

Technology White Paper

Understanding power LED lifetime analysis

How intuitive graphical data sets help lighting designers accurately predict power LED reliability in different operating environments.

Introduction

When designing LED-based lighting systems, engineers need to understand LED lumen maintenance and mortality in similar terms to those used when designing with conventional light sources. However, comparable data has been nearly impossible to find. In addition, designers need extra information to predict the lifetime of LEDs under a variety of operating conditions. A number of techniques to predict LED lifetimes have been proposed, but these have not been sufficient to generate the clear and unambiguous data that lighting engineers can use easily.

This white paper provides lighting designers with an understanding of a new tool introduced by Philips Lumileds Lighting Company that simplifies the process allowing full flexibility in design options. This one tool provides designers with information that they need to make decisions about product lifetimes, driver constraints, number of LEDs required, and thermal management.

1. Ageing and failure modes of lighting sources

Usually, incandescent light sources display little change in light output until the bulb fails catastrophically. In a large lighting installation, each individual lamp failure reduces the overall light output of the system. In many such installations, a minimum illumination level is mandated by prevailing standards. These may be set by customer requirements or by legal minimum limits applicable in public spaces, workplaces and similar environments. When the light level falls below the specified minimum, relamping is required. This is an expensive process, involving

administrative overhead as well as labour to change the lamps. The total cost of relamping can be 16 times higher than the purchase cost of the lamp itself.

LED light sources, on the other hand, do not tend to fail catastrophically. Instead, the light output degrades gradually over time. The useful operating lifetime of a power LED is extremely long, and often longer than the lifetime of the product in which it is embedded. In a large installation, depending on the mission life of the fixture, the effect of this fading over time may be to reduce the overall light output to a level below the specified minimum. However, as relamping is so infrequent, the total cost of ownership is reduced.

When designing lighting systems using either conventional incandescent or gas-discharge lamps, designers consider the total illumination, the minimum light level specified, the expected lamp failure rate (mortality), the desired relamping interval (mission life), and the lamp operating conditions.

Depending on the installation, traditional drivers can adjust the operating voltage for traditional lamps; reducing the operating voltage reduces the brightness of the lamp but also extends its lifetime. To manage the same trade-offs for LED installations, designers can specify drivers to control the forward current, and resulting thermal management to control the operating temperature. As noted below, a longer relamping interval can result in large cost savings for the end customer.

2. Established lighting industry definitions of useful life

To enable designers to meet customer requirements for:

- minimum illumination
- relamping interval
- initial purchase price
- ongoing energy costs

the lighting industry historically rated devices in terms of the time by which a certain percentage of the population is expected to have failed (see figure 1). For example, a B10 value for any given lamp denotes the time by which 10% of the population is expected to fail. Also used is the B50 value; the point where the failure rate is 50% - sometimes called the rated or average life.

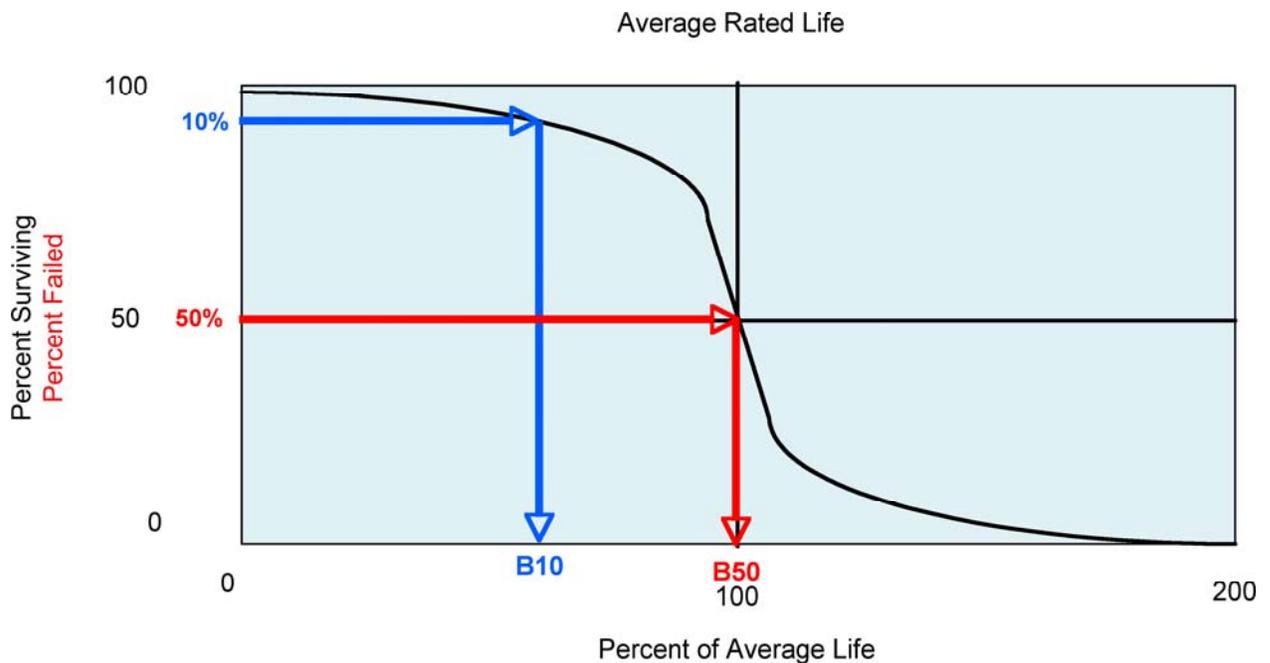


Fig. 1: the standard industry expression for failure rates of lighting devices

3. Established LED industry definitions: Lumen maintenance

Recently, the growing adoption of power LEDs in lighting applications presented designers with a new set of metrics for lifetime. It is rare for an LED to fail completely. Instead, the intensity of light emitted tends to fall over time, as shown in figure 2. This effect is termed “lumen maintenance”. In a lighting installation, this reduction in lumen maintenance may, eventually, result in a drop in light output to below agreed limits for the environment.

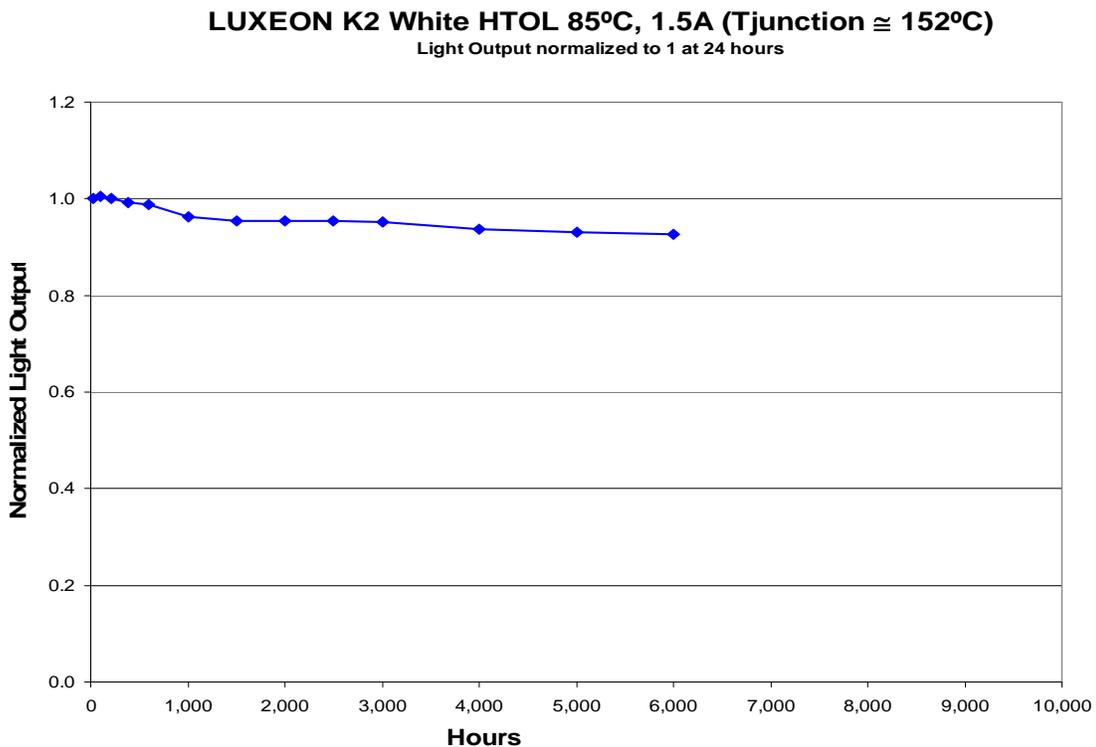


Fig. 2: graph showing the light output of a Philips Lumileds K2 LED declines over time

A power LED industry group, the Alliance for Solid-State Illumination Systems and Technologies (ASSIST)¹, found that 70% lumen maintenance is close to the threshold at which the human eye can detect a reduction in light output. The ASSIST research shows a 30% reduction in light output is acceptable to the majority of users for general lighting applications.

On the other hand, ASSIST also recommends that higher or lower figures for lumen maintenance should be considered for certain types of applications. For example, where lights are seen side-by-side, such as in wall-washing applications, the useful life should be calculated on a higher figure for lumen maintenance – typically 80%. A lower lumen maintenance threshold could be acceptable in decorative systems where light output is not critical to performance.

4. Understanding LED operation and lifetimes

ASSIST proposed that two co-ordinates be used to express the useful lifetime of an LED component or system. These are:

- a). The time to 70% lumen maintenance (denoted by L70), and
- b). The time to 50% lumen maintenance (denoted by L50)

With both of these co-ordinates available, lighting designers are able to make trade-offs.

However, in practice, designers need much more information to fully specify the system. For example, maintaining constant current is vital to ensuring uniform illumination, but the chosen current value also has an important bearing on lumen maintenance. Driving the LED at a level below its maximum rated forward current will extend its useful lifetime, thereby increasing the quotable L70 and L50 lifetimes.

The temperature of the LED junction also influences lumen maintenance: designing for a lower junction temperature will extend the L70 and L50 figures for the LED. For this reason, thermal design considerations are an important aspect of designing an LED-based lighting system.

Figures 3 and 4 illustrate the effect of changes in forward current and junction temperature on lumen maintenance on a Luxeon brand high-power LED from Philips Lumileds.

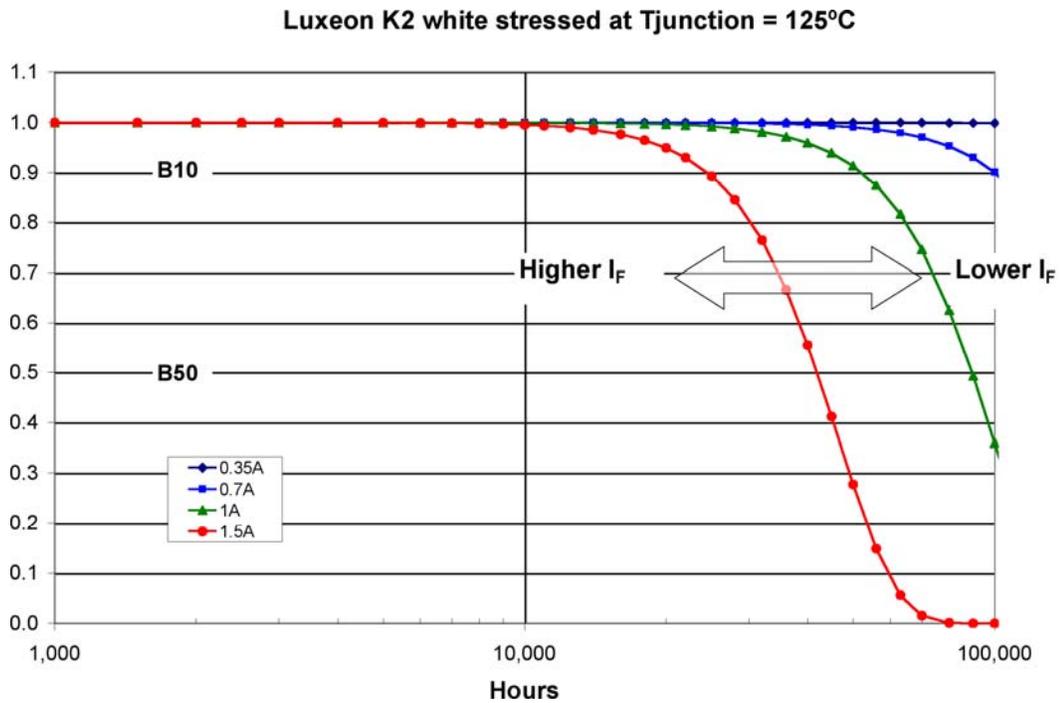


Fig. 3: how changes in forward current affect the useful lifetime of an LED

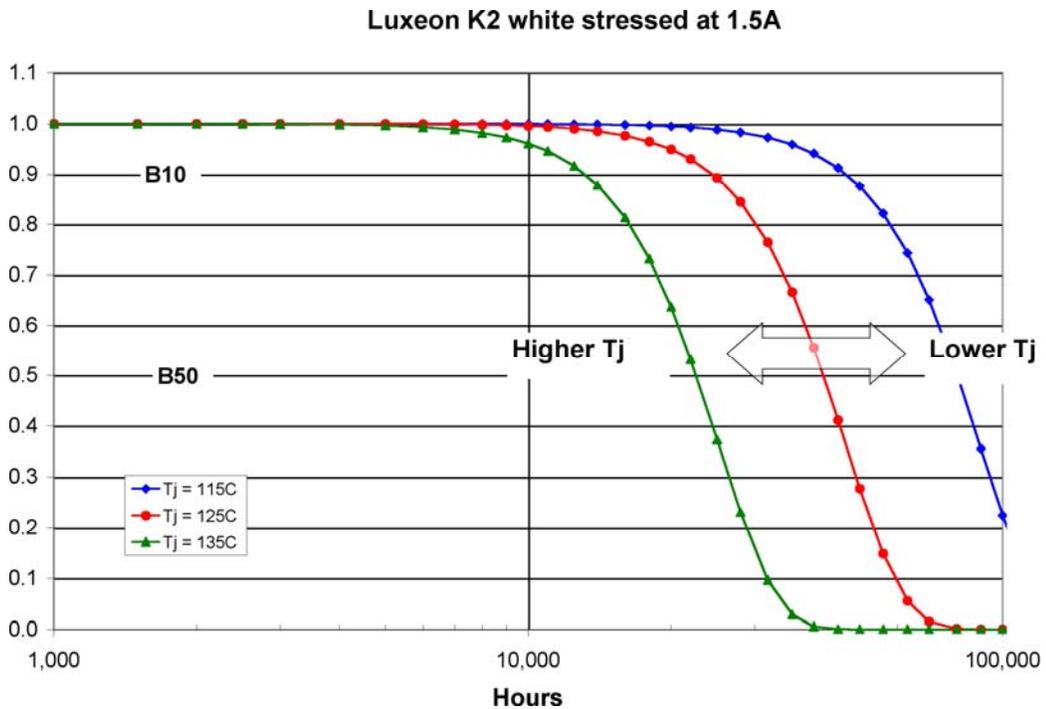


Fig. 4: how changes in junction temperature affect the useful lifetime of an LED

To ensure that designers have sufficient information to design a complete system to meet established criteria for light output and relamping intervals, ASSIST and others recommend understanding that LED performance depends on many parameters and LED vendors should publish information on:

- The number of samples tested
- A description of the test heatsink used
- The ambient temperature
- The thermal resistance of the package and leads
- The voltage and current applied to the device during the test

Moreover, this data should be provided at three test temperatures, as measured at the closest possible location to the LED junction.

Clearly, LED performance is influenced by many parameters – more than some lighting designers are accustomed to. But there is no reason why this more complex information should be unwieldy or difficult to use. In practice, sufficient information can be presented graphically, in an intuitive format, to help designers build LED-based lighting solutions to meet the required performance targets.

5. Completing the expression for lumen maintenance

To enable a simplified graphical approach, more information than that expressed by the L70 or L50 figures is required. An equivalent to the traditional B-lifetime (failure or mortality) figure is also necessary for designers to understand the percentage of LEDs in which the lumen output has fallen below the agreed threshold (remember, an LED exhibiting “lumen maintenance failure” still provides illumination, but slightly below the established threshold). This B-figure enables designers to specify the LEDs to meet all design requirements for the installed system.

Hence, to ease the challenge for designers who need to factor-in drive current and thermal management needs, Philips Lumileds proposes that LED lifetime testing data should be expressed in terms of L-lifetimes *AND* B-lifetimes and presented graphically with reference to driving current and junction temperature.

Figure 5 illustrates such a graph for the Luxeon K2 LED family from Philips Lumileds. The graph shows lifetimes for four values of continuous forward current up to the maximum rated value, with reference to a range of junction temperatures.

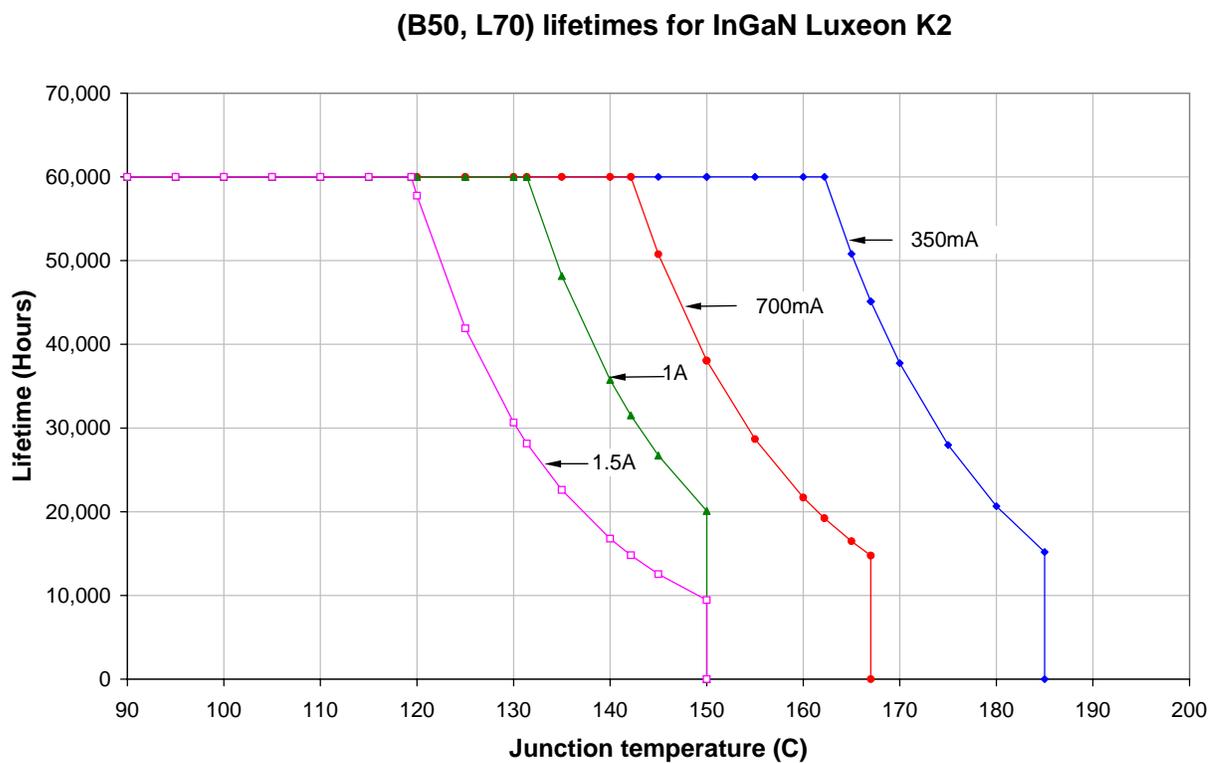


Fig. 5: B50, L70 lifetime data across current and temperature variables for K2 LED

6. Designing with B/L data for optimal lighting performance

Using the graph in figure 5, a designer seeking a B50 solution to a lighting requirement can determine the forward current and junction temperature necessary to meet the desired lifetime. From this information, the driving circuit parameters and heatsink size can be determined.

To comply with common practice in the lighting industry, as well as the ASSIST recommendations, Philips Lumileds publishes information for B10/L70 and B50/L70, against junction temperature and forward current.

This data allows designers to make intelligent decisions when optimising the performance, cost, size and operating conditions of an LED lighting solution. Simply put, the number of LED sources required, the power supply rating, the thermal management requirements, and cooling arrangements are easily determined. All of these have an important bearing on the bill of materials as well as cost of ownership.

7. Predicting LED lifetimes

Philips Lumileds uses the Weibull distribution function, a universally-respected statistical technique, to predict the useful lifetimes of power LEDs based on experimental data. The Weibull function, developed in 1951 by Waloddi Weibull, has proved effective in reducing the amount of experimental work required - and therefore the costs and time involved - to model the behavior of systems or populations containing large numbers of units. It has been applied successfully throughout many industries. Examples include Weibull's own work on fatigue testing of materials and engineering assemblies. Wider applications include industrial process control, wireless communications, radar systems, and weather forecasting.

The Weibull distribution function can be written as:

$$f(x; k, \lambda) = \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}$$

where x , k and λ are derived from experimental data.

Based on collected data, such as recorded lumen maintenance of power LEDs undergoing lifetime testing, values for x , k and λ can be calculated. The Weibull distribution function is then used to extrapolate the recorded data to predict behavior over a period longer than that measured.

The application of the Weibull function acknowledges that the size of the recorded data set influences the accuracy of the calculated values x , k and λ . A larger body of experimental data produces values that more closely resemble the behaviour of the system.

Having spent over 30 years developing power LEDs, performing lifetime testing continuously throughout this period, Philips Lumileds has the industry's largest accumulated database of LED lifetime test data. Components are tested in a matrix of different environmental and drive conditions for many thousands of hours, resulting in millions of device-hours of information. This approach enables a highly confident (90% Confidence Interval) extrapolation of product performance, resulting in low divergence between forecasted and actual data. It is worth noting that the data from fewer parts on test for fewer hours support performance predictions that extend less far into the future.

Based on the quantity of data now available to Philips Lumileds, prudent statistical policies allow lumen maintenance to be forecast accurately to 60,000 hours. By continually adding to its database of actual lifetime data, Philips Lumileds will continue to present extremely reliable forecasts for power LED lumen maintenance in the future.

Conclusion

The lighting industry needs LED manufacturers to provide data that is compatible with current design practice. However, this only answers a part of the challenge. LED vendors should also be in a position to provide more detailed information about product lifetimes under various operating conditions. This data allows lighting designers to deliver the best combination of purchase price, lighting performance, and cost of ownership for the life of the product.

From a user's perspective, this data is most usefully expressed as a combination of B- and L-lifetime as junction temperature and forward current are varied. This allows the system designer to make intelligent choices about the number of LEDs required, how they are driven, and the operating temperature.

Every power LED customer should therefore expect their supplier to provide this data as a matter of course, in any combination of B, L, T_j and I_f values, with clear definitions of failures (e.g. lumen maintenance below specified condition, electrical failures).

Only with these combinations of data can designers optimise their applications for performance, cost of installation and lifetime cost.

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1. ASSIST, the Alliance for Solid-State Illuminations and Technologies, is an independent body whose sponsors include Boeing, GELcore, New York State Energy Research and Development Authority, Nichia America Corporation, Osram Sylvania/Osram Opto Semiconductors, Philips Lighting and the US Environmental Protection Agency.

More details about ASSIST, including published papers, can be found at www.lrc.rpi.edu/programs/solidstate/assist/index.asp.