

Solid State Lighting Systems and Where They Fit in Modern Lighting Design

The frequency of use of solid-state lighting (“SSL”), also known as light emitting diode (“LED”) technology, in architectural applications is rapidly growing. Recent interest in this still emerging technology has been accelerated and fueled by promises of monumental energy savings. With fuel costs recently spiking and a general public desire for conservation, it is no surprise that such a technology with so many apparent attributes is being thrust into the fore. At no other time has so much public awareness of a new lighting technology been so strong. We are not just seeing articles about LED’s in our own trade magazines anymore. We now see them in mainstream publication from our own local paper, to the Wall Street Journal, to prominent magazines. With public interest peaked, we are being inundated with requests for SSL to be used on projects, without regard to the feasibility. We along with the design community need to be prepared to counsel people on the appropriate use of this technology.

There is little doubt that SSL technology has much to offer; it is destined to become a staple in our lighting instrument tool bag. Nevertheless, it is currently wrought with controversy. During this initial period of flux, there will be misapplications and certainly some premature applications of product. Unfortunately, emerging technology climates, such as this, can be rife with opportunity for the less than honest. We have already seen much evidence of this, in the form of exaggerated longevity and light output claims. Even more, we now have lighting fixture companies who are now working to become electronics experts, and we have electronics companies who are working to become lighting experts. There are disputes on how light from this new technology should be measured. Discussions abound on the topic of photopic vs. scotopic vision, and on whether we should be measuring light from raw LED’s or from the actual output of fixtures (relative vs. absolute photometry). The bottom line is that there is a lot of information to digest and disseminate. The purpose of this paper is to outline the facts surrounding solid state lighting technology, as they stand today. Our hope is that this paper will help guide interested parties through the abyss of information and misinformation, and will assist in applying the technology properly and responsibly.

Since this technology is a moving target, we realize that anything we write today will most likely be outdated very soon. With this in mind, it is our intention to revisit our statements and positions on at least a semi-annual basis.



Effects of Rapidly Changing Technology:

With millions of R&D dollars being spent on SSL technology, it is no surprise that things are improving rapidly. Efficiencies are improving at a monumental pace. As wonderful as this is, there are detriments to such a quick evolution.

First, lighting fixture manufacturers are finding it difficult to apply the technology. When you consider that product development in the lighting fixture world can take from months to years, imagine trying to incorporate a lumen generator with characteristics that change monthly. By the time a fixture design is complete, the LED source intended for use in it might well be obsolete.

Second, this affects the end users, too. A building owner, who has SSL installed in his facility, may soon after be faced with an inability to replace defective units, due to discontinuation as a product of evolution.

Correlated Color Temperature (“CCT”):

How do we get different color temperatures?

LED’s do not inherently produce the warm white light we are used to in other artificial light sources. There are two primary ways that we can alter the color temperature from LED’s. The first is by using colored LED’s and mixing their output. With this process, most any color can be attained. This technology, also known as additive color mixing, is used in many architectural color-washing applications and now in theatrical venues, as well. This is a wonderful solution for these types of applications. However, it can be expensive and cumbersome, as the use of control systems must be incorporated. The more common way to achieve white light is by adding a phosphor coating to the LED. Much like in fluorescent lighting, the phosphors allow us to affect the color of the output. Unlike fluorescent lamps, the more we warm the output from the LED, the less efficacious they become. (White LED’s are inherently very cool, about 6500 degrees K. You’ll find that most ultra-high light output claims from LED manufacturers are not using color corrected products; they are not using products that we would actually incorporate into a typical architectural lighting design.)

So why do we care about CCT? Why not just go for the efficacy?

With all architectural lighting systems, the design involves a series of compromises. If one was looking only for pure efficacy and cared nothing about visual comfort, he or she would use all open lamp fixtures. Since visual comfort is a concern, reflector systems are used. These systems redirect light and shield eyes from unwanted glare. So it goes with SSL products and CCT.



Over the years we have found that CCT and high color rendering (the ability to better distinguish color) can have a profound positive effect on the mental and psychological well being of people. Modern office spaces have substantially benefited from improvements in this area, with improved productivity and lower rates of employee absenteeism. It is also important to be able to closely match the color output of adjacent sources that might exist, such as fluorescent and ceramic metal halide. If we didn't, aesthetics would suffer greatly.

How do we achieve consistent color temperature in LED's?

Manufacturers of LED's that are intended for use in architectural lighting incorporate a process called binning to categorize the different color temperatures. Binning is a manual process, performed by people who look at the color output of a given LED using a spectral radiometer, and then assign each one to the appropriate color temperature category based on a range. In order to gain a higher degree of accuracy, some companies will repeat this process several times. The idea here is that each time the process is performed, a higher level of accuracy should be attained. As you can imagine, there is much room here for variances in interpretation, and therefore variances in actual results.

The real world problem that comes from this process is primarily color temperature variations between batches of fixtures. Fixtures replaced under warranty or in a project addition might not match the original, adjacent fixtures. Even in a situation where all new fixtures are installed at once, but came from a manufacturer's stock, they still might not match. Here, there might not be a way to guarantee that all the fixtures in a manufacturer's stock came from the same batch; it would depend on how much time and focus the manufacturer put into the process.

Outdoor Lighting:

In the outdoor world, there is a push from some to limit the Kelvin temperature of artificial light sources to a maximum of 4125 degrees; this is the CCT of moonlight. The argument is that anything above this threshold can have negative effects on nocturnal wildlife and can add to sky glow issues. Nevertheless, you'll find that the Department of Energy tends to favor the higher CCT's solely based on efficacy.

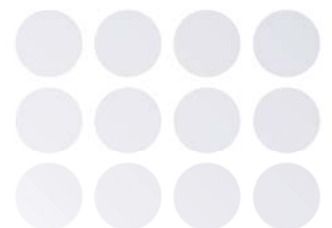


Photopic versus Scotopic Photometry:

Discussions of photopic vision versus scotopic vision, as they pertain to artificial light sources are not new. However, the recent push in the SSL field has brought these discussions to the fore. Human vision utilizes both rods and cones, which are components of the eye. The cones allow us to see in color, but require higher light levels. This represents the photopic range. The rods allow us to see in low light, but only monochromatically. This represents the scotopic range.

Because the rods in our eyes are more sensitive to the blue portion of the spectrum, and white LED's in their most natural state emit light in the 6000 degree plus Kelvin range, it stands to reason that some SSL manufacturers promote their products as being ideal for low light level applications. The argument being that since the rods in the human eye better utilize the cooler color temperature light, less light is needed to see just as well. Though there is some merit to this approach, part of the equation is still missing. For the full benefits of scotopic vision, where only the rods are used, to be realized, the lighted area in question must be uniformly lit to a low level without the introduction of glare. This scenario can be almost impossible to attain, as just one set of headlights from a car in the area is enough to disrupt human scotopic vision. Additionally, most current SSL area lighting fixtures have not sufficiently addressed glare control issues in their outdoor lighting fixtures. Once our scotopic or night vision is disrupted, and sufficient light for photopic vision is not available, it can be difficult to see. The fact is that in most metropolitan outdoor lighting situations, the human eye is actually working in the mesopic range, in between scotopic and photopic. Here the rods and cones both contribute to our vision.

Because of the added benefit that higher Kelvin temperature light offers to scotopic vision, there is a push from some SSL manufacturers to reassess the means by which we measure light in the outdoor and other low light level arenas. As previously discussed, this idea has little merit as it does not take into account the mesopic range, which is most commonly used. There is another means of measurement being proposed by the Lighting Research Center at Rensselaer, which is more unified. It accounts for both photopic and scotopic luminous efficiency functions and it weights them according to the light level in the area. The result is a system of measurement that is more meaningful no matter how high or low the light level.



Warranties:

Most lighting fixture manufacturers offer a one year limited warranty on their products. Manufacturers of SSL fixtures need to offer longer than standard warranties. The warranty of the product should better reflect the manufacturer's claims of longevity and should cover the entire fixture. Since this new technology is such an integral part of the fixture, and the way any given manufacturer handles thermal issues can vary greatly, all components of the fixture should be covered by a common warranty from the fixture manufacturer. This would eliminate finger pointing between component manufacturers, thus shielding the end user from the associated negative effects that would certainly harm the reputation of the SSL industry. Building owners are being asked to put forth major investment capital for this emerging technology; in return, they should be offered a better than normal insurance that their dollars will not be wasted. A warranty is only as good as the company behind it. For this reason, the companies offering the warranty should be highly scrutinized and their long term viability fully assessed. There are large numbers of companies entering the SSL field, every day. Much like we saw in the fluorescent industry in years past, there will be many who fail. There will also be those who are in it for the long run, and will invest the necessary resources to rise to the top. These will become the leaders in the SSL industry. Only those companies with the resources to continually offer well engineered, top quality products that they can and will stand behind for the long run will survive.

Lamp Life:

It is important to keep in mind that though SSL products can last a very long time, they still have a maximum useful life. The Department of Energy defines the useful life of an LED as the point when the light output from an LED diminishes to seventy percent of what it initially produced. Most major brands have followed suit, in using this definition. SSL lighting products degrade in light output over time, but generally do not fail outright, like traditional sources do. This characteristic might cause some liability issues. For instance, if an SSL lighting system is used in a public parking garage, and no one is responsible for monitoring the actual light levels in that garage, over time the light levels could fall well below the design criteria levels. In this case, if someone were injured and low light levels were found to be a component of the blame, most certainly the facility owners could be found at fault, and subsequently held accountable. Though this scenario could happen with any traditional lighting system which is not properly maintained, it would be less likely.

Generally speaking, when a lamp goes out, that triggers maintenance. Since the LED's would not fully extinguish, there would be less likelihood of a maintenance trigger. In other words, people don't generally replace working lamps.



The diminishing light output issue needs to be addressed by the SSL industry. One thought is to build in on board monitoring, that would somehow alert the building occupants when a fixture's output has dropped below recommended levels.

The primary enemy of LED's as with any electronic component, is heat. Proper heat dissipation is a key component to long life. Though LED's don't emit heat out the front, where they emit light, heat does exist at the junction within the LED, and is normally radiated out the back. If the junction temperature gets too high, the LED will dim and prematurely fail. Generally speaking, lower junction temperatures allow for longer life and higher light output. Reputable SSL manufacturers will publish their junction temperatures. If a manufacturer will not offer this information, they should be avoided.

SSL Product Standards:

What the SSL industry has been lacking are standards. Without standards, anyone can make any claim, virtually unchallenged. This type of issue has been prevalent in the vitamin and health food industry, for a long time now. Unsubstantiated claims that go unchallenged can suddenly become fact to the uninformed. Fortunately we now have some guidelines.

IESNA has recently adopted two approved methods for evaluating SSL products:

IES LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products.

LED is recognized as a unique light source requiring different evaluation methods.

Photometric info requires includes total luminous flux (lumens), luminous efficacy (lm/W), luminous intensity (candelas) in one or more directions, chromaticity coordinates, correlated color temperature and color rendering index.

Testing the LED fixture is recommended.

IES LM-80-08 Approved Method: Measuring Lumen Maintenance of LED Light Sources.

LED's exhibit a long life and unlike traditional light sources don't fail catastrophically. Over time lumen maintenance can result in lower light levels than the specification intended resulting in potential conflict with local codes or regulations. Additionally gradual shifts in the emitted spectra over time may result in unacceptable appearance or color rendering. Lumen maintenance is also affected due to varying spectral power distribution influencing lumen output.

Standardization is essential to the specification community and to sales consultants serving the design community. Many of the unverifiable claims will hopefully disappear with this standardization. With standardization in testing, true comparisons between fixtures can be made.



LED's and Fixtures:

Light output and longevity characteristics of LED's can vary greatly depending on the environment in which they reside. In other words, an LED in a test lab may, and most likely will, act completely differently than an LED in a fixture. This is due primarily to heat dissipation issues. The light output and life expectancy of an LED can degrade greatly when the junction temperature within the LED rises. Increases in ambient temperature can easily translate into increased internal fixture temperatures. This can then translate into a higher junction temperature within the LED, resulting in shortened LED life and lower light output. In short,

any given LED can have completely different life expectancy and net light output when subjected to different temperature environments. This means that we need to test light levels of LED's not in their raw state, but in the fixture they will reside in. In fact, we need to test the actual output of the fixture itself. Only from this can true comparisons to more traditional lighting fixtures be made.

Disclosure is also important. The manufacturer of SSL equipment should readily share information including the brand of LED, junction temperature, and the ambient temperature their fixtures are designed to reside in. These factors can greatly affect light output and longevity. With this information, along with the LED manufacturer's recommendations, a specifier can reasonably ascertain if a fixture manufacturer's claims are valid, or not.

LED's and reflector systems:

Most current SSL fixture designs incorporate LED's with primarily a direct lighting component; they do not utilize reflector systems. Though, some do employ lenses, or refractors, to affect the distribution of light. Because they do not generally utilize reflector systems, SSL products can achieve higher efficiencies. The actual efficacy of the LED is generally much lower than that of a fluorescent or metal halide source. However, since the light emitting from the LED can directly leave the fixture without multiple redirections from a reflector system, the overall efficiency of the lamp/fixture package can rival that of traditional sources. Add to this the other attributes of SSL technology, such as long life, imperviousness to vibration and cold weather, and you can see why the implementation of the technology is moving so quickly.

There is a primary detriment to the direct output of the LED; that is glare. Glare can be at best obnoxious, and at worst disabling. This is a primary concern for not only indoor environments, but especially for parking areas and street lighting. This issue is a major obstacle that will keep SSL from becoming a primary source of lighting, especially in the outdoor world. The attributes of the SSL are not enough to throw out decades of R&D in glare control and visual comfort.



LED's and the environment:

Sustainability:

SSL by nature incorporate semiconductors. Most are aware that the semiconductor industry has not historically been a particularly clean one. Even so, SSL products are touted as being sustainable and, “Green.” This is primarily due to the general public perception that LED's will last forever and that they consume virtually no energy. Both of these points are untrue. The efficacy of LED's is becoming better, all the time. Right now, though, they are on par with fluorescent at best. This is when they are compared using absolute photometry, or what light is actually getting out of the fixture. As for life, the most common rating being given now is 50K hours. Since a good quality fluorescent lamp is rated at 30K hours, the 50K seems like a good claim until you consider what it takes to replace the LED. In most current cases, the entire fixture has to be replaced. Disposable fixtures can hardly be considered sustainable.

The fact is that most of the current SSL fixture designs do not allow for field re-lamping. Some manufactures do currently offer factory re-working of their fixtures, which is a step in the right direction; but this still falls short of where we need to be. One can imagine the frustration of a building owner faced with hundreds of SSL products at the end of their useful life, when having to deal with the complicated and costly logistics of a factory refurbishment program. Until this problem is rectified, the idea of SSL being generally used as a primary lighting source will remain just that, an idea. Most of the more progressive manufacturers we have spoken to, see a field replaceable LED module as a reasonable goal for their R& D teams. This would allow for continued use of the general fixture envelope and possibly recycling of the replaced components.

RoHS:

RoHS stands for, “restriction on the use of certain hazardous substances in electrical and electronic equipment.” This is a standard from Europe that many US manufacturers are starting to adopt. It regulates manufacturing processes as they relate to the amount of hazardous metals used. The idea is to make electronic products that can be thrown into landfills, without detrimental effects. The metals regulated include, but are not limited to lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB) and polybrominated diphenyl ether (PBDE) flame retardants. ROHS is becoming more prevalent in US manufacturing, too. Most reputable SSL manufacturers are designing to RoHS standards.



Summary:

SSL is a promising technology that will continue to evolve at a monumental rate. However its current uses are still limited today. The purpose of this document is to help the design community understand where the technology is now, and how it can best be utilized in its current state.

With all its merits, today's SSL still does not stack up to fluorescent and ceramic metal halide sources, for general lighting purposes. Until we get a handle on such major factors as cost, glare control without major losses in efficiencies, higher overall efficiencies with lower CCT's, and field replaceable components or modules, SSL products will remain on the periphery of lighting design. Other than in regional pockets, they will be relegated to the limited uses they are currently fit for. These lighting uses include accent, landscape, task, decorative, and other specialty uses where fixtures are hard to get to for maintenance and where they are subject to higher levels of vibration. Other specialty uses also exist where color changing and mixing are required. The key, like with all products, is to weigh all the factors of the project, to see if the attributes of SSL products outweigh the detriments, for the particular use at hand.

Evaluation of SSL products is many faceted. We have outlined what we believe to be the key components in this paper. We urge the consideration of all these points when considering the use of SSL products. It does take extra time to weigh all the factors; however, ignorance and naiveté' can be very costly.

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Related Links:

Illuminating Engineering Society of North America – Homepage

<http://www.iesna.org>

U.S. Department of Energy - SSL Homepage

www.ssl.energy.gov

U.S. Department of Energy - LED Device Lifetime

http://www1.eere.energy.gov/buildings/ssl/reliability_device.html

RoHS Compliance FAQ

<http://www.rohsguide.com/rohs-faq.htm>

ASSIST: Alliance for Solid-State Illumination Systems and Technologies

<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends.asp>



Questions and Concerns for Specifying Solid State Lighting

Is SSL appropriate for the application?

What is the Lumen Output of the fixture?

Has the luminaire been tested per IESNA LM-79 and LM-80?

Are the photometric reports readily available?

What is the total fixture Input Watts?

What is the Fixture Efficacy (Lumens / Watt)?

What is the rated life of the LED?

Do they publish Junction Temperature data?

What is the CRI of the LED?

What is the CCT of the LED?

Are there different CCT's available?

Who is the manufacturer of the SSL components in the luminaire?

Are the SSL components field-replaceable?

Who manufactures the LED Driver?

Is the LED driver dimmable?

What other components would it take to make it dimmable?

What is the rated life of the driver?

What is the Warranty and what all does it cover?

What is the viability of the company in question?

Will they be around to warranty their products?

Is the overall construction quality good?

Is there a maximum ambient temperature the fixture was designed for?

