Gauging the Lifetime of an LED

By Fritz Morgan, Chief Product Officer, Digital Lumens

LEDs have already taken over the electronics industry, lighting everything from traffic signals and cell phones to computers and TVs, due to their extremely low energy use, long lifespan and high-quality light. For the same reasons, LEDs are on track to overtake the general illumination market within the next decade, including high-intensity industrial and commercial applications such as warehousing, manufacturing, and retail.

In fact, this transition is already taking place as industrial facilities increasingly turn toward LED-based lighting systems to reach strategic energy efficiency, sustainability, and cost-containment goals. Consequently, the issue of how to effectively measure the lifespan of a specific light source is growing in importance. To compare expected lifetimes of lighting alternatives, from high-intensity discharge (HID), high-intensity fluorescent (HIF), and various LEDs, there are three parts to the equation that are relevant to industrial consumers:

- Lifetime Rating Calculations for Traditional Light Sources (HID & HIF)
- Useful Lifetime Calculations for LEDs
- Lamps versus Luminaires

For anyone considering a new or retrofit lighting project, the following is a brief overview of how lifetime ratings are calculated for the various lamping alternatives. Understanding how ratings are calculated simplifies the comparison process by enabling facilities managers to leverage easily accessible data to make informed lighting decisions.

Lifetime Rating Calculations for Traditional Light Sources

The lifetime rating for incandescent bulbs is defined as the number of hours it takes for 50% of the bulbs to fail completely, assuming ideal conditions. This is called Mean Time Between Failure, or MTBF. While this simplistic, "ideal conditions" definition of MTBF is only used to inform household purchase decisions, with additional constraints it is the same failure rate guideline that is used by the industry for its more rigorous industrial light source tests.

It is important to note that testing conditions play a major role in lifetime rating results, particularly for applications with frequent ON/OFF cycles, which substantially reduce the useful life of incandescent and fluorescent bulbs. To enable easy comparisons of competing light sources, manufacturers rely on standardized testing methodologies published by the Illuminating Engineering Society (IES). These standardized tests are usually performed by independent rating agencies hired by the lamp manufacturer and include:

- **LM-49** — The IES-approved protocol for lifetime testing of incandescent filament lamps. It requires a manufacturer to: (1) test a statistically valid sample of lamps within the product's specified temperature and voltage operating ranges, and (2) cool the lamps to ambient room temperature (25°C) once a day for the duration of the test. The lifetime rating is determined when 50% of the lamps fail. The lifetime ratings for incandescent filament lamps range from 750 hours on the low side, to 2,000 hours on the high side for "long-life" bulbs.
- **LM-65** — The IES-approved protocol for lifetime testing of compact fluorescent lamps (CFLs). It, too, requires the testing of a statistically valid sample, with the following additional constraints: (1) that the tests be performed at an ambient room temperature of 25°C, and (2) that the lamps be cycled on a three hours ON, 20 minutes OFF, basis until 50% of the lamps fail.

The more rigorous cycling guidelines for CFLs are due to the fact that frequent cycling considerably shortens CFL lamp life. (Since incandescent lamps are not recommended for applications that require frequent cycling, the same guidelines are not applied to these lamps.) The lifetime ratings for CFLs are in the 10,000-hour range.

The high-intensity versions of these lamps, notably HID and HIF, are tested using the same LM-49 and LM-65 methodologies discussed above, resulting in lifetime ratings in the 20,000-hour range.

Useful Lifetime Rating Calculations for LEDs

Unlike incandescent lamps, which either work or don't work, at the end of their lives, LEDs rarely fail outright. Instead, long past their useful lifetime (in excess of 50,000 hours) nearly 100% of LEDs will continue to emit appreciable light, albeit at a slowly diminishing rate over time. Thus, MTBF has little meaning in the LED world. The most valuable gauge for determining the lifetime rating of an LED light source is lumen maintenance — also known as lumen depreciation — the percentage of initial lumens an LED maintains over a specified period of time.

The prevailing lumen maintenance standard for industrial applications is L_{70}, which is the expected number of operating hours before light output diminishes to 70% of its initial levels. This percentage is favored because in-depth research (conducted by the Alliance for Solid State Illumination Systems and Technologies, aka ASSIST) indicates that most users fail to notice the slow loss of light until well after it passes the 70% mark.

Arriving at L_{70} is a two-step process. First, LED light sources are tested to the IES LM-80 specification, which requires 6,000 hours of testing (and optionally 10,000 hours) at three junction temperatures: 55° C, 85° C, and a temperature selected by the manufacturer. (Note: Junction temperature, the internal temperature of the LED chip itself inside the fixture is an indicator of the quality of a system's thermal management, and is important because high temperatures can significantly affect LED light output and lifetimes.) L_{70} is then extrapolated from these test results. L_{70} is an extrapolated value because actual testing would take years longer than a product's shelf life — e.g., the lamp would be obsolete before testing is complete. (For example, a 50,000-hour test would correspond to 5.7 years of continuous testing.)

The useful lifetime ratings for LEDs range from 36,000 to 60,000 hours, based on those extrapolated calculations.

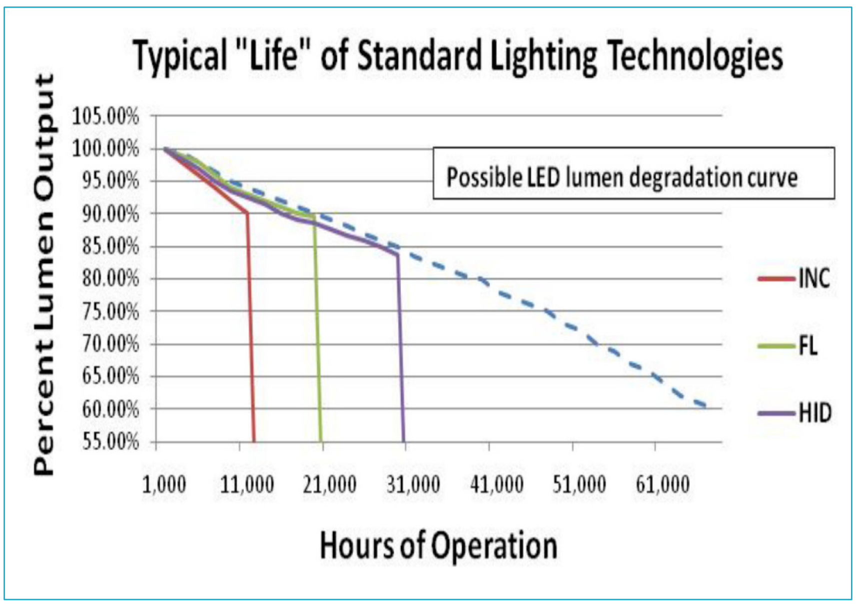

Figure 1: Typical light output change for different light sources vs. operating hours. The curves for incandescent, fluorescent, HID drop off rapidly after a point because the light source fails. (Source http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/richman_tm21_lightfair2011.pdf)

Extrapolated Values Unplugged

Until very recently, the formula used to extrapolate IES LM-80 testing results to determine the L_{70} lifetime rating for an LED was not standardized, meaning that each vendor performed these calculations differently. This resulted in lifetime ratings claims that varied widely among vendors, leading to an unnecessary level of uncertainty and doubt among industrial consumers.

To address this issue, IES recently introduced the TM-21 specification, which standardizes the L_{70} extrapolation formula and dictates which LM-80 test results can be used in the L_{70} calculation. TM-21, for example, stimulates which values can be used in the extrapolation formula based on the sample size, number of hours and intervals tested, and test suite temperature (ambient, high ambient). It also creates an upper limit to the extrapolation — no more than six times the number of hours tested — thereby eliminating excessive vendor claims. Most LED chip vendors only test to 6,000 or

10,000 hours, capping the maximum rating to 36,000 to 60,000 hours. If you see claims in excess of those numbers, be doubly sure to request the underlying data and make sure it is from a reputable source.

With IES TM-21 being adopted by LED vendors and test labs, industrial consumers gain a useful and standardized tool for comparing the varying lifetime ratings of LEDs. Here is an example of TM-21 data:

CREE

TM-21 Lifetime Report

LED	XLamp XP-G White		
I	1000 mA		
Data Set	10	11	12
Tsp	55°C	85°C	105°C
Sample Size	20	20	20
Test Duration	10,080 hrs	10,080 hrs	6,048 hrs
α	-4.219E-06	1.284E-06	5.561E-06
β	9.847E-01	1.016E+00	1.007E+00
Calculated Lifetime	α<0; see Reported Lifetime	L70(10k) = 290,000 hours	L70(6k) = 65,500 hours
Reported Lifetime	L70(10k) > 60,500 hours	L70(10k) > 60,500 hours	L70(6k) > 36,300 hours

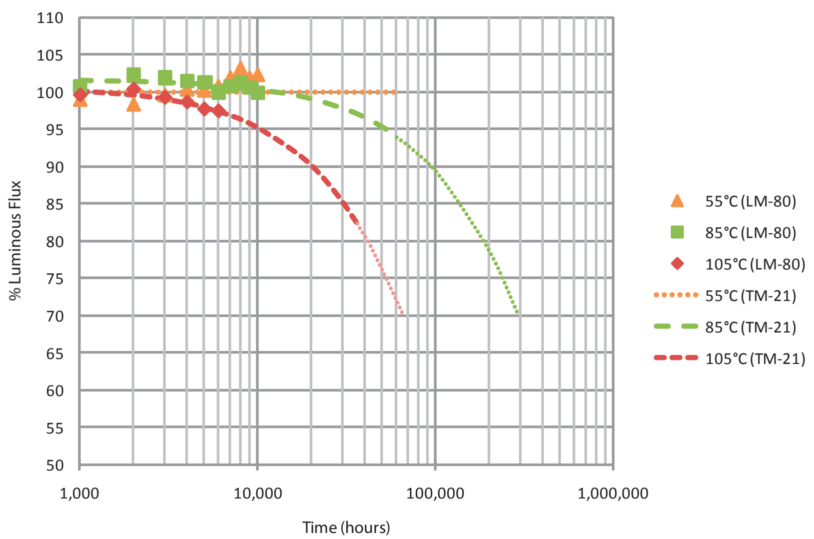

Table 1: *TM-21 data for a Cree XP-G LED run at 1000mA with a solder point temperature of 55°, 85°, and 105° C respectively. As can be clearly seen in the 85° C case, the calculated life is well over 250K hours but the reported lifetime is only six times the 10,800 hours that the LEDs have actually been tested to, as can be seen in the table and graph to the left. Note: This data is updated periodically. Please refer to* http://www.cree.com/products/pdf/LM-80_Results.pdf *for the most up-to-date information.*

Useful Lifetime (LED) versus Lifetime Ratings (Incandescent)

The question then becomes: Can LED useful lifetime ratings be compared, on an apples-to-apples basis, to the lifetime ratings of incandescent lamps, which are based on MTBF? The short answer is yes. If incandescent lifetime ratings were extrapolated to their corresponding L_{70} values, the lamps would fail (e.g., exceed MTBF) well before they reached these thresholds (see *Figure 1*).

Evaluating the Luminaire (Entire Light Fixture)

While lamping is a critical component of lighting system longevity, the performance of the entire lighting fixture also merits considerable attention due to its role in driving lifetime costs. Issues such as the efficacy of heat dissipation or lumen delivery, for example, play a major role in determining total cost of owning these products over an extended period of time.

In the near future, rigorous lifetime rating standards will be available from a variety of sources (the U.S. Department of Energy and IES) to help industrial customers evaluate the cost/performance implications inherent in the design of the entire luminaire. These ratings will provide additional depth to existing best practice considerations, such as:

- *Is the lighting fixture on the DesignLights™ Consortium's (DLC) Qualified Products List in the relevant category (e.g., highbay, lowbay)?*

  Through rigorous evaluation of lighting products and vendors, the DLC (a collaboration of utility companies and regional energy efficiency organizations) is working to ensure that high-quality, energy-efficient lighting becomes commonplace in all areas of the commercial lighting market. Placement on DLC's Qualified Products List fast-tracks the utility rebate process, as it is the primary tool participating utilities use when considering rebate applications from industrial and commercial customers who use products that are not currently covered by the U.S. Department of Energy's Energy Star™ program.

- *Does the entire lighting fixture (not just the individual components) carry proper listings (UL, ULC, CE, CB, NOM, C-Tick)?*

  Many industrial lighting vendors tout their UL listings. Dig a little deeper, however, and it becomes clear that while individual components of their lighting fixtures are UL-listed, the entire fixture is not. For safety and reliability, it is important that both the components and the entire fixture be UL-listed. Very few LED light vendors can make this claim, so it is important to ask.

Informed Decision-Making

Given the very real differences among the various lamping alternatives, lifetime ratings are an important element in the evaluation process for anyone considering a new or retrofit lighting project. Understanding how these ratings are derived provides greater clarity to the wide array of data published by manufacturers and independent testing labs and, when combined with rating information for the entire luminaire, ensures that a facility's chosen lamp source meets the organization's strategic energy efficiency, sustainability and cost-containment goals while meeting performance expectations.

Other Relevant Notes

- Unlike fluorescents, there are no ON/OFF cycling limitations for LED light sources, because frequent switching does not impact the useful life of an LED. So, when LEDs are integrated with occupancy and/or daylight harvesting sensors, and are cycled on and off more frequently, useable lifespan is being extended because they are being turned off when not needed.

- For systems with incandescent light sources, such as HID and HIF, engineers typically over-light space to account for rapid initial lumen depreciation. This adds to up-front costs and lifetime energy costs of incandescent lighting applications.

- Regarding maintenance costs for HIDs, given a 50% MTBF rating, expect significant annual re-lamping on a portion of the fixtures.

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About the Author

A seasoned engineering leader, Fritz Morgan brings more than 18 years of experience in systems design across multiple technology sectors to his role as Chief Product Officer at Digital Lumens. At the Company, he oversees development of all elements of the Intelligent Lighting System, including LEDs, networking hardware, and the software-based energy management system.

Fritz joins Digital Lumens from Joule Unlimited, developer of the Helioculture platform for converting sunlight and waste CO_2 into liquid fuels, where he was Senior Vice President of Engineering. While there, he managed all aspects of system design and development, and oversaw the design and deployment of the company's first pilot facility.

Previously, Fritz was Chief Technology Officer of Color Kinetics, which was acquired by Philips Lighting in 2007. In the course of 11 years, he was responsible for the development of Color Kinetics' award winning products and technologies — with responsibility for defining the strategic product direction for the company. Fritz also established the company's operations in China, with manufacturing capacity and new product introductions, and helped develop and manage an extensive IP portfolio. After the Philips acquisition, Fritz was responsible for the technology merger and integration, and had responsibility for LED research and development programs for Philips worldwide.

Earlier in his carrier, Mr. Morgan worked on medical robotic and computer-assisted surgical applications and surgical simulation products, including the hardware and software systems development, for Mitsubishi Electric.

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