Implications

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Solid State Lighting Design Considerations

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Solid State Lighting (SSL) utilizing Light Emitting Diodes (LEDs) is fast becoming a main component of lighting solutions for commercial, institutional, and industrial lighting applications. The rise of SSL to its current notoriety in lighting began in 1962 when General Electric (GE) introduced the first visible LED that generated 0.001 lumens. Since then, LED performance has improved about 10-fold every decade or so.

In 1991, it was the blue LED that enabled SSL to become a viable technology for the lighting industry. With the advent of the blue LED, the ability to create color with lighting using RGB LED arrays became a reality. A RGB LED array is essentially a red, green, and blue LED clustered together. The output of each LED is modulated to create various colors of light. As a result, color changing SSL products soon became available and have seen increasing utilization (e.g., library and retail applications) over the past decade. Additionally, the blue LED is the technological foundation of the white light LED. White light LEDs have spurred even greater growth of the SSL industry.

White light LED technology is proving to be a practical solution for both interior and exterior lighting. The white light LED is essentially a blue LED with a coating of yellow phosphor. The yellow phosphor adds the additional visible light frequencies to achieve white light. As you can see from Figure 1 (p. 2), there tends to be more energy in the blue frequencies. However, to achieve the warmer color temperature, the LED phosphor coating is formulated to convert more of the blue energy towards the red end of the visible spectrum and efficacies diminish as a result. In other words, as LEDs become warmer in color temperature, their efficacy decline.

Today, SSL products using white light LEDs are beginning to rival the efficacy (lumens of light generated per watt of energy consumed) of linear and compact fluorescent sources, both of which are the mainstays of non-residential interior lighting. For outdoor applications LEDs are beginning to challenge High Intensity Discharge (HID) sources, primarily metal halide (MH) source types. While this is an exciting development for the lighting industry, LEDs do present some unique challenges when it comes to specifying SSL solutions.

Special Considerations for LEDs

There are three specific issues that the designer should be aware of when it comes to specifying SSL products: (1) absolute versus relative photometry; (2) LED spectral distribution relative to the Color Rendering Index (CRI); and (3) impact of ambient thermal conditions on SSL performance. Each is defined and described below.

Absolute versus Relative Photometry

Photometry of lighting products is a well-established practice that adheres to a standardized methodology. Until the advent of LEDs as a light source, the standard methodology, known as relative photometry, has applied to all traditional source types (e.g., incandescent, fluorescent, and HID). Relative photometry assumes that a light source consistently delivers a given amount of lumens. For example, a 32-watt T8 fluorescent lamp generates 2900 lumens. This value is consistent from lamp to lamp, and with only minor variances, consistent from manufacturer to manufacturer. Therefore, it is possible, with a high degree of confidence, to predict the performance of any lighting fixture that utilizes T8 lamps. The actual lumen output of a fixture that uses T8 lamps is relative to the total available lumens generated by the T8 lamps.

In contrast, for an SSL product there is no reference "lamp." Any given SSL product may produce more or less light at the same input watts. Therefore, relative photometry is of no value in predicting the photometric performance of a given SSL product over many iterations. As such, the lighting industry has adopted a new standard, called LM79, which establishes that SSL products can only be photometrically evaluated using absolute photometry methodology. That is, only the absolute lumens exiting the lighting product are measured. Absolute photometry allows the lighting specifier to compare SSL fixtures based on the light they can deliver to the space. Absolute photometry requires the specifier to evaluate the LED lighting system efficacy (i.e., lumens delivered per watt of energy consumed) versus lighting fixture efficiency—delivery of light relative to a reference lamp. One very important aspect of evaluating SSL products is for the manufacturer to state that their LM79 photometry is indicative of the performance of all like products. However, the Department of Energy (DOE) CALiPER investigation of SSL manufacturer photometric claims have, in some cases, proved to be problematic (DOE, 2009). For more information about LM79 visit http://www1.eere.energy.gov/buildings/ssl/newtest.html

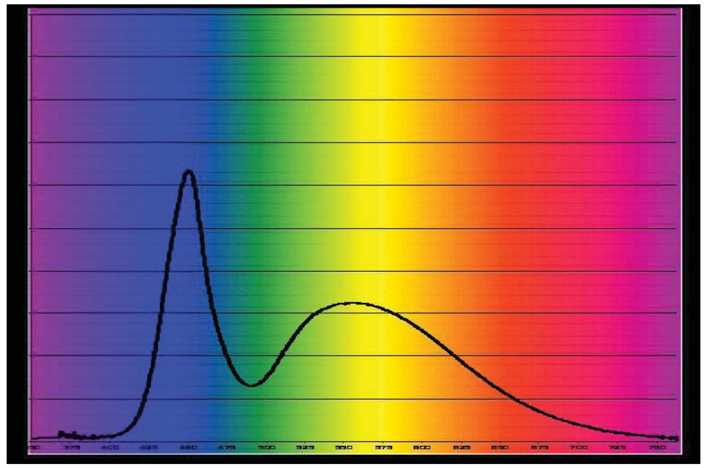

Figure 1: This chart illustrates the tendency for greater energy to be present at blue frequencies.

LED Spectral Distribution Relative to the Color Rendering Index (CRI)

CRI was established to help designers predict how different light sources would affect the human perception of color. The index is based on an incandescent light source and therefore a CRI of 100 would replicate a color as viewed under an incandescent source. However, the CRI calculation penalizes light sources for shifts in hue, chroma (chromatic saturation), and lightness, in any direction. While a decrease in chroma always has negative effects, an increase in the chroma of objects is considered desirable in many cases. Increases in chroma yield better visual clarity and enhance perceived brightness (Hashimoto & Nayatani, 1994). The net result is that when LED sources are utilized, the CRI value is not a good predictor of color perception by a viewer.

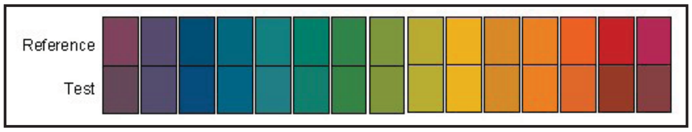

Figure 2: An LED with a CRI of 80 (bottom row) shows significant color shift for saturated red versus the reference colors (top row). Source: http://physics.nist.gov/Divisions/Div844/facilities/vision/color.html.

In Figure 2 above, an LED with a CRI of 80 (bottom row) shows significant color shift for saturated red versus the reference colors (top row). To address this issue, the National Institute of Standards and Technology (NIST) in conjunction with the lighting industry and the International Commission on Illumination (CIE), are working to develop a new standard called the Color Quality Scale (CQS). The CQS evaluates several aspects of the quality of the color of objects illuminated by a light source. This metric involves several facets of color quality, including color rendering, chromatic discrimination, and observer preferences. As a comparison, the CQS for Figure 2 would be 73.

Impact of Ambient Thermal Conditions on SSL Performance

The impact of ambient thermal conditions on SSL performance is probably the most significant aspect of SSL from a design perspective. There is both good and bad news related to the relationship between heat and LEDs. The good news is that LEDs only generate light in the visible spectrum. As such, no infrared or ultraviolet radiation and the heat associated with these non-visible light frequencies is projected into the illuminated space. All the heat generated by recessed SSL fixtures is radiated into the ceiling plenum. Therefore, lighting interior spaces with SSL will reduce HVAC loads as there will be less heat to extract from conditioned (i.e., occupied) spaces. The bad news is that heat has a significant impact on the performance of LEDs, both in terms of lumen generation and life.

Thermal management is critical to SSL products performing as advertised. The issue revolves around the area between the LED's P-type and N-type materials (Figure 3) that form the basic elements of the LED chip itself. As the area between the P and N Type materials (referred to as the P-N Junction) heats up, the overall performance of the LED declines. Practically speaking, we cannot measure the P-N Junction temperature in a real world lighting application, but we can measure and control the ambient temperature that an LED lighting fixture must function within. And, it is possible to measure overall fixture performance relative to ambient temperature.

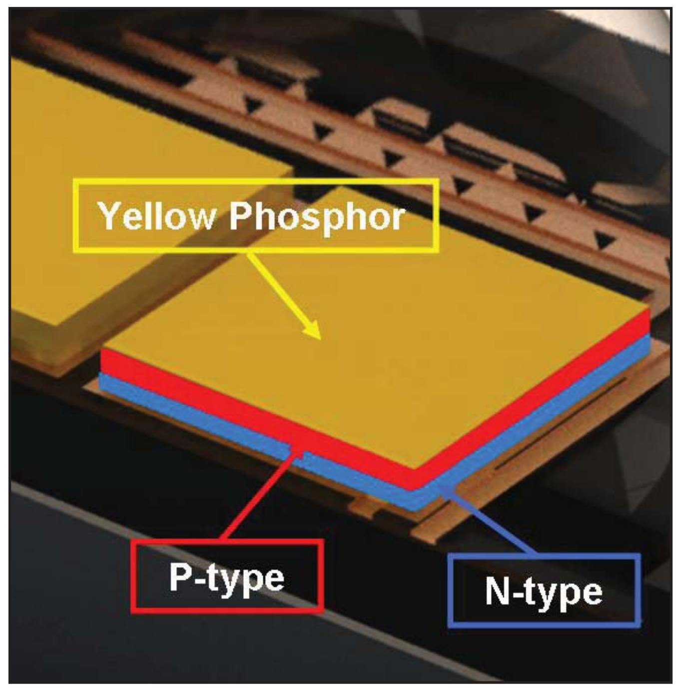

Figure 3: As the area between the P and N Type materials (referred to as the P-N Junction) heats up, the overall performance of the LED declines.

Figure 4 (p. 4) illustrates that a reduction in ambient operating temperature has a direct impact on LED light generation and life. In this example, L70 (green line) is achieved at about 50,000 hours. However, an 11 degree Celsius change in the ambient operating environment significantly improves the lumen depreciation and life of the LEDs. Understanding the required operational ambient thermal conditions of an SSL fixture and choosing products that will perform within that environment are critical to ensuring optimal SSL system performance.

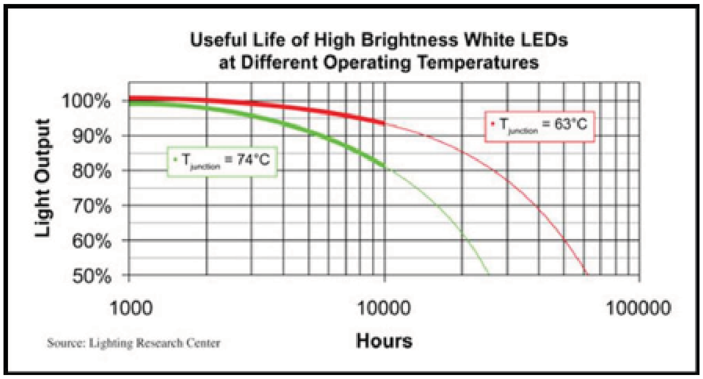

Figure 4: A reduction in ambient operating temperature has a direct impact on LED light generation and life.

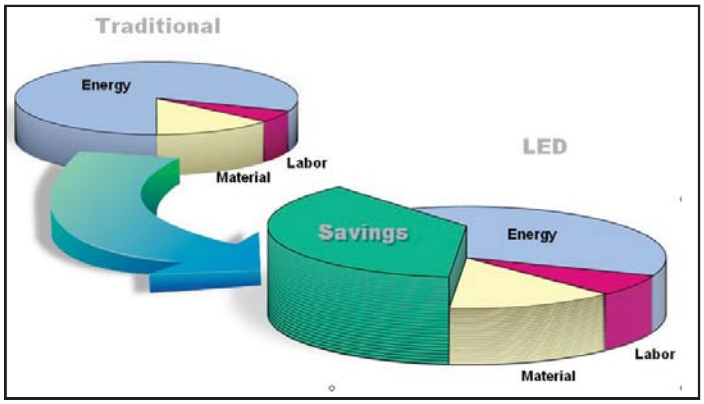

Figure 5: Today, SSL solutions can achieve significant life cycle cost savings, particularly when integrated with lighting control strategies.

Benefits of LEDs

Today, SSL solutions can achieve significant life cycle cost savings, particularly when integrated with lighting control strategies (Figure 5). SSL is not affected by repeated on/off switching and can be easily dimmed. When a SSL fixture is turned on, you get 100% light output with no warm up time required. Because of these unique capabilities, when compared to fluorescent or HID sources, the utilization of automated lighting controls such as occupancy and photo sensors makes perfect sense. Turning lights off when not needed or reducing the light levels in proportion to natural daylight are the most effective and easily implemented energy saving strategies. This is especially true now that LED light fixtures are coming to the marketplace with control capabilities already built into the fixture's electronics. Furthermore, with the advent of "plug and play" sensor devices, the implementation of sensor controlled lighting is easier then ever before, allowing for easy connection of SSL and non-SSL fixtures to lighting controls (e.g., occupancy or daylighting sensors, dimming controls, on/off controls).

As the market for LED lighting continues to grow, so do the demands for reliable information and standards. To this end, the U.S. Department of Energy (DOE) has been working to implement transparency and standardization into the LED lighting industry. There are three DOE programs that specifically address SSL and can be of benefit when specifying lighting: ENERGY STAR®, DOE CALiPER, and Lighting Facts℠. Each is described below.

ENERGY STAR®

According to their web site (www.energystar.gov), ENERGY STAR was first created as a United States government program in 1992, but Australia, Canada, Japan, New Zealand, Taiwan, and the European Union have also adopted the program. Devices carrying the ENERGY STAR logo generally use 20%–30% less energy than required by federal standards. The ENERGY STAR SSL (solid-state lighting) program went into effect on September 30, 2008. The program covers residential, commercial, industrial, and outdoor SSL applications of all types (ENERGY STAR, n.d.). To find out more visit http://www.energystar.gov/index.cfm?c=new_specs.ssl_luminaires

DOE CALiPER

According to their website (http://www1.eere.energy.gov/buildings/ssl/about_caliper.html), the DOE CALiPER program supports testing of a wide array of SSL products available for general illumination, using industry-approved test procedures.

CALiPER test results:

- Guide DOE planning for SSL research and development and market introduction activities, including ENERGY STAR program planning;

- Support DOE GATEWAY demonstrations and technology procurement activities;
- Provide objective product performance information to the public in the early years, helping buyers and specifiers have confidence that new SSL products will perform as claimed; and
- Guide the development, refinement, and adoption of credible, standardized test procedures and measurements for SSL products (DOE, 2009).

For more information on the CALiPER program visit their Web site, noted above.

Lighting Facts[CM]
According to their web site (http://www.lightingfacts.com/), Lighting Facts is designed for lighting buyers, designers, and energy efficiency programs. The Lighting Facts label provides information essential to evaluating products and identifying the best options. Only products that are registered and listed on the Lighting Facts product list may use the Lighting Facts label provided to manufacturers in accordance with the program's requirements. Any unauthorized use, reproduction, or recreation of this label is subject to penalties for trademark infringement (DOE, 2010). For more information visit their Web site, noted above.

Going Forward

In summary, SSL and specifically LEDs are changing the face of the lighting industry at an ever-growing pace. The efficacy of SSL solutions are now beginning to surpass like fluorescent products for interior applications and HIDs for exterior applications. The LM70 photometry standards has been developed to accommodate the unique aspects of SSL fixture performance. The industry is working to establish a Color Quality Scale (CQS) to replace the older Color Rendering Index (CRI) so that designers can take advantage of the enhanced color representation derived from SSL sources. However, industry professionals who specify SSL solutions must be aware of the heat implications in the application of SSL products in real world environments.
LEDs ease of controllability is a key factor in achieving operational savings with SSL systems. The ability to integrate room-by-room control, using occupancy and/or photo-sensing control technologies, enables the designer to more easily achieve sustainable design objectives.

As the SSL industry continues to expand, the lighting industry in cooperation with government agencies are working to bring better information and standards to industry professionals. DOE programs like Energy Star, CALiPER and Lighting Facts are working to formulate standards and better ensure reliable information to designers and their clients. Over the next 10 years, SSL efficacy is projected to continue to grow and pricing will continue to decline. The net result is that over the next three to five years, SSL will become the logical choice for both interior and exterior non-residential lighting applications.

The shift to SSL will continue to accelerate over time as the SSL market transitions from early adopters to early majority. This advance in lighting technology requires all designers to become knowledgeable so that they can evaluate SSL lighting just as they do all other, perhaps better understood, sources. In this way, SSL products will be applied when and where they make sense.

References

— Hashimoto, K., & Nayatani, Y. (1994). Visual clarity and feeling of contrast, *Color Research and Application, 19*(3), 171-185.

—ENERGY STAR (n.d.). *Solid state lighting luminaires*. Retrieved May 20, 2010 from http://www.energystar.gov/index.cfm?c=revisions.ssl_luminaires

—U.S. Department of Energy. (2009). *Energy efficiency and renewable energy solid state lighting: Market-based programs*. Retrieved May 20, 2010, from http://www.eere.energy.gov/buildings/ssl/market.html

—U.S. Department of Energy. (2010). *Lighting Facts.* Retrieved May 20, 2010, from http://www.lightingfacts.com

About the Author

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