Nadarajah Narendran, Jean Paul Freyssinier, Indika Perera and Jennifer Taylor

Two Techniques Identifying methods to better estimate LED product lifetime

The growth of LED lighting in the past 20 years has propelled the lighting industry toward a complete technology transformation. Where once LEDs were considered exotic and viewed with suspicion, now they are a mainstay on the shelves at big-box stores. Today, LED lighting offers many advantages, yet one nagging disadvantage remains: unpredictable lifetime. We probably have all experienced LED light bulbs burning out after a shorter-than-expected lifetime when used in certain types of luminaires or applications, such as with the surface-mount fixtures shown in **Figure 1**. Under perfect conditions, an LED lighting product can outlive a traditional incandescent lamp by 50 times and a compact fluorescent lamp by five times. In the real world, however, perfect conditions are rare, yet most available lifetime test methods for LED products do not consider real-world conditions, including those methods set forth by some standards-setting bodies. Most consumers still believe that LED products will last the same amount of time no matter the application or operating condition, and current test methods adhere to that belief.

Early last year, the Lighting Research Center (LRC) was approached by the International Energy Agency's 4E Solid State Lighting Annex and asked to explore and summarize the literature on LED system lifetime. Over the course of a year, we conducted an international literature search that included definitions of LED life, failure mechanisms of LED components and systems, parameters that accelerate failure, and available test methods for estimating LED system lifetime. The results were accumulated into a report published in June by the IEA 4E SSL Annex, *Literature Summary of Lifetime Testing of Light Emitting Diodes and LED Products*, which is available online (*https://www.iea-4e.org/wp-content/uploads/publications/2021/06/SSL-Annex-Lifetime-Literature-Review-Report-by-the-LRC_final.pdf*).

> "Most consumers believe that LED products will last the same amount of time, regardless of application or operating condition

THE MAJOR OUTCOME OF THIS report is the LRC's recommendation of two test methods as the most promising for accurate life prediction of LED lighting products. The selection of these two methods was based on an understanding—from both the literature and from our own laboratory testing and research for the past two decades—of the ways in which LED systems fail and the operating conditions that lead to their failure.

LED lighting systems consist of many components working in conjunction, including LEDs, optics, drivers, heat sinks, circuit boards and housing. The failure of any one component can lead to the failure of the entire system. In general, we have found that two types of system failure can occur: catastrophic and parametric. Catastrophic failure of a system results in a complete and sudden cessation of light output, such as what occurs when solder joints of the LEDs to the printed circuit board fail. Parametric failure is characterized by a gradual change over time to the point where certain performance characteristics, such as light output level or color, deviate from acceptable values and the system is considered to have reached its end of life based on predetermined limits.

Most life testing methods in use today consider only the possibility of parametric failure (i.e., light output depreciation and change in chromaticity), and further consider only the failure of the LEDs at the package or the LED-module level, and not other components within the system. The literature suggests that LED system lifetime depends on both the application environment and the use pattern (i.e., on-off cycling) conditions. When combined, these conditions can either elevate the LED junction temperature, which degrades the components surrounding the LED chip and leads to parametric failure, or they can introduce thermal stress at the interconnects, resulting in the broken solder joints that lead to catastrophic failure. To accurately estimate the life of LED lighting systems, the test method must have the ability to configure the environmental condition and the on-off switching pattern to match those of the intended application.

To give examples of why this is important, **Figure 2** shows the effects of the application environment on the resulting LED junction temperature of the same A-lamp product, and **Figure 3** illustrates the results of cycling versus continuous operation on LED life.[1] Past studies show that the median lamp life, based on lumen depreciation, has an inverse linear relationship with the maximum operating temperature. Likewise, the differences in operating temperatures during on-off cycling (maximum temperature and dwell time) have an inverse linear relationship with the number of cycles to failure (for varying median life).

Given what we know about application environment and on-off cycling effects on LED life, it is imperative that both types of failure be considered during life testing and that the shorter of the two times be advertised as the product lifetime.

As noted earlier, during the course of the literature survey two test methods were identified as the most promising for providing accurate estimations of LED product lifetime:

Figure 1. LED lamp life test setup at the Lighting Research Center. Surface-mount fixtures with three lamps, like the ones shown here, often represent applications where LED lamps tend to fail sooner because of the high environment temperature.

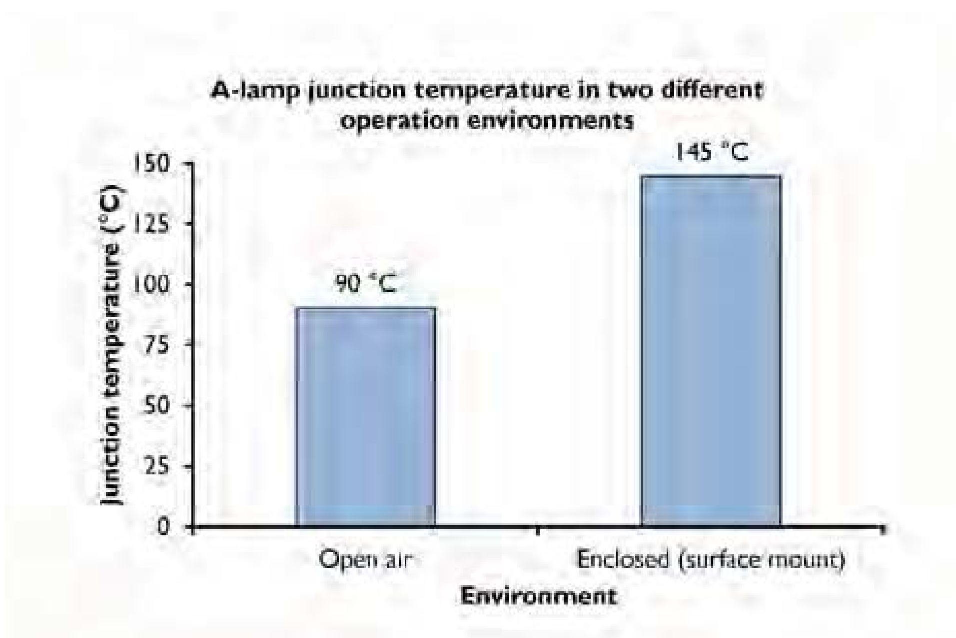

Figure 2. LED junction temperature in the same LED A-lamp when operated in open air and in an enclosed luminaire, such as a three-lamp surface-mount fixture.[1]

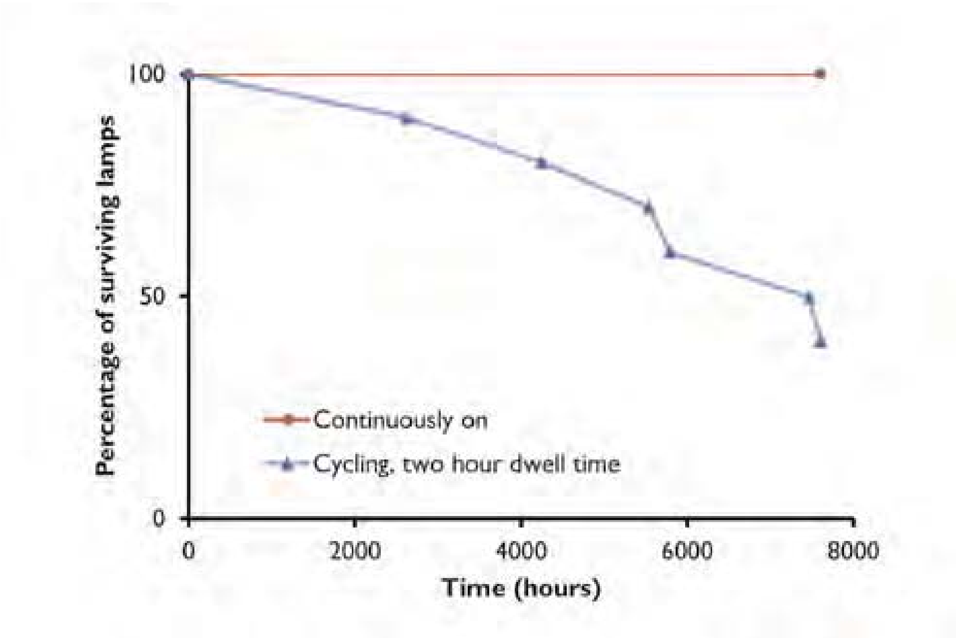

Figure 3. A-lamp catastrophic failures as a function of time for the same 80-deg (Celsius) LED junction temperature difference between ambient and fully stabilized conditions, but in one case the lamps have a two-hour dwell time and in the other the lamps are operated continuously on.[1]

- The first method, adopted recently by the European Union, considers both environmental condition and use pattern. This is an important advancement in the industry because it recognizes the effect of the operating conditions of LED products in different applications on lifetime. However, in its present form, this method only considers one temperature and use pattern condition and was implemented to report lumen depreciation and percentage of surviving products at the end of the test. Before this method can be used for predicting lifetime in different applications, other test conditions representative of those applications need to be added.
- The second method was proposed by the Lighting Research Center and formalized by the Alliance for Solid-State Illumination Systems and Technologies (ASSIST). This method allows for any combination of environment temperature and use pattern to be specified, and thus provides a means to predict LED product lifetime within the boundary conditions of the test. One thing to note is that humidity is not considered in either of these test methods. Humidity was conveyed as a concerning factor in a number of studies discovered during our literature search. Considering the dominance of LED products for outdoor applications, such as for lighting parking lots, roadways, parks, airports and more, the effects of humidity should be weighed, especially where safety is concerned.

Overall, much has been learned over the years about LED lighting performance and the means of achieving high-quality LED products. Now is the time to advance what we know into a robust, comprehensive and reliable method of predicting LED system lifetime, so that more accurate lifetime values can be conveyed to users based on where and how the systems are used.

For details and publications about the LRC's system life testing research, visit *https://www.lrc.rpi.edu/programs/solidstate/LEDSystemLife.asp*.

Nadarajah Narendran, Ph.D., is a professor and director of research at the Lighting Research Center at Rensselaer Polytechnic Institute.

Jean Paul Freyssinier is a senior research scientist with the Lighting Research Center at Rensselaer Polytechnic Institute.

Indika Perera, Ph.D., is a research scientist with the Lighting Research Center at Rensselaer Polytechnic Institute.

Jennifer Taylor is a senior communications specialist at the Lighting Research Center at Rensselaer Polytechnic Institute and works primarily in the fields of solid-state lighting research and 3D printing for lighting.

References

1. Development of a Predictive Life Test Method for LED Luminaires, Light Engines, and Integral Lamps – Final project report, December 2016, sponsored by Bonneville Power Administration (BPA TIP 322), New York State Energy Research and Development Authority (NYSERDA Agreement No. 46905), and Alliance for Solid State Illumination Systems and Technologies (ASSIST); https://www.lrc.rpi.edu/programs/solidstate/pdf/PredictiveLifeTestFinalReport-Dec2016.pdf.