrier for the design community that must specify lighting projects within a budget. With over 40 percent of all 4ft. linear fluorescent lamps sales still T-12, compared to the more energy efficient T-8 and T-5 technology, (NEMA 2005) it is hard to deny that first cost is still an issue.

Emerging Trends and Applications

The efficacy of white LEDs in both warm and cool temperatures is definitely improving based on manufacturer weekly press releases reported in several magazines dedicated to reporting about LEDs. Laboratories and research institutes are reporting successes as well. It is anticipated that any actual number (lumens per watt) reported in this paper would be outdated by the time it is published.

While the previously mentioned barriers may limit the acceptance of white LEDs there are some niche markets that are quickly emerging and being promoted to the design community.

Task lighting is an emerging market. While some of the initial applications included desk lamps and under-cabinet lighting, the trend is growing to include other applications such as reach-in coolers and freezers, library shelves, and applications where the white LED light source is being placed close to the target object.

Decorative lighting, where light output may not be critical, is another emerging market. In the same way that colored LED light was used to create moods and effects, some designers are using white LEDs as a decorative element or to highlight areas to attract attention. Digital programming and controls offer the benefit of timed and sequenced effects that create a focal point with an LED "light show."

Egress and stairway markers are being marketed because of their small size and long life. The ability to install small, two-inch by two-inch luminaires or to bend continuous rows of LEDs to flow with the stairs' outline makes LED technology attractive for the application.

These are just some of the emerging trends and applications for white LEDs that hold promise to meet the design community needs. Other applications that are becoming popular with manufacturers are recessed downlights, MR-16 lamps, and LED "A" type lamps (typical incandescent bulb shape) to replace general service incandescent. Some of these products are bunching together several LEDs into a small tight package that may cause excessive heat, which can affect the long term performance.

On the bright side, one recent press release announced a recessed downlight that continuously produced more than 700 lumens using less than ten watts with a white light source (3200K) with a CRI of 92 (LED Lighting Fixtures, Inc. 2006). The product was tested by an independent lab after reaching thermal equilibrium. If durability and thermal control can be achieved, this type of product offers great potential for designers. While the 700 lumens is slightly less than a standard 65 Watt flood, if photometric reports are provided, then designers can evaluate if the product can deliver the light to the work plane.

A sophisticated engineering design that balances the choice and arrangement of LED devices with appropriate thermal controls and optics is required to ensure good performance. In each application the designer needs to know more than the energy savings based on the LED wattage and the lumen output. They need to know if the product will really perform in terms of effective illumination from the complete unit, the total energy consumption, durability, and the other performance issues mentioned earlier.

Opportunities for Utilities and Energy-Efficiency Organizations

Product performance, standardization, flexibility, and economic issues of white LED light sources for ambient illumination are key issues to understand and address if LEDs are to be accepted by the design community. Designers have to please their clients. This means designers must know how the product will perform over the entire useful life. This requires more than evaluating the lumen output of the LED.

One of the best opportunities for energy-efficiency organization and utilities is to support, either directly with funds or with other methods such as case studies, LED product research. A good example of this is the reach-in freezer LED lighting project being sponsored by the New York State Research Development Authority (NYSERDA) at the Lighting Research Center (Raghavan et al. 2002). By helping to fund research, test market the product on a limited basis, and then report the findings in a case study, other researchers and manufacturers are able to improve on the product and designers can better analyze if the product is ready for specification. Similar studies are needed for white LED general illumination products.

Another opportunity exists in working together as a community to help support system standard efforts for efficiency and quality. This goes beyond accepting products based on the "reported" lumen output of the LED or the wattage of the light source. Energy-efficiency organizations need to understand the performance metrics and standards being considered by various organizations. The development of national standards and rating systems for new products enables designers and consumers to compare products made by different manufacturers, since all companies must test their products and apply the rating in the same way. No ratings or standards have been adopted industry wide (yet) for SSL products. The DOE is in the process of implementing programs to enable standards activities, and standards-setting organization like National Electrical Manufacturers Association (NEMA), the American National Standards Institute (ANSI), and others have been working on setting standards. ASSIST is conducting research to develop information that can be useful for establishing metrics and setting standards. (Narendran 2006, 7).

Standards for brightness, life, consistency, and energy efficiency are all part of the lighting system performance. Supporting standard product reporting will allow energy-efficiency organizations to evaluate the products before trying to promote them to the design community. Setting standards is nothing new to energy-efficiency programs. Programs such as NYSERDA's **New York Energy $mart^{SM}** Small Commercial Lighting Program and Smart Equipment Choices Program set standards for both efficiency and quality (NYSERDA 2006). Similar standards can be set for LED lighting products in the same way the ENERGY STAR® program sets standards for energy efficiency and quality. Setting standards will help utilities and energy service providers avoid offering incentives for untested, unproven LED products that can not verify short term and long term performance. If energy-efficiency organizations offer incentives on products that do not meet designer and end-user needs the bad news will spread like wildfire and spoil the market (at least regionally) for LEDs, delaying market transformation.

In order to properly evaluate energy efficiency and performance, energy-efficiency organizations need to understand what makes a product good beyond simple manufacturer claims. To do this they need to stay informed of the LED issues and developments. NEMA, DOE, and Next Generation of Lighting Alliance web sites all offer relevant updated information. In addition, laboratories and research institutes provide documented information and case studies, while manufacturer product information can be found in on-line publications.[3] Staying involved and updated will position energy-efficiency organizations to support the proper technologies when the time is right.

National efforts are underway to showcase successful LED lighting products. Energy-efficiency organizations can benefit by supporting these efforts and learning about the "winners." As an example, the 2006 Lighting for Tomorrow program includes a solid-state lighting (SSL) competition. The contest, organized by the American Lighting Association, the Consortium for Energy Efficiency, and the U.S. Department of Energy, is designed to encourage and recognize attractive, energy-efficient residential lighting fixtures. The SSL competition will help spark an exploration of the use of SSL in niche applications (Lighting for Tomorrow 2006). Developments in the residential arena will aid product development in other areas and should be supported by energy-efficiency organizations. Similar efforts on a regional or local basis by energy-efficiency organizations could further help develop products that effectively use LEDs to provide good quality white light.

Energy-efficiency organizations should share information on successes and failures. Information sharing should include the specific applications where LEDs had problems and also applications where they performed well. Sharing this information can help prevent pre-mature promotion of products that are not ready for prime time.

Energy-efficiency organizations should continue to promote and offer incentives on the proven colored and monochromatic products. This will help keep the SSL economically solid, allowing for further research and development while reducing energy consumption. As white

[3] Additional relevant web sites are included in the reference section.

LED efficacy improves, system efficiency is increased, quality and performance barriers are overcome, and standards are developed that will allow energy-efficiency organizations to properly evaluate white LED products. A time is approaching where this will be the case and energy-efficiency organizatons need to be ready to offer incentives to help drive down first costs.

Conclusion

Because of their enormous potential for energy efficiency, LED technology deserves the money and attention it is getting for research and development, especially for commercial and residential lighting. The rapid increase in lumen output and efficiency proves that white LEDs are on their way to becoming an energy-efficient white light source. But beware! White LEDs are at great risk of market failure because of premature marketing, selling and promotion.

Performance of an LED in laboratory conditions is not necessarily an indication of how it will perform as part of a total system. LEDs are part of an entire system that must be evaluated based on uniform testing and performance standards.

In order to gain acceptance from the design community, the barriers to LEDs must be overcome, standard testing and performance standards must be set by the industry, and that information should be provided in the same format as other lighting sources to allow for reasonable comparisons and importing into lighting software tools. Further acceptance by the lighting community will be hastened by component compatibility that will allow the designer to better 'mix & match" LEDs, drivers, and controls.

No one can keep any company from introducing a low-quality product, but energy efficiency organizations need to be well positioned to set expectations and provide the marketplace the know-how to recognize higher quality products.

Energy-efficiency organizations can help market transformation to white LED lighting by supporting existing proven technologies, encouraging research and development, supporting standardization efforts, being knowledgeable about the performance and quality issues, sharing information, and being prepared to promote white LED lighting products when they are ready and not before. Though strategic efforts and cooperation with the solid state lighting community, associations, government agencies, and each other, energy-efficiency providers can help set the stage for timely and rapid acceptance of SSL products without experiencing the pains of the early CFL market failure.

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