Long-term performance of white LEDs and systems

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Long-term Performance of White LEDs and Systems

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ABSTRACT

In this manuscript we describe two experiments. The first one is life testing of three commercial high-power phosphor-converted (pc) white LEDs under three different operating temperatures. The second is life testing of two commercial lighting systems that use high-power pc-white LEDs. Life testing was conducted per *ASSIST recommends* guidelines. Results showed that LED life is very much affected by the heat at the p-n junction. To illustrate the usefulness of the *ASSIST recommends* test procedure for quantifying the performance of LED systems, two 26-watt commercial downlights were tested. Results showed that the life of pc-white LEDs follow an exponential decay as a function of board temperature. One of the commercial LED downlights tested showed an increasing light output degradation rate even within the first 1000 hours of testing. Both commercial products showed significant color shift over time.

1. INTRODUCTION

One of the promises for light-emitting diode (LED) technology for use in general illumination applications is long service life, greater than 50,000 hours. For long-lived light sources, life testing at rated conditions is not a feasible approach, since it can take years to determine the life. Therefore, the interest in accelerated testing to determine the performance degradation of GaN-based phosphor-converted (pc) white LEDs has been growing since early 2000 [1-11]. Typically, LED performance is affected by the drive current and the ambient temperature surrounding the LED. Therefore, most accelerated life-testing studies use either drive current or operating temperature as stress parameters.

Low-power pc-white LEDs, usually driven at 20 mA current, have clearly shown rapid light output degradation, mainly caused by the yellowing of the epoxy encapsulant that results in much shortened life [1-3]. Some early studies that used 5-mm pc-white LEDs demonstrated that the light output degradation with time followed an exponential decay [1-3], and the life as a function of drive current or operating temperature also followed an exponential decrease [3,7]. In 2007 Bürmen et al. confirmed this behavior and concluded that an exponential model best predicted the lifetimes of several commercial 5-mm type pc-white LEDs [9]. Compared to low-power LEDs, high-power pc-white LEDs typically show a much slower degradation rate, but they too show similar trends: exponential decrease of light output as a function of time and life as a function of junction temperature [7,8]. To the first order the life of pc-white LEDs correlated well to the junction temperature of the LED [7,8]. Based on these observations, an industry alliance in the United States with global participation, the Alliance for Solid-State Illumination Systems and Technologies (ASSIST), developed a recommended definition and test method for measuring LED life [12]. Presently, the LED lighting industry has adopted the definition and test method recommendations put forward by ASSIST [12]. LED life for general illumination is defined by the time it takes for the light output of an LED to reach 70% of its initial light level, denoted by L70 [12]. Furthermore, ASSIST recommends that the LEDs be tested at three different ambient temperatures, so that the relationship of LED life with LED board temperature is understood. The LED board temperature is determined by attaching a thermal sensor to a point on the LED board close to the pin [12]. LED life as a function of board temperature is useful to original equipment manufacturers (OEMs) who design and build LED fixtures. The fixture manufacturers can provide suitable thermal management strategies to enable their systems to achieve a long lifetime. Ultimately, it is the life of the complete system in a given application what matters to the end-users and not the performance of individual LEDs.

The junction temperature of the LED in a lighting system depends on the drive condition and the application environment. Usually, a lighting system can experience different thermal environments depending on where it is installed in the application. To obtain realistic performance data for a lighting system, the test environment must mimic the actual environment where the fixture would be used. A recent *ASSIST recommends* publication created three environmental conditions, based on indoor lighting system operating environments, to test the performance of LED systems [13]. The proposed environments are:

Open air: Here the light source and the driver have plenty of ventilation around them for convection heat transfer to keep them at appropriate temperatures.

Semi-ventilated: Here the light source and the driver have limited ventilation around them for convection heat transfer. In certain applications, a non-IC[†] luminaire would be considered to operate in a semi-ventilated environment.

Enclosed: Here the light source and the driver have almost no ventilation around them for convection heat transfer. An IC-rated luminaire is an example of a luminaire operating in an enclosed environment.

Testing and reporting data per *ASSIST recommends* would provide more useful information to the end-users [13]. In this manuscript we describe two experiments and the associated results. The first one is life testing of three commercial high-power pc-white LEDs under three different operating temperatures for each of them. The second is life testing of two commercial lighting systems per *ASSIST recommends* [13].

2. EXPERIMENT

LED Life Testing

The objective of the first study was to understand the light output degradation and color shift over time of commercial products and how this degradation varies with increasing board temperature (corresponding to junction temperature increase). Eighteen commercial high-power pc-white LEDs were procured from three different manufacturers, six LEDs for each manufacturer. The life-testing procedure was similar to some past studies [5,7,8]. Here, the current through the LEDs and the ambient environment were adjusted such that the board temperatures of the three commercial LED groups were nominally 65°C, 85°C, and 95°C. The test procedure followed *ASSIST recommends* [12] for collecting data. A total of 6000 hours of data was collected. Neglecting the initial 1000 hours, the following 5000 hours were used for projecting to determine L70, in hours. An exponential fit was used to extrapolate the data to determine L70 value.

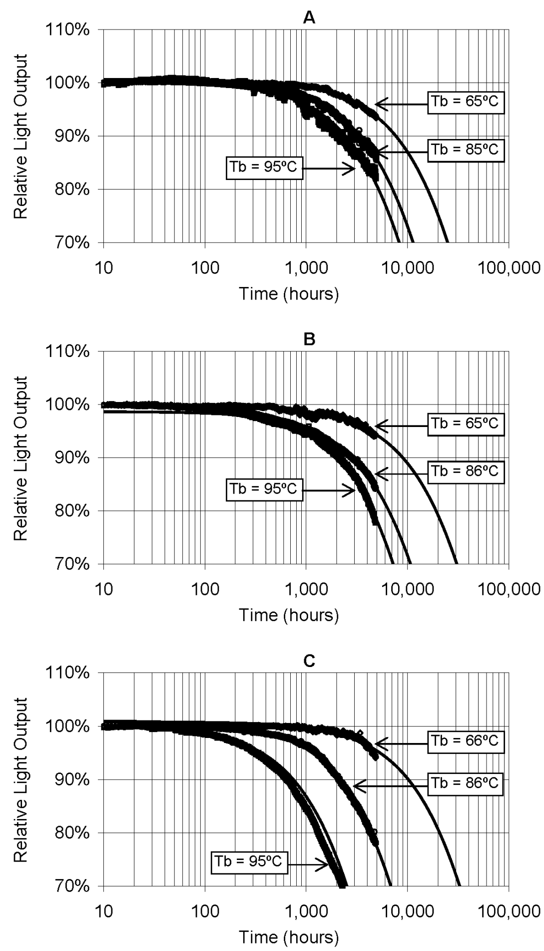

Fig. 1. Life-test data for three commercial pc-white LED groups.

[†] In North America, lighting fixtures that are intended to be installed in direct contact with insulation require an Insulated Contact (IC) rating. If the space where the fixture is installed does not have insulation present, a non-IC rating is sufficient. If there is insulation present, there must be a minimum clearance of 7.6 cm (3 in) between a non-IC fixture and the insulation. Nationally Recognized Testing Laboratories approved by the US Occupational Safety and Health Administration, such as Underwriters Laboratories (UL), are in charge of testing and certifying luminaires for IC or non-IC ratings.

Figure 1 illustrates three plots for the three commercial pc-white LEDs, named, A, B, and C, where relative light output as a function of time is plotted for the three life-test conditions. Each group of LEDs was operated at 65°C, 85°C, and 95°C, for the board temperature. All data were normalized to 100% at the 1000-hour condition. Figure 2 shows how the life, L70, changed when the board temperature increased for the three high-power white LED products. All LEDs had very similar long-term performance. All three products showed an exponential decay as a function of board temperature. We wish to point out that some of the other commercial products that are presently undergoing life testing do not show similar performance; therefore, it should not be assumed that all white LED products in the marketplace have similar performance characteristics. Past studies have shown life-test results for commercial white LEDs that have significantly different performance characteristics [8].

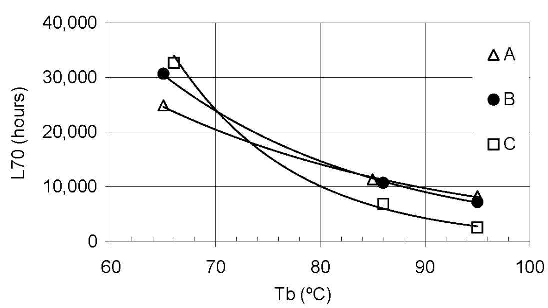

Fig. 2. Life, L70, as a function of board temperature for three LED groups.

Color shift

Table 1 illustrates the chromaticity values at the beginning and end of the life study. As seen in this table for product A, the color shift over time was toward yellow; whereas for product B and C it was toward blue. Unlike in the 5-mm type pc-white LEDs where yellowing of the epoxy is the dominant factor, in the case of high-power LEDs it is not clear exactly what is causing the color shift. Some recent studies have speculated that the change in LED reflector color could be one reason [11]. If the shift is toward blue, the yellow part of the spectrum is reducing with respect to the blue, indicating that the phosphor efficiency is decreasing with heat and time. On the other hand, the yellow shift could be still due to the yellowing of the epoxy dome beyond the silicone encapsulant. To thoroughly understand the reasons behind color shift over time, additional studies are needed.

Table 1. Chromaticity values at the start and end of the life test for the three commercial LED groups at the three operating conditions. Color shift is indicated in number of MacAdam ellipse steps.

		A		
		65ºC	**85ºC**	**95ºC**
Start	CIE x	0.2854	0.2853	0.2895
	CIE y	0.2917	0.2928	0.2930
End	CIE x	0.2950	0.3077	0.3224
	CIE y	0.3095	0.3294	0.3468
	Color shift	11-step	23-step	32-step
		B		
		65ºC	**86ºC**	**95ºC**
Start	CIE x	0.3123	0.3125	0.3136
	CIE y	0.3395	0.3410	0.3371
End	CIE x	0.2923	0.3119	0.3051
	CIE y	0.2993	0.3348	0.3164
	Color shift	21-step	4-step	11-step
		C		
		66ºC	**86ºC**	**95ºC**
Start	CIE x	0.3144	0.3240	0.3169
	CIE y	0.3260	0.3400	0.3267
End	CIE x	0.3103	0.3170	0.3030
	CIE y	0.3204	0.3233	0.2974
	Color shift	3-step	8-step	15-step

LED Lighting System Life Testing

The objectives of the second study were to understand the performance of a complete LED lighting system when used in application conditions and to demonstrate the usefulness of the *ASSIST recommends* test procedure [13]. Two 26-watt commercial downlights with several high-power pc-white LEDs were tested. These LED downlights were rated for both non-IC and IC-rated ceiling applications. Three samples of each downlight were placed in one of the three different testing environments (open air, semi-ventilated, or enclosed) per *ASSIST recommends* [13]. Temperature sensors were attached to the LED board to measure board temperatures, Tb.

After an initial 100-hour seasoning period, the LED downlights were turned on and were allowed to stabilize for 24 hours. The temperature values, Tb, for the three conditions (open air, semi-ventilated, or enclosed) were measured.

Next, the LED downlights were mounted inside a specially designed heated chamber that monitored the board temperature, Tb, and maintained it throughout the test period via a feedback control circuit that provided a signal to a supplemental heater built inside the chamber (Figure 3). This procedure ensured that the LED junction temperature remained equal to what it would be if the LED downlights were mounted in an actual application. An integrating sphere with an optical spectrometer attached to one of the ports was placed below the LED system (Figures 3 and 4). At regular intervals, the integrating sphere measurement system was moved under each of the LED downlights and measurements were taken for light output and spectrum.

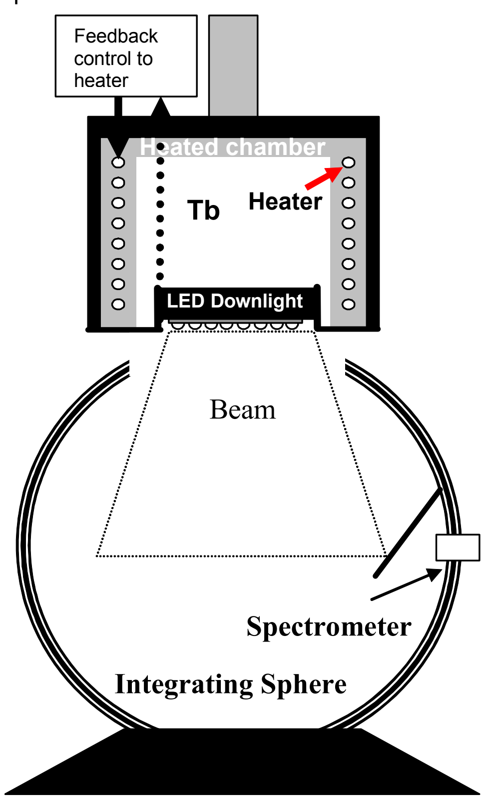

Fig. 3. Schematic of LED system life-test setup.

Fig. 4. LED fixture life-test setup.

Figure 5 illustrates the relative light output data for the two 26-watt LED downlights in the three application conditions. The board temperatures, Tb, for the three conditions, open air, semi-ventilated, and enclosed, were 83°C, 95°C, and 115°C, respectively, for product A, and 89ºC, 108ºC, and 119ºC, respectively, for product B. For product A, it is too early to see any substantial degradation.

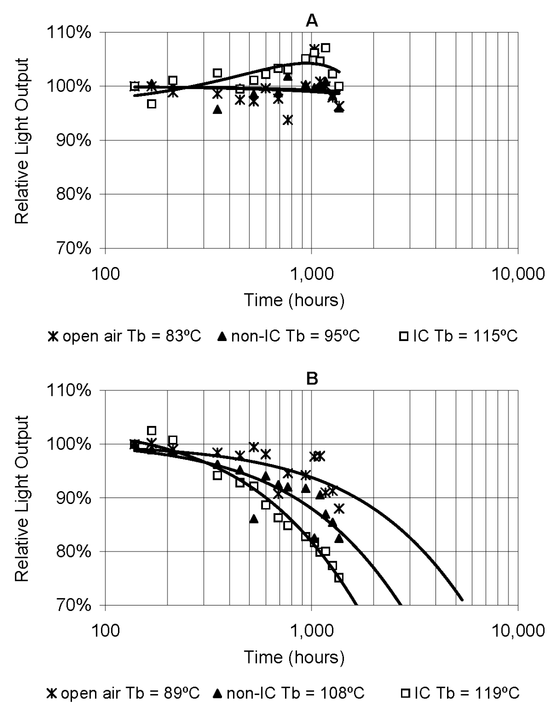

Fig. 5. Light output over time for the three environmental conditions for two 26-watt downlights.

Even though the number of hours for data collection is still very low, based on extrapolated data it appears that product B will reach end of life, L70, within 1500 hours for an IC-rated application, 2600 hours for a non-IC rated application, and 4600 hours if it is placed in open air with plenty of ventilation around it.

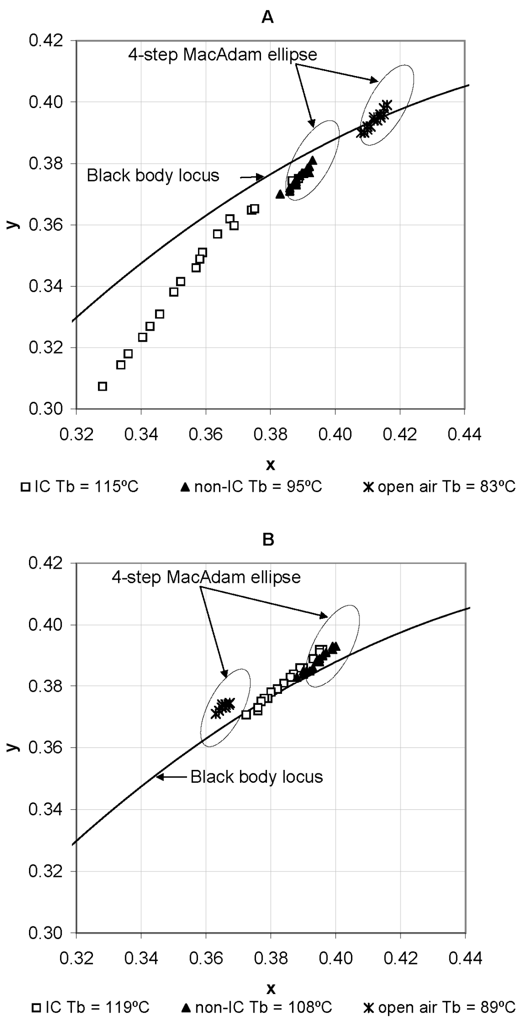

Fig. 6. Chromaticity values over time for the two commercial downlights tested in three application conditions.

Additionally, from Figure 6 it can be seen that even in this short 1000 hours, the color shift of the LEDs in both products is very high, and with exception of the open air condition of product B, the rest of the conditions have exceeded a 4-step MacAdam ellipse. Generally, light sources with high color shift are not considered appropriate for interior lighting. The results seen thus far are not very encouraging for this commercial LED system. If used in an application, consumers will be disappointed because their expectation is that LED systems are supposed to last 50,000 hours.

We wish to note that the initial data for some of the other systems presently on our life-test rack have much better performance than the ones shown in this study. Since the number of data collection hours is still low, we have not shown the data here. As part of the ongoing study, we will be monitoring the performance of several commercial downlight fixtures and the results will be published elsewhere once the study is completed.

3. DISCUSSION

One of the key benefits that LED technology offers for general lighting applications is reduced maintenance due its long-life potential. However, heat affects LED life and therefore, poorly designed LED systems or applications where heat cannot be removed could significantly reduce the life of LEDs in systems. One of the drawbacks of many performance standards presently used in the lighting industry is the call for testing lighting fixtures only at standard ambient conditions. The intent for these performance standards is to promote quality, high-performing fixtures. However, qualifying LED fixtures per these standards, where the measurement condition is open air with an ambient temperature of 25°C, could hurt the industry. Lighting systems used in poorly ventilated areas could fail much more rapidly, as illustrated in this study. LED lighting systems that do not realize their long-life promise could turn off end-users from LED technology completely. It is for this reason that ASSIST developed test procedures that can provide useful information to end-users and the applications community. Providing such data would set the right expectations for the longevity of LED systems and in the long run would help the entire LED lighting industry.

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