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Lumen maintenance predictions for LED packages

W.D. van Driel [a,c,*], M. Schuld [b], B. Jacobs [a], F. Commissaris [a], J. van der Eyden [a], B. Hamon [d]

[a] Philips Lighting, High Tech Campus, Eindhoven, The Netherlands
[b] CQM, Eindhoven, The Netherlands
[c] Delft University of Technology, DIMES-ECTM, The Netherlands
[d] Philips Lighting, Rue des Brotteaux, 01708 Miribel, France

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ABSTRACT

Commercial claims for LED-based products in terms of lumen maintenance are fully based on TM-21 extrapolations using LM-80 data. This paper indicates that there may be a risk in doing this as TM-21 only relies on the behavior of the average LED degradation, instead of taking into account the degradation of all individual LEDs. Therefore, we propose a more profound statistical analysis in order to make the appropriate step from TM-21 extrapolation to lumen maintenance on a product level. This is needed as some commercial claims are based on 10 years of warranty and some service bids provide periods of 20 to 25 years of operation. This paper reviews the different approaches currently available to perform lumen maintenance extrapolations. We propose a new method to analyze and extrapolate LM-80 data using a more profound statistical approach.

1. Introduction

Solid State Lighting (SSL) refers to a type of lighting that uses semiconductor light-emitting diodes (LEDs), organic or polymer light-emitting diodes (OLED/PLED) as sources of illumination rather than electrical filaments, plasma (used in arc lamps such as fluorescent lamps), or a gas. SSL applications are now at the doorstep of massive market entry into our offices and homes. This penetration is mainly due to the promise of an increased reliability with an energy saving opportunity: a low cost reliable solution [1].

Per today, commercial claims for LED-based products in terms of lumen maintenance are fully based on LM-80 data [2] and TM-21 extrapolations [3–5]. IES LM-80-08 is an approved method for measuring lumen maintenance of LED lighting sources. The IES standard TM-21-11 provides a guideline for lifetime prediction of LED devices. It uses average normalized lumen maintenance data coming from LM-80 measurements and performs non-linear regression for lifetime modeling. It cannot capture the dynamic and random variation of the degradation process of LED devices. The lumen maintenance life is defined as the time when the maintained percentages of the initial light output fall below a failure threshold. There may be a risk in doing this as TM-21 only relies on the behavior of the average LED degradation, instead of taking into account the degradation of all individual LEDs. A more profound statistical analysis is required to make the step from TM-21 extrapolation to lumen maintenance on a product level. In this paper we investigate the different approaches that are able to perform lumen maintenance extrapolations. For that, we have analyzed several LM-80 data sets from a statistical point of view.

2. Problem formulation

Lumen maintenance is the basis for commercial claims of LED-based products [6–8]. As such, it is extremely vital to perform projections that are statistically sound and correct. Being an industry agreement, TM-21 flaws in this respect and alternative approaches are needed. Such an alternative approach should encompass the following nature:

- Use all the raw data, per setting, per LED and per time point
- Provide statistically sound results in terms of prediction stability
- Provide a true value for the lumen life of the LED technology

Chapter 3 describes the current agreed methods and provides an alternative statistical approach.

3. Statistical methods

3.1. Current agreed methods

Per today, all LED suppliers deliver LM-80 datasets typically at three currents and three temperatures. A typical data set is depicted in Fig. 1 [6]. This relative data is then used for the TM-21 extrapolation tool to create a prediction that is listed in Fig. 2. The result is truncated using the so-called 6x rule, where one can only claim a value that is six time

* Corresponding author at: Philips Lighting HTC 45-3B, 5656AE Eindhoven, The Netherlands. Tel.: +31 (0) 650123153; fax: +31 (0) 40 27 56564.
E-mail address: willem.van.driel@philips.com (W.D. van Driel).

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2.0 TEST CONDITION 1: 55 °C 0.200 A

TABLE 2.1 - LUMEN MAINTENANCE RESULTS
TEST CONDITION 1: 55 °C 0.200 A

Photometric test drive current: 0.200 A
Photometric test ambient temperature: 25 ± 2 °C
Failures observed: none

Load board ID	Device number	Zero hour measurements: Flux (lm)	Zero hour measurements: V_F (V)	Lumen Maintenance (%) 168	500	1000	2000	3000	4000	5000	6000	7000	8000	9000
A800000B9457031C	1	515.10	25.79	100.4	100.5	99.9	99.7	100.0	99.9	99.9	99.2	99.1	98.9	98.1
	2	518.67	26.40	99.9	99.9	99.4	99.1	99.3	99.2	98.9	98.5	98.4	98.3	97.6
	3	518.57	25.75	100.1	100.3	99.8	99.6	100.1	100.0	100.0	99.4	99.3	99.2	98.5
	4	511.77	26.23	100.7	100.9	100.3	100.3	100.7	100.8	100.7	100.3	100.1	100.0	99.1
	5	517.49	26.12	99.9	99.9	99.4	99.0	99.7	99.8	99.7	99.2	99.0	99.2	98.4
	6	516.60	27.17	100.2	100.2	99.6	99.6	99.9	99.8	99.8	99.2	99.1	99.0	97.7
	7	522.52	27.56	100.3	100.4	100.0	99.9	100.3	100.3	100.3	99.4	98.8	97.7	96.0
	8	512.03	26.30	100.4	100.4	99.8	99.7	100.1	100.0	99.9	99.3	99.1	99.1	98.5
	9	516.71	25.83	100.5	100.3	99.9	99.8	100.2	100.1	100.1	99.6	99.6	99.5	98.5
	10	516.33	25.70	100.3	100.3	99.8	99.9	100.4	100.4	100.5	99.9	99.7	99.5	98.6
	11	520.62	25.94	100.2	100.1	99.6	99.5	99.9	99.9	99.9	99.4	99.3	99.2	98.4
	12	515.88	26.51	100.1	100.1	99.6	99.6	100.2	100.2	100.3	99.7	99.6	99.3	98.5
F600000B9E7D031C	1	524.22	26.27	100.0	100.2	99.6	99.7	99.8	99.8	99.6	99.0	98.9	98.7	97.8
	2	516.25	27.44	99.9	100.0	99.4	99.5	99.6	99.4	99.4	98.6	98.2	97.4	95.8
	3	514.76	26.05	99.3	99.3	98.8	98.8	98.8	98.7	98.5	97.7	97.9	97.7	96.8
	4	515.71	25.99	99.5	99.7	99.1	99.1	99.3	99.2	99.2	98.8	99.0	99.0	98.3
	5	517.33	25.99	99.9	100.1	99.6	99.8	100.0	99.8	99.9	99.3	99.4	99.3	98.4
	6	512.51	25.96	99.9	100.0	99.8	100.1	100.4	100.3	100.3	99.8	99.8	99.4	98.0
	7	514.99	25.59	99.8	99.8	99.1	99.2	99.1	99.1	98.9	98.4	98.6	98.5	97.6
	8	514.99	26.45	99.9	100.1	99.7	99.9	100.0	100.1	100.0	99.6	99.6	99.3	98.2
	9	520.72	25.88	99.7	99.9	99.4	99.7	99.8	99.7	99.7	99.2	99.3	99.3	98.6
	10	517.69	25.52	99.8	100.1	99.6	99.8	99.9	99.9	99.9	99.5	99.6	99.6	98.9
	11	507.07	26.24	100.5	100.9	100.6	100.7	101.1	101.0	101.0	100.5	100.5	100.4	99.3
	12	522.09	25.92	99.8	100.0	99.4	99.5	99.8	99.7	99.6	99.1	99.1	99.1	98.2
			n	24	24	24	24	24	24	24	24	24	24	24
			mean	100.0	100.1	99.6	99.6	99.9	99.9	99.8	99.3	99.2	99.0	98.1
			median	100.0	100.1	99.6	99.7	100.0	99.9	99.9	99.3	99.2	99.2	98.4
			std. dev.	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.9
			min	99.3	99.3	98.8	98.8	98.8	98.7	98.5	97.7	97.9	97.4	95.8
			max	100.7	100.9	100.6	100.7	101.1	101.0	101.0	100.5	100.5	100.4	99.3

Fig. 1. Typical LM-80 data set showing lumen decay per LED as function of measurement time [6].

the LM-80 time (e.g. with 6 kh test time, one can only claim 36 kh lumen maintenance).

Within the TM-21 committee, an initial approach to the problem of projecting lumen maintenance life was the consideration of multiple mathematical models [4,5]. These ranged from 1-parameter exponential decay until 3-parameter multi-exponential decay.

Note that there is a risk in accepting lifetimes that are predicted far beyond the LM-80 testing time because of the significant effect of measurement errors. In order to prevent that, it is important to use either golden samples or to use (agreed) censoring data points.

Within TM-21, being an industry agreement, finally, the simplest possible form was chosen as:

$$\Phi(t) = \exp(-\alpha t^{\beta}) \tag{1}$$

where:

- T is the time in hours;
- $\Phi(t)$ is the averaged normalized luminous flux output at time t;
- α is the decay rate constant derived by a least squares curve-fit;
- β is the shape parameter.

For each separate temperature and/or current L70, that is $\Phi = 0.7$, can then be calculated using averaged normalized luminous flux output:

$$L_{70} = (-\ln(0.7)/\alpha)^{1/\beta} \tag{2}$$

Estimates of (α, β) can be easily obtained by applying the least squares method. Temperature acceleration, within the measured temperatures, is allowed and supposed to follow the Arrhenius equation:

$$\alpha = C \exp\left(\frac{-E_a}{k_B T_s}\right) \tag{3}$$

where:

- C is a pre-exponential factor;
- E_a is the activation energy (in eV);