Considerations for Successful LED Applications

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Invited Paper

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ABSTRACT

LEDs systems are now favorably competing with traditional systems in many architectural lighting applications. LEDs offer many unique attributes not available before in other light sources. However, matching the needs of each application to the specific attributes of LEDs is critical to achieving successful applications.

INTRODUCTION

Light emitting diodes (LEDs) are now one more light source in the repertoire of lighting designers and users. New technologies typically offer one of two possibilities, namely either an incremental increase in performance or a completely new way to approach certain applications. Certainly, LEDs promise to enable the later, but the question is how to effectively use LEDs to achieve successful applications.

Much has been done to promote the use of LEDs in many different lighting applications, from colored-façade lighting to white light general illumination and while LED technology has been used successfully in the past for signaling and display applications, currently this technology is in a very important stage of its development. New markets for general illumination continue to open and LED manufacturers worldwide are diligently working to improve efficiency, color qualities, and light output of LEDs. With increased light output, LEDs now can be used beyond traditional indicator applications to provide illumination in a variety of indoor and outdoor applications. Considering their unique features, there is a great possibility that LEDs may one day change the way we light our living spaces. In the meantime, the selection of LED lighting solutions for use in various lighting applications will depend on the value they bring to each application.

LEDs are evolving rapidly; hence, they are starting to offer benefits in many more niche applications. Among the many reasons for this is that LEDs have distinctive features that offer the possibility for unique solutions that were not possible with conventional light sources. Many believe that LEDs will replace all light sources for all applications in the near future. While there is some truth in that belief, all light sources at one point or another have won out against their competitors, mostly because each technology excels at some aspects over other technologies. Some light sources are more efficient at producing light, whereas others last longer, and yet others have better color properties, for example. Also, most technologies are available in numerous packaging options, including a wide range of wattages, light outputs and sizes, to name a few. This large variety of light sources facilitates their use in a wide range of applications with different requirements.

Despite its many benefits, LEDs still face difficult competition for general illumination because success is defined by correctly matching a technology with the needs of the application, and not by a comparison of technology characteristics in absolute terms without a context. In other words, metrics such as efficacy, color rendering index, light output, life and the like are almost meaningless without a context for comparison among technologies. This is why it is so important to understand not only the strengths of a given technology but its weaknesses as well, and how these characteristics change depending on the specific conditions of the application. The reader is encouraged to keep in mind that the effectiveness of a given technology depends upon its application and not upon the intrinsic characteristics of the hardware. Effective lighting design is not about the knowledge of lighting technologies, but about knowing where, when and how to apply those technologies. Hopefully after reading this paper, the reader will conclude that it is advisable to not force LEDs into every imaginable application without due diligence. LEDs are evolving at an amazing pace, but the technology is mature enough to compete with traditional light sources only in some general illumination applications. An aggressive approach would probably set up LEDs to fail in many cases, creating disappointment and making market adoption more difficult. The reader is encouraged to keep in mind that the value of LEDs is in the possibility to rethink traditional lighting solutions, rather than in retrofitting older technologies on a one-by-one basis.

This paper outlines general concepts for the effective design of lighting with LEDs, specifically in architectural applications presenting opportunities for their successful use.

UNIQUE ATTRIBUTES OF LEDs

Lighting designers strive to create safe, functional, and visually pleasing environments. Designers are also constantly looking to provide innovative lighting solutions, but always within the schedule and budgetary constraints of each project. Ideally, the lighting design process results in a solution that balances the user's needs, the economics and environment, and the architecture. Among the tools that designers use toward this end include a set of lighting techniques (such as wall-washing, accent lighting, sparkle elements, etc.) and the knowledge of how lighting hardware performs in order to create visual effects by using such lighting techniques.[1][2]

In the past few years, the lighting industry has focused on the potential for long life and energy savings offered by LEDs as their two main benefits, but in fact there is more to it when it comes to selecting a light source for a given application. In other words, there are many applications for which these two factors may not be as important as others. In order to make a selection of lighting equipment for general illumination, designers look into many characteristics of light sources and fixtures and may ask some of the following questions:

- Does the lighting fixture provide greater flexibility than other fixtures?
    - Is it easy to apply? Does the light source provide a wide range of light outputs, beam distributions, and color properties? What are its control features of light output and color?
- Is photometric data provided, and in a familiar format?
- Does the fixture have a pleasing appearance in the space (visual aesthetics)?
- How much does the lighting installation cost, including initial, installation, commissioning, maintenance, and energy costs
- Is the fixture easy to relamp? And, is it easy to obtain replacement lamps?
- Is the lighting fixture appropriate for retrofit or new construction?

Comparison between lighting technologies is a thorough process that can only be made with an understanding of the different features and functions that are required from the lighting equipment. It is worth emphasizing that comparisons ought to be made at system level rather than at component level and whenever possible under realistic conditions rather than under ideal laboratory conditions. The reader is encouraged to consult publications that offer more detailed good practices for different applications and guidance on how to select LED equipment.[1]-[5] The most relevant features of lighting systems are outlined below.

1. Photometric features

a. Light output and intensity distribution
b. Light output depreciation
c. Color properties: correlated color temperature (in kelvin) and color rendering
d. Starting, warm up, and restrike time
e. Color consistency
f. Ultraviolet and infrared radiation

Presently available LED products can compete favorably with traditional light sources in terms of the above photometric features while offering an advantage in some other aspects. For example, there are a relatively large number of applications that can benefit from a distributed light source with low light output, such as undercabinet lighting, pathway lighting, edge lighting, and many others. Another unique attribute of LED systems is the potential for minimal infrared and ultraviolet radiation, which results in reducing considerably the potential to damage light sensitive objects. This is particularly beneficial in applications such as museums and retail shops. Furthermore, an RGB system used to illuminate objects of art would provide, for the same illuminance and correlated color temperature as with an incandescent lamp, significantly less radiation onto the surface of the object.[6]

2. Electrical features

a. Power conditioning needs (e.g., is a ballast or driver required? Does the system run on alternating current or direct current? Does the system operate at line or low voltage?)
b. Effect of burning cycle duration (on and off cycles)
c. Dimming characteristics
d. Warm up and re-strike characteristics
e. Safety during installation, use, and maintenance

LEDs are direct current (dc), low voltage devices that perform best when operated at constant current. [7] Because of this, LEDs can be easily and efficiently integrated into photovoltaic or other dc systems. Interestingly, dimming (i.e., driving LEDs at low currents) usually increases the energy efficiency of the device. This gain in efficacy at lower operating currents is certainly an advantage over fluorescent and incandescent technologies. In the case of fluorescent lamps, dimming is not generally thought to compromise significantly the system's efficiency,[8] but anecdotal evidence suggests that lamp life may be affected if the ballast and lamp combination is not fully compatible. However, incandescent lamps suffer great decrements of efficiency as they are dimmed, along with significant changes in color temperature.[8] Furthermore, spaces where frequent on and off cycles are present, such as high use areas controlled by occupancy sensors, and where light sources with long warm-up times are not desirable can benefit from LED technology. With the innumerable possibilities that electronics offer, LED technology easily lends itself to different control strategies to further increase flexibility or energy savings. Continuous and multi-level dimming, load-shedding, and integration with occupancy sensors are just a few control features that could be designed easily into LED drivers. None of these features poses any special requirement on the LED itself.

3. Thermal management

Thermal management of lighting fixtures is one of the most challenging tasks of fixture development. It is even more difficult in the case of LED technology, given the significant amounts of heat in very small areas. LEDs are notoriously more sensitive to temperature effects than any other light source.[8] However, unlike any other light source, LEDs have the potential for extremely long life; because of this, some applications may allow LED equipment to become part of permanent structures, such as in elevators, bridges, or suspended ceilings, helping to dissipate heat more efficiently.

4. Economics and general performance

a. Life of the equipment
b. Ease of maintenance and reliability
c. Total cost of ownership (initial, maintenance, and energy costs)

The promise for long life of tens of thousands of hours is one of the most attractive characteristics of solid-state technologies for general illumination, especially in applications where maintenance is difficult or expensive. Long life is usually associated with lower total cost of ownership, a very important factor when selecting lighting equipment. However, LED-based systems have yet to fully demonstrate this capacity. Under nominal operating conditions LEDs rarely burn out or fail catastrophically. Rather, as with most light sources, the light output of LEDs decreases gradually over time.[9][10] This non-catastrophic failure mode of LEDs enables service companies to schedule lighting maintenance, as opposed to having to respond to burned out lamps as soon as a failure happens. Although the useful life of LEDs is expected to reach tens of thousands of hours, it is important to keep in mind that the end-user is mostly interested in the performance of the system as a whole. The useful life of LEDs integrated in a system certainly will depend on the packaging design but mostly on the thermal management solution. The main variables affecting life of a LED within a system are the packaging options (size, materials, etc.); drive current; and the characteristics of the operating environment (e.g., temperature, humidity). It is worth noting that since the degradation of LEDs is so closely correlated to operating temperature, it is necessary to specify the operating temperature at which the system life is reported. The second most publicized benefit of LEDs is the potential for energy savings. Current research is geared toward reaching a luminous efficacy goal of 200 lumens per watt by the year 2012. Although it may seem that, on a one-to-one comparison, LEDs are not ready to save energy in applications that use light sources other than incandescent and some compact fluorescent lamps, it is still possible to achieve savings against other technologies when the needs of the application are fully understood and the system is designed accordingly. In many applications, the promise of energy savings from LEDs comes from the possibility of using light more effectively (i.e., high application efficacy), reducing the losses, and by re-designing solutions that require less light to achieve target design criteria, hence using less power. [1][2][11]-[14]

ARCHITECTURAL LIGHTING APPLICATIONS THAT CAN BENEFIT FROM LEDs NOW

Over the past few years the LED advances and market transformation activities have enabled primarily five architectural applications with white light using LEDs. These are directional (down and accent) lighting, refrigerated display cases, undercabinet lighting, LED lamps and engines for decorative fixtures, and outdoor lighting including area and parking lot applications.[13]

LEDs offer different benefits in each and every one of these five applications, primarily because LEDs are better than incumbent technologies in at least one aspect in meeting the application's needs.

When the needs of the end users are kept in mind, it is easier to design systems that result in successful applications. For example, interest in outdoor lighting has been increasing markedly in the past year. Because of the trends to control and reduce light pollution, energy consumption, and maintenance costs, many organizations are looking at new ways to provide outdoor lighting. LEDs appear to be an ideal light source to provide solutions to these issues while providing additional advantages in terms of fine tuning the spectral composition of the light so that the visual needs at low light levels are addressed. The Lighting Research Center and ASSIST have published a number of recommendations, best practices and evaluation methods for outdoor lighting that address good lighting design, technology requirements, visual needs (visibility, mesopic vision, glare), light pollution, and life cycle costs.[5][11][12][14][15][16][17][18] One key characteristic of these publications is the use of application specific criteria for the performance evaluation of lighting systems. The evaluation is based on how effective a system is at meeting the target criteria of the application. As part of these design tools, an online calculator available at www.lrc.rpi.edu/programs/solidstate/assist/recommends/parkinglot.asp provides guidance to compare the performance of lighting fixtures for parking lot applications independently of the lighting technology they use. As part of the evaluation, this online calculator provides an estimated life cycle cost for each option and aids in the evaluation of additional energy savings by adjusting the light levels needed for the application when the spectral composition of the light source is taken into consideration.

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