LED LUMINAIRE LIFETIME: Recommendations for Testing and Reporting

Solid-State Lighting
Product Quality Initiative

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INTRODUCTION

UNDERSTANDING SSL LUMINAIRE LIFETIME

Surprisingly to many, the true reliability and lifetime of light-emitting diode (LED) lighting systems is currently unknown. Even worse, lumen maintenance values of LED devices are widely used as a proxy for the lifetime of an LED lighting system, which is misleading since light degradation or lumen maintenance is but one component of the reliability of a luminaire. For many manufacturers this approach cannot simply be ascribed to overly ambitious marketing efforts, but rather to dependence on anecdotal numbers in the absence of real data. In addition, we can impute simple ignorance in taking specifications at face value which may or may not live up to claims.

It isn't just about the LED. Good LEDs can be incorporated into poorly engineered products and turn the Methuselah of lighting into the exponent of "live fast, die young." The promise of LED lifetime is often presented in terms of hours and years but with little background data to support anything beyond vacuous promises. The statement of 100,000 hours of LED luminaire lifetime has given way to the realization that there is little consistency, very little published data, and few hard facts around so-called luminaire lifetime numbers. The situation is better at the LED package level, where reputable manufacturers have thousands of hours of data under varying conditions. But this is not enough.

To manufacturers and specifiers in the solid-state lighting (SSL) community, the dawning realization is that we need to work together towards understanding the issues surrounding true lifetime and reliability. We need to begin by cataloguing such failures and developing good models for underlying failure mechanisms. This process of understanding and explanation is very common in technological progress. Steam engines existed long before deep understanding of thermodynamic processes. With LEDs, we have a substantial head-start on the underlying physics and many years of experience in both lighting and semi-conductors as well as reliability of related products.

There is no reason not to begin this journey and every reason to start. We will figure this out, find reliability methods and metrics, and learn the underlying root causes of failure. But without data, experiments and models, it is all conjecture. We need a program to drive to reliability metrics.

WHAT THIS GUIDE IS AND IS NOT

This guide is a set of recommendations for reporting and demonstrating reliability in terms of luminaire product lifetime. Initially, we sought to provide guidance for the Lighting Facts^{CM} program, which gives users, retailers, and manufacturers a common short-form reporting mechanism to improve the quality of solid-state lighting products on the market. The Lighting Facts label provides a summary of key performance criteria but does not include lifetime, for which there have been numerous requests. Ideally, it would be the addition of a single number, e.g., "eight years." But SSL product lifetime needs to be considered a combination of conventional failure mechanisms as well as a gradual decline of light output over time. Describing it is not simple; demonstrating it is difficult and expensive. So, we have come to appreciate the importance of gathering the full strength of the SSL community to address this critical issue. This guide is purposefully entitled "First Edition." In developing these initial guidelines, the committee recognizes that there remain many incomplete areas of knowledge, and we intend to pursue and improve these recommendations over time.

These recommendations have been developed by a working group under the U.S. Department of Energy Solid State Lighting program. This group is under the guidance of the SSL Quality Advocates oversight committee, a joint body of DOE and the Next Generation Lighting Industry Alliance (NGLIA). The reliability and lifetime working group is composed of members of the NGLIA as well as other experts in reliability, lighting, and LED technology. As such, this guide is not an accepted international standard. Rather, it is meant to provide standards bodies with recommendations for their work in supporting the needs of the SSL community. These standards organizations will ultimately determine the details of the methods to measure and report the reliability of SSL luminaire products.

This document covers only luminaire lifetime—i.e., change over time in normal operation—and not initial performance criteria or product consistency. Initial performance criteria for LED luminaires have been separately discussed in the December 2008 publication *Reporting LED Luminaire Product Performance,* found on the DOE SSL Web site at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_productperformanceguide.pdf.

TYPES OF FAILURES ENCOUNTERED

An LED luminaire is in many ways more complex than a traditional lighting fixture. It is an electromechanical system that includes, in addition to the essential light-emitting source, provisions for heat transfer, electrical control, optical conditioning, mechanical support, and protection, as well as aesthetic design elements. Because the LEDs themselves are expected to have long life, all of these other components, adhesives, and other materials must be equally long-lived, or, to the extent they are not, they will limit the system lifetime.

While LEDs do not radiate heat, with current products half or more of the input energy may be converted to heat that must be conducted away from the diodes. This situation requires a reliable, heat-conducting assembly, be it mechanical or adhesive, in addition to a heat sink component or means for further conduction. For proper operation, the power supply and electronics must provide a well-controlled DC drive current and possibly other control features, and must not fail for the life of the product. Any optical

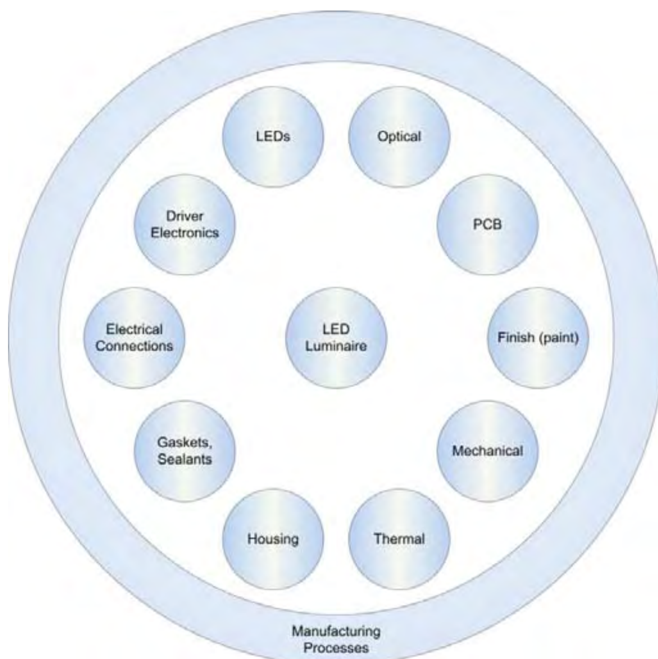

Figure 1: Total system or luminaire reliability is the product of all of the individual reliability considerations as follows:
$R_{Luminaire} = R_{LEDs} * R_{Optical} * R_{PCB} * R_{Finish} * R_{Mechanical} * R_{Thermal}\ \ R_{Housing} * R_{Gaskets} * R_{Sealants} * R_{Electrical} * R_{Driver} * R_{Manufacturing}$.

SOURCE: PHILIPS HADCO

components must be able to withstand years of exposure to intense light and possibly heat without yellowing, cracking, or other significant degradation. Reflecting materials need to stay in place and maintain their optical efficiencies.

Even if the design itself has addressed all of these issues, questions of proper manufacturing remain. Was the epoxy properly mixed? Was an essential heat-transmitting paste omitted? Were the wire bonds properly made? Any of the failure mechanisms inherent in electronic assemblies, and many others, may apply to an LED luminaire. Figure 1, above, is an attempt to visualize this larger scope of SSL reliability.

For the best lifetime in a well-designed and properly assembled luminaire, the principal failure mechanism should be lumen depreciation—a gradual reduction of light output from the packaged LED over time. But other mechanisms could come into play. One LED vendor has reported that the principal causes for customer complaints involve either the use of chemicals in the luminaire that are incompatible with the LED or the driver overstressing the LED. These are design issues, but equally important are early failures of other components or subsystems or manufacturing defects. These additional failure mechanisms will always persist to some degree and will usually lead to catastrophic failure, but they may sometimes simply accelerate lumen depreciation. An important message of this guide is that these mechanisms must be accounted for in describing product life.

THE ROLE OF WARRANTIES

Given the early stage of LED lighting technology, it is difficult to accurately predict product lifetime. Warranties provide a means for the potential buyer to reduce risk. While this document provides some guidance on what might be included in a warranty, it is ultimately the manufacturer's decision on how best to provide this protection and how much risk to take in doing so. The warranty may logically be shorter than the claimed lifetime as defined below. As there will be a distribution of times of failures for any product, the degree of risk on the part of the manufacturer depends on the level of confidence in the projected lifetime and the amount of variation in that distribution.

LUMEN LIFETIME

RECOMMENDED DEFINITION OF LIFETIME

For conventional technologies, the "rated average lamp life" is the point at which half the lamps cease to emit light. All sources lose light output over time, but generally not more that 15–20 percent over the rated lamp life as defined by complete, lights-out failure. A well-designed LED package, however, would typically have a very long-rated life, as conventionally defined, but, because it is so long, would also have more lumen depreciation over that life than conventional technologies. Accordingly, we need a new approach.

Whatever the stated lifetime of any lighting product, it is a *statistical* measure of the performance of a given design. For an individual LED package, lifetime has typically been considered to be the hours of operation at which the light output has fallen to 70 percent of its original value ("L_{70}").

Lifetime is typically reported as the median time to failure of a population of diodes under normal operating conditions, called "B_{50}." In other words, after this period of time, half of the units will fail due to low light output. While B_{50} represents a *time* interval, L_{70} is the lumen *performance level* defining a low-light failure. For some applications the median time, B_{50}, may be unacceptable. Designers in these cases might prefer to know when 10 percent of the product has fallen below the defined level. Depending on the target market, therefore, manufacturers may choose to report B_{50}, B_{10}, or some other time for a particular. L_{70} is widely accepted in LED lighting, but for non-demanding cases, L_{50} may be acceptable. In other words, lumen depreciation cannot be adequately described by a single metric.

This kind of lifetime definition, lumen depreciation, can be and has commonly been extended to a luminaire, but that is not enough. We must consider other failure mechanisms as well. Reporting failure only in terms of low light output, regardless of cause (i.e., including catastrophic failures) does not give the designer enough information. If the lifetime is stated to be 20,000 hours, does that mean half the lights are at 70 percent of their initial output, or does it mean half the lights are nearly at full output and the others are completely out, or something in between?

To address this ambiguity, two numbers are needed: the lumen maintenance lifetime, e.g., B_{50} or B_{10}, *and* the conventional electric failure lifetime, e.g., F_{10} or F_{50}, when 10 percent or 50 percent of the luminaires fail in a conventional sense. Both times—B and F—must be measured on the complete luminaire because of the interactions among the components.

These B and F numbers can describe four types of luminaire failure:

1. All LEDs light up, but at a reduced light level (defined by time to B_{XX}).
2. There is a single catastrophic LED failure, but other LEDs are still functional, perhaps running at a reduced light level (defined by time to B_{xx}).
3. There are multiple catastrophic LED failures, but other LEDs are still functional, perhaps running at a reduced light level (defined by time to B_{xx}).
4. No LEDs light up, due to system failure other than the LED (defined by time to F_{yy}).

If a lifetime claim is made, we recommend using the L_{70} reference value for light output and reporting two time values as follows:

1. B_{xx} – the *lumen maintenance lifetime* at which for xx% (e.g., 50%) of the product light output falls below 70% of the nominal initial value.

2. F_{yy} – the *electrical failure time* for which yy% (e.g., 10%) of the population has experienced conventional lights-out failure.

Ideally, the numbers above should reflect a sufficient set of measurements that can be reported with a reasonable degree of confidence. The reported lifetime should have at least sufficient measurement accuracy and sample size to provide a 50 percent confidence level. While this may be a practical limit in the near term, 90 percent or higher is more desirable. However, the working group recognizes that these measurements are expensive and time-consuming, and not all manufacturers may have the ability to comply when the product is first introduced. However, if the recommended minimum confidence levels are not achieved, manufacturers still have the option not to make a lifetime claim in the technical sense, but to *warrant* performance for a specific period of time instead.

The choice of *xx* and *yy* is up to the manufacturer and may vary by intended customer base or manufacturer; however, it should be explicitly stated. The examples of B_{50}/F_{10} above might not suit high-performance applications, for example, but may be satisfactory to the consumer. This definition of lifetime does not include color shift. It is strictly in terms of light output, although that could be because of either gradual lumen depreciation *or* catastrophic failure *or* accelerated degradation from many causes. For many users, excessive color shift might also be deemed a failure, so this guide recommends that color shift may optionally be a separately stated specification for the stated lumen life of the product. Color is more fully discussed in a later section of this guide.

The means of determining lifetime are not fully standardized at this time. Additional observations concerning the determination of lifetime and methods of projecting lifetime from shorter-term measurements are discussed below.

DEMONSTRATING LIFETIME

When you demonstrate a product's L_{70} lumen maintenance claim of B_{50} lifetime, or any other values, you need to validate the product life not only when you first release the product, but also when you make changes to the product during its lifetime. This section addresses some of the necessary steps to demonstrate the product's lumen maintenance life claim, separately considering a new platform, and then how to deal with variations in that platform. While some examples are shown, they are not intended to specify a standard procedure. Responsibility for specific standards lies with standards organizations and is beyond the scope of this guide.

NEW PLATFORM LUMEN MAINTENANCE

For a new platform it is the manufacturer's responsibility to demonstrate life performance compliance by testing luminous flux, in accordance with LM-79, in a sufficient sample of product for a sufficient amount of time to have confidence in the lifetime figures. An important question concerns the required period of time. A TM21 committee of the Illuminating Engineering Society of North America (IES) is exploring the issue of extrapolating L_{70} from limited measurements, such as recording changes every 1,000 hours up to 6,000 hours. Several studies have shown how difficult this extrapolation can be. The eventual result of these continuing studies will most likely indicate a maximum degradation of light output over a specific period that is required to demonstrate a given lifetime. For example, for a claimed life of 36,000 hours, the lumen maintenance might be required to be 91 percent or better after 6,000 hours. As of this writing, the results of this work have not been published, but when available, they may be used to extrapolate to the L_{70} value.

To show compliance, a test report might include the following:

- Graphical presentation (with error bars) of lumen output versus time, color shift versus time, and input power versus time
- Summary table showing in lumen maintenance (percent) change in input power (percent), and change in color after 6,000 hours of testing

- LM-79 reports at T = 0 and T = 6,000 hours
- Description and details of the product under test and test setup
- Sample size and/or confidence interval

Although extrapolated LM-80 data for packaged LEDs has been used as a proxy for luminaire lifetime (and is an ENERGY STAR requirement), it may not be very accurate for the many reasons cited in this guide. The working group, therefore, recommends LM-79 testing of the complete luminaire to determine lumen output over time.

PRODUCT VARIATION OF NEW PLATFORM

Recognizing possible platform variations to extend the product line for other applications (product groups) or material or design changes, additional measurements may be needed to ensure the platform is still qualified. Consideration may be given to minimize the number of test hours to demonstrate the long-term life performance as described above. In this regard, it is reasonable to consider the different types of change (or model variations) and their likely impacts on lifetime. Ultimately, this is the customer's choice, but it is recommended that manufacturers develop and document specific rules for change control to maintain the integrity of their products.

For example, changes in the following areas may be deemed to require significant retesting:

- Housing/chassis
- Thermal management/heat sink
- Change of assembly method or materials
- Light source (includes operating current, V_f, and LED supplier)
- Power supply

Other changes, such as in finish or out of the optical path, may require less requalification. Analytical data may often be used in part to demonstrate that the change has not influenced the lumen maintenance performance of the luminaire. But typically a small number of luminaires may need to be retested for some, perhaps shorter, period of time. If the manufacturer cannot demonstrate via analytical data or limited testing that life performance is not diminished, then the luminaire should be treated as a new platform and subject to full qualification requirements.

The relevant recommendations from this guide are that manufacturers develop and document their own change control process, and that they are responsible for providing sufficient justification to their customers so that any change will be accepted as having no material, deleterious effect on product lifetime.

EARLY FAILURES AND DESIGN FLAWS

As noted above, while this discussion focuses on lumen maintenance, any other failures that turn up in the course of testing do count in determining the median time to failure. This may result in a need to test additional fixtures in order to have a statistically valid result.

Based on experience in the CALiPER program, this guide recommends a minimum 1,000-hour burn-in (continuous use) test of a small number of products to verify that there are no serious, immediately apparent design flaws in a new platform. While this recommendation may be seen as a bit vague and in no way guarantees a good design, any failures that occur in this short period of time are a cause of concern that may warrant another look at the design before product release. Other ways to verify a design may also include accelerated tests to failure in order to uncover root causes of the premature demise of a product. Selection of such tests is beyond the scope of this guide, but it may be worthy of further study by the industry and a sharing of best practices to promote the overall market. This information would be especially helpful for smaller manufacturers lacking the means to do extensive reliability qualification. This topic is further discussed in the section titled "A System Reliability Approach."

COLOR SHIFTS

RELATION TO LIFETIME

As noted above, "lifetime" refers only to lumen output of the fixture, but it includes failures due *not only* to systematic degradation as measured by LM-80, but also to any other mechanisms of overall lumen degradation, including changes or failures in components other than LED. Lifetime does not include color shift, per se, even though for some applications excessive color shift might be considered a failure by the user. The decision to prioritize lumen output reflects the fact that lumen maintenance is related to life safety issues in various applications while color stability is related to aesthetic concerns. However, this reality could, nevertheless, result in customer dissatisfaction, so we discuss color shift in this section of the guide.

LM-80 recognizes that color is important[1] and, further, requires that the test report include "chromaticity shift reported over the measurement time."[2] It does not, however, provide any recommendation to project the shift to the end of life, nor does it address color shifts that may be attributable to the luminaire design or manufacturing. Regarding lumen maintenance, experiments suggest that, assuring that the temperature of the LED does not exceed certain limits and that the drive current does not change excessively, it is possible to extrapolate the LED lumen maintenance contribution to lumen depreciation to the luminaire. This approach may not work, however, for color shift. Furthermore, full luminaire color measurements are prohibitively expensive, all but ruling out the option to predict color shift over the life of the product. A final challenge to providing useful color shift information to users is that there is no simple, consumer-friendly way to describe it. Correlated color temperature (CCT) alone is really not a precise-enough metric to describe the change in many situations.

It is clear that considerable work remains before we will be in a position to accurately specify end-of-life color shift limits for a specific luminaire design. Given this situation, and pending further work by standards organizations, we recommend that manufacturers designate products in one of

[1] LM-80, Section 6.2.

[2] Ibid., Section 8.0, item 13.

three categories: "lamp replacement," "luminaire (standard grade)," or "luminaire (specification grade)," and then treat color shift differently for each segment.

1. Lamp replacements are more amenable to LM-80 color shift measurements and projections since the design is consistently repeated, and sales volumes are high. Color can be specified on the Lighting Facts label in general terms for what is assumed to be a non-critical market.
2. Standard-grade luminaires would specify a maximum warranted color shift, probably in terms of CCT for now. It would be up to the manufacturer to determine what limits should be specified and for how long a period the warranty applies, which may or may not coincide with the lumen lifetime.
3. Specification-grade luminaires are intended for more discerning customers. More sophisticated color metrics may be included in the specifications, and the maximum color shift over the stated lumen lifetime would be provided. Some professional-use lamp replacements might be included in this category as well.

All three categories require some means for the manufacturer to predict color shift over a period of time, but with greater or lesser precision depending on the classification. Additional work is needed outside the scope of this document to improve these methods. The remainder of this section describes in more detail the challenges for color specification and the three product categories.

THE FOUR CHALLENGES

PROJECTION OF COLOR SHIFT

LM-80 requires LED manufacturers to collect data on color shift over 6,000 hours of operation. However, there is no accepted standard way to use this data to extrapolate color shift. The IES TM21 committee is working to set standards on how to extrapolate LM-80 data for lumen depreciation but has deferred the issue of color shift.

Factors that will make color shift so difficult to extrapolate include differences in LED design, materials, manufacturing process, optics applied to the LED, and the temperature and time the LED operates. Many experts indicate that it will be a long while (possibly years) before there is general agreement on how to project color shift for an LED over an extended period of time.

IMPACT OF LUMINAIRE DESIGN AND MANUFACTURING PRACTICES

Color stability, like lumen depreciation, is not exclusively determined by the performance of the LED. Examples of how luminaire design and manufacturing practices will impact color quality and color shift include:

- Different heat sink designs will mean that LEDs and the associated electronic circuits will likely see different operating conditions despite operating similar times under similar temperature conditions.
- Different materials used in secondary optics may age differently.
- Different environmental conditions (including air quality) may cause materials in different luminaires to behave differently.

- Different luminaire designs may create non-uniform color characteristics such as halos or yellowish, bluish, or greenish hues around the edges of the beam, and these color characteristics may vary over time.
- Some manufacturing processes have tight initial selection criteria, and others loose selection criteria, and that will complicate the determination of color shift over time.
- Finally, some luminaires address color shift with active color management, including sensors and controls. However, sensors and controls may themselves shift over time and affect color.

LIMITATIONS DUE TO EXPENSE

As LED lighting is a relatively new industry, we lack field data on how much color shift is likely due to the LED compared to the color shift due to the luminaire design. For this reason, as well as for the luminaire and manufacturing effects just cited, the only definitive way to determine color shift is to measure the entire system comprising the LED, the other parts of the luminaire, its operating time, and its operating environmental conditions.

Currently, however, collecting LM-80-style data at the luminaire level is prohibitively expensive for many luminaire types for several reasons:

- It can take hours to stabilize the temperature of a large luminaire.
- Luminaires are tested at steady state currents, not pulsed as with LEDs.
- Extensive space may be required for storage and test fixtures, as compared to LEDs.
- Luminaire tests using LM-79 require skilled technicians and are labor intensive.

Luminaire-level testing would also seriously delay product introduction, which adds to overall expense and limits the rate of market penetration. While such expenses may be justified in limited professional applications sensitive to color, that is the exception rather than the rule.

DESCRIBING COLOR SHIFT

Consumers have no experience with, and cannot be expected to easily relate to, scientific or engineering terms that are used to discuss color, including “chromaticity,” “black body curves,” “LED bins,” or “Macadam ellipse.” There is no standard consumer definition that can be used as an alternative, although the current Lighting Facts label describes color in terms of CCT, and qualitatively using words such as “warm” or “neutral.” This may be adequate, as it is similar to descriptions now being used for conventional lighting, and recent progress with consumers learning to read food labels suggests consumers will be able to learn to look for and understand the data on the Lighting Facts label.

Even so, these descriptions do not provide a simple way to describe color shift. While professionals may be able to decipher terms such as the change in color coordinates (“d_{uv}”) or even the change in color temperature (“ΔK”), it will probably be some time before they would be useful for the consumer. Simpler terms reflecting a qualitative, relative color stability may be more appropriate.

RECOMMENDED APPROACH

SEGMENTATION OF THE LUMINAIRE MARKET

Despite these four extremely challenging factors, we recommend the following approach. First, segment the overall luminaire market into “lamp replacements,” “specification-grade luminaires,” and “standard-grade luminaires.” By doing this, we can begin to make progress on a number of fronts:

- Lamp replacements
  - Lamp replacements will be sold through distribution channels where the Lighting Facts label is likely to have the greatest impact.
  - Lamp replacements have a form-factor that makes LM-80 testing more affordable than specification-grade luminaires.
  - Many lamp replacements will operate at ambient temperatures that make testing less complex and expensive.
  - Lamp replacements will be high-volume items where the successful manufacturers will have extensive quality and process controls in place and the top manufacturers may welcome standards to help keep out poor-quality product.
  - Lamp replacement manufacturers will always have the data that exists on the Lighting Facts label.
  - Consumer-friendly terms such as “no-shift,” “limited-shift,” or “wide-shift” might work well to describe color shift.
- Specification-grade luminaires
  - Specification-grade luminaires are sold though different sales channels and purchased differently from replacement lamps.
  - The data needed for the Lighting Facts label always exists for a specification-grade luminaire.
  - Beyond the Lighting Facts label, additional specifications and warranties for color variation (day one) and color-shift (over time) will be added by experts to address application-specific needs.
  - Outdoor applications, indoor office and school applications, cold spaces, and hot spaces may require different specifications.
  - Color shift may be more important for some applications than others.
  - In some applications, the manufacturer may find that LM-80-style data provides a competitive benefit despite its cost.
- Standard-grade luminaires
  - Standard-grade luminaires should be covered by the Lighting Facts label with the addition of a clearly stated, more loosely defined specification and warranty for color variation and color-shift "warranty” period for color.
  - The industry should continue to educate customers that quality luminaires carry the Lighting Facts label and that luminaires without the label are suspect.

STANDARDS AND MEASUREMENT WORK

A number of follow-up activities are suggested in order to firm up specifications to promote market adoption:

- For consumer-directed products, there should be a short-term effort to develop standard, broad qualitative descriptions of color shift.
- A working group on bulb-replacement specifications should review these recommendations and determine if other specifications are needed.
- Segment-focused specification-grade luminaire teams should determine the appropriate standard specification for individual applications.

In summary, color and color shift are among the more complex issues that need to be addressed with the introduction of LED-based replacement bulbs and luminaires. Segmenting the market into the three broad areas listed above, and then identifying work-around solutions for short-term problems appears to be the best approach. In parallel, individual working groups should begin to address each segment's requirements in more detail to develop documented standards of color shift requirements and measurements.

A SYSTEM RELIABILITY APPROACH

LED operation is interdependent upon drive electronics, the thermal management system, and the optical system, as well as upon proper and controlled materials and manufacturing processes. Because of the resulting complexity, it may be more efficient and effective to take a system reliability approach in the design of the LED lighting fixture. By understanding how each of the system's components contributes to failure, one can estimate overall reliability and optimize the design for best performance.

One important reason for a systems approach is due to the differences in how LED manufacturers and LED fixture manufacturers measure LED performance. LED manufacturers typically use pulse mode operation with a very short pulse—typically 10 or 20 milliseconds—which will not heat up the LED; therefore, no heat sink is required and T_J can be assumed to be equal to ambient temperature T_A, which is typically held constant at 25°C. Therefore, LED manufacturer data sheets typically show LED performance as a function of T_J = 25°C.

On the other hand, LED fixture manufacturers measure LED performance *in situ* with the LEDs installed in the fixture. When *in situ* there are numerous LEDs, often in close proximity to one another, operated continuously. These conditions elevate T_J above 25°C, thereby affecting photometric and colorimetric performance of the LEDs. Therefore, LED fixture manufacturers measure LEDs *in situ* as a system under the drive, thermal, and optical conditions specific to their products.

In order to effectively measure LED fixture performance, LED fixture manufacturers need performance data from the LED and driver manufacturers. One important data set LED manufacturers will provide is data collected per *IESNA LM-80-08 Approved Method: Measuring Lumen Maintenance of LED Light Sources*. LM-80 prescribes uniform test methods under controlled conditions for measuring LED lumen maintenance and color shift while controlling the LED's case temperature (T_S) using continuous mode operation for a specified minimum duration. LED fixture manufacturers can then use the LM-80 data to correlate to the LED T_S measured *in situ* during their LED fixture thermal testing to predict LED lumen maintenance when installed in the fixture and to assess the degree of potential color shift- for their specific LED operating parameters. Note that these results only provide estimates of lumen depreciation for the LEDs under specified conditions; *they are not alone sufficient to estimate lumen lifetime*.

The DOE SSL *Manufacturing Roadmap* recommends that LED *driver* manufacturers provide the same "LM-80-style" uniform data for LED fixture manufacturers to include a number of specific performance results to assist in luminaire design. This is a good approach, and might also apply to other components and materials.

The preferred tool for measuring performance of LED systems is *IESNA LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products*. LM-79 prescribes uniform test methods under controlled conditions for photometric and colorimetric performance as well as electrical power measurements for LED fixtures as they would be manufactured for production. A key systemic element of LM-79 is that the LED fixture must be tested using absolute photometry which measures LED performance *in situ*.

LED fixture safety and other approbation testing should also be performed systemically with the LEDs *in situ*. The following is a recommended list:

- UL Subject 8750, *Outline of Investigation for Light Emitting Diode (LED) Light Sources for Use in Lighting Products*
- Applicable UL Standards such as UL 1598 *Luminaires*, UL 1838 *Low Voltage Landscape Lighting*
- IP (Ingress Protection) testing per IEC60529—dual IP ratings are recommended for versatility
- *As required*: vibration testing per ANSI C136-31-2001

LIGHTING FACTS[CM] LABELING RECOMMENDATIONS

The Lighting Facts label should be augmented to include the **product lifetime**, $L_{70}/B_{xx}/F_{yy}$, as defined in this document. Recognizing that some manufacturers may not have the ability or time to demonstrate lifetime in accordance with these recommendations, the label should not *require* that lifetime be stated, but if it is stated, then it should be reliably established with standard tests. Otherwise, a specific lifetime should not be claimed at all.

The Lighting Facts label should also be modified to include, *optionally*, a **warranty period** to cover either lumen lifetime, color shift, or both. The warranty period may or may not coincide with lifetime (if claimed) at the manufacturer's discretion. This warranty may be particularly useful to manufacturers who, while not able to demonstrate a lifetime in accordance with the recommendations, are nonetheless prepared to guarantee performance over some period of time. This may be especially useful for new products also.

Lighting Facts may require substantiation of any lifetime claim put forth for use on the label. Also, the burden of proof to show that any platform changes have not materially affected lifetime lies with the manufacturer.

The label should further be modified to show, *optionally*, certain **color shift** information depending on the market segment:

- A general qualitative description of color shift, or
- A maximum color shift warranted for some period of time, or
- The maximum color shift over the stated lifetime

For the short term, color shift, if quantitatively specified, could be described in terms of change in CCT. For some applications, and for professional use, actual limits on the change in color coordinates should be specified, but might not be included on the Lighting Facts label.

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