Useful Life

Technical Brief

Understanding LM-80, Lumen Maintenance, and LED Fixture Lifetime

PHILIPS

COLOR KINETICS™

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As with key photometric measurements, such as lumen output and efficacy, life calculations for LED light sources and conventional light sources differ considerably. Reliable comparisons between conventional and LED light sources require an understanding of these differences, and often involve some analysis of reported figures.

While life testing might appear to be as straightforward as turning a unit on and seeing how long it lasts, measurement and evaluation are not so simple, especially for LED light sources. Today, life testing methods for conventional light sources — incandescents, fluorescents, high-intensity discharge lamps, low-pressure sodium lamps, and so on — are well established and well understood. The life testing method for LED light sources is relatively new and less well understood.

This technical brief explains how to interpret useful life calculations for LED sources and LEDs sources incorporated into lighting fixtures, and suggests a method for making accurate comparisons between conventional lamps and LED lighting fixtures.

Photography: Robert Sansone

The 200-year-old steeple of the First Baptist Church in Beverly, Massachusetts was illuminated with incandescent floodlights, which have a rated life of around 2,000 hours. At about six hours of use per day, the lamps burned out within a year. Since the lamps could only be replaced every seven or eight years, when scaffolding was in place for painting, the steeple was usually dark. In 2009, the steeple was renovated, and LED lighting fixtures from Philips Color Kinetics were installed. With useful life of about 50,000 hours, these fixtures can deliver high-intensity light for over 20 years at current usage, ensuring that the steeple is continuously and brilliantly illuminated.

Rated Lamp Life of Conventional Sources

Approved methods for life testing of conventional light sources call for measuring and reporting *rated lamp life*. These methods are published by the Illuminating Engineering Society (IES) in a variety of official publications. For example, LM-65-01 defines life testing procedures for compact fluorescent lamps (CFLs), while LM-49-01 defines life testing procedures for incandescent filament lamps. Both LM-65-01 and LM-49-01 have been available and in use since 2001, and both methods revise older standards, published in 1991 and 1994 respectively.

Life calculations for conventional light sources are typically expressed as rated lamp life, *the mean time to failure of a statistically valid sample of lamps.*

Both publications establish testing conditions, sample sizes, and methodologies for generalizing test data to arrive at rated life specifications. For CFLs, LM-65 specifies a statistically valid sample to be tested at an ambient temperature of 25° C, in a cycle of three hours on and 20 minutes off (as CFL life is appreciably shortened by the frequency with which the lamp is started). The point at which half the lamps fail is the rated average life for that lamp.

For incandescent filament lamps, LM-49 specifies a statistically valid sample to be tested within the manufacturer's stated operating temperature range and voltage. Lamps are allowed to cool to ambient temperature once a day (usually for 15 to 30 minutes). As with CFLs, rated life for incandescent filament lamps is the total operating time at which half the lamps are still operating.

The two basic types of LEDs are indicator-type LEDs and illuminator-type LEDs. Indicator-type LEDs, such as 5 mm LEDs, are usually inexpensive, low-power LEDs designed for use as indicator lights in panel displays and electronic devices. Illuminator-type LEDs are durable, high-power devices capable of providing functional illumination. These high-power LEDs are the subject of this brief.

Lumen Maintenance and Lumen Depreciation

In September 2008, the IES published *Measuring Lumen Maintenance of LED Light Sources*, publication IES LM-80-08. LM-80 is the LED counterpart of LM-65, LM-49, and other life testing standards for conventional light sources, but it differs from the older standards in a number of important — and potentially confusing — ways.

Instead of measuring rated lamp life, LM-80 calls for measuring how much an LED source's lumen output decreases over a certain number of hours of operation. Technically, the term for this decrease is *lumen depreciation*. The converse of lumen depreciation is *lumen maintenance*, the industry-standard term for the percentage of initial lumens that a light source maintains over a certain period of time.

Lumen maintenance *is the industry-standard term for the percentage of initial lumens that a light source maintains over time.*

All electric light sources lose lumen output over time — indeed, annexes to both LM-65 and LM-49 address lumen depreciation of CFLs and incandescent filament lamps. In incandescent lamps, lumen depreciation is caused by depletion of the filament and the build-up of evaporated tungsten particles inside the bulb. Incandescents typically lose 10% – 15% of their initial lumen output over an average lifetime of 1,000 hours. In fluorescent lamps, lumen depreciation is caused by photochemical degradation of the phosphor coating and glass tube, and the build-up of light-absorbing deposits inside the tube. High-quality fluorescent lamps using rare earth phosphors lose only 5% – 10% of initial lumens over 20,000 hours of operation. CFLs depreciate more, but the most well-designed products lose no more than 20% of their initial lumens over an average lifetime of 10,000 hours.

In LED sources, factors that cause lumen depreciation include drive current and heat generated within the device itself (technically speaking, at the diode's p-n junction), which degrades the diode material. Some white-light LEDs may experience degradation of the phosphor coating like that of fluorescent lamps. Some LEDs can also lose lumen output due to clouding of or impurities in the encapsulant used to cover LED chips.

Lumen maintenance measurements take the form *Lp*, where *L* is the initial output of a light source, and *p* is the percentage maintained by the light source over a certain number of hours. L_{97} measures how long a light source retains 97% (or loses 3%) of its initial output, L_{44} measures how long a light source retains 44% (or loses 56%) of its initial output, and so on.

Since high-performance LED light sources can produce useful light for tens of thousands of hours, and since they rarely fail outright, lumen maintenance is often used in place of rated life measurements for LEDs. Measuring the rated life of LED light sources — the mean time to failure of a representative sample — would require operating the sources continually until they finally faded to darkness, a process which would take many years. Because LED light sources continue to deliver light even after their initial lumen output has decreased by 50% or more, lighting specifiers and designers need to know how long an LED lighting fixture will retain a meaningful percentage of its initial light output, not how long it will take for the light sources to fail.

Photography: Darius Kuzmickas / kudaphoto.com

World Market Center in Las Vegas, Nevada, uses over 8,000 ft (2,438.4 m) of eW Cove Powercore linear LED lighting fixtures from Philips Color Kinetics to illuminate the complex geometries of the atrium in its Building C. LED cove lighting offers advantages over conventional cove lights in high-end installations such as this one. With useful life of up to 70,000 hours, and a very low failure rate, LED cove lights virtually guarantee reliable illumination around the clock for many years, without dark spots from lamp outages that can mar the elegant and uniform presentation of a premier space.

Defining the Useful Life of LED Light Sources

The Alliance for Solid State Illumination Systems and Technologies (ASSIST), a group led by the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, New York, has published a series of recommendations defining the *useful life* of LED light sources. ASSIST defines useful life as the length of time a light source delivers a minimum acceptable level of light in a given application.

Research performed by ASSIST indicates that changes in general office lighting levels go largely undetected as long as light levels stay above 70% of their initial levels, especially if the changes are gradual. For general lighting applications, therefore, ASSIST recommends defining useful life as the length of time it takes an LED light source to reach 70% of its initial light output (L_{70}). For decorative and accent applications, ASSIST recommends defining useful life as the length of time it takes an LED light source to reach 50% of its initial output (L_{50}).

L_{70} and L_{50} are widely used by the LED lighting community as two important thresholds for useful life, covering a wide range of lighting applications.

LED light sources deliver light even after their initial output has decreased by 50% or more. Lighting specifiers, therefore, need to know how long an LED light source will retain a meaningful percentage of its initial output, not mean time to failure.

Useful life *is the length of time a light source delivers a minimum acceptable level of light in a given application.*

For LED light sources in lighting fixtures, two widely accepted useful life thresholds are L_{70} for general lighting and L_{50} for accent lighting.

The Lumen Maintenance Gap

All well and good — so far. But there's a disconnect between the test results typically provided by LM-80 on the one hand and the L_{70} and L_{50} thresholds that define useful life on the other. This disconnect, which could be called the lumen maintenance gap, is the source of a fair amount of confusion among lighting specifiers, designers, and other lighting professionals who need to understand how long an LED lighting system will deliver effective light in a particular application. This understanding is crucial for making valid comparisons between conventional and LED lighting fixtures, and for accurately calculating installation, maintenance, and replacement costs. Let's see if we can sort things out.

Lumen Maintenance of LED and Traditional Light Sources

When properly controlled and driven, LED light sources can have useful lives that last considerably longer than the rated lives of conventional sources. The following table compares the typical useful life range of LED light sources with the typical rated life ranges of conventional light sources.

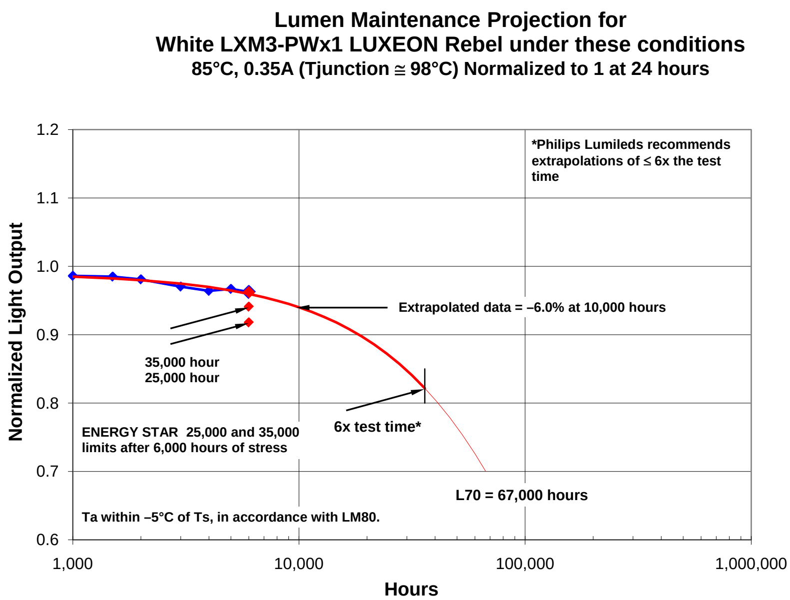
Light Source	Typical Range (Hours)
Incandescent	750 – 2,000 / rated life
Halogen Incandescent	2,000 – 4,000 / rated life
CFL	8,000 – 10,000 / rated life
Metal halide	7,500 – 20,000 / rated life
Linear Fluorescent	20,000 – 30,000 / rated life
White-light LED	35,000 – 50,000 / useful life (L_{70})

Source: U.S. Department of Energy

LM-80 requires testing of LED light sources for 6,000 hours, and recommends testing for 10,000 hours. It calls for testing LED sources at three junction temperatures — 55° C, 85° C, and a third temperature to be determined by the manufacturer — so that users can see the effects of temperature on light output, and it specifies additional test conditions to ensure consistent and comparable results.

Unfortunately, LM-80 provides no recommendations on how to extrapolate measured data to L_{70} or L_{50}. Such a methodology, IES Technical Memorandum TM-21 is currently under development. Until TM-21 is published, the only way an LED source manufacturer can claim that their L_{70} and L_{50} figures conform to LM-80 is to measure their LED sources until they reach those thresholds. Since a typical L_{70} number is 50,000 hours, such a test would last longer than five years! Not only would this test be impractical, but LED technology evolves so quickly that a given product would be obsolete by the time the test was completed.

In practice, leading LED source manufacturers test their products to the LM-80 minimums of 6,000 or 10,000 hours, then apply their own extrapolation methodologies to arrive at L_{70} and L_{50} figures. Since these methodologies are proprietary, manufacturers can choose to disclose as much or as little of the mathematics and supporting data as they wish.



Long-term lumen maintenance projection model from Philips Lumileds, a leading LED source manufacturer, based on LM-80 test results. LED sources are tested for 6,000 hours, and long-term lumen maintenance numbers are extrapolated.

For example, a leading LED source manufacturer publishes the raw data for a high-performance white-light LED Their report includes data on a significant sampling of devices, each tested to 6,000 hours in accordance with LM-80 methods, and L_{70} extrapolations based on an exponential model. While this set of data is sufficient to establish the manufacturer's credibility, users would benefit from more transparency into the model's extrapolation formulas and assumptions.

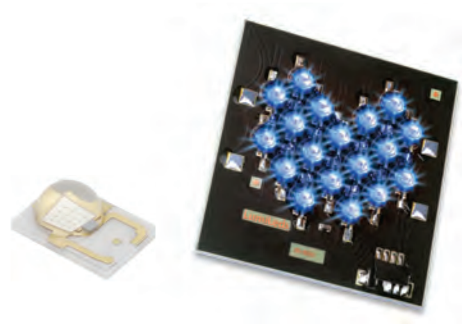
Another leading LED source manufacturer bases the lumen maintenance model for a high-performance white-light LED on their interpretation of raw LM-80 test data. According to their published specifications, the data indicate that lumen maintenance is linear after the first 5,000 hours of operation, so they apply a linear model using variables such as the temperature of the thermal pad on the bottom of the LED, junction temperature, ambient temperature, and drive current. While they do not disclose their extrapolation formulas or raw test data, they do clearly explain their approach, and they provide an extensive set of charts to show expected lumen maintenance to L_{70} at different ambient temperatures and drive currents.

Regardless of the extrapolation method used, keep in mind that L_{70} and L_{50} figures may be *based* on LM-80 measurements, but they are *not* LM-80 measurements.

Because LED suppliers and fixture manufacturers must make their own predictions, L_{70} and L_{50} figures may be based *on LM-80 measurements, but they are* not *LM-80 measurements.*

Useful Life of LED Sources in Lighting Fixtures

The approved method for making photometric measurements of LED lighting products specifically calls for the testing of complete LED lighting *fixtures* (as spelled out in IES LM-79-08). The approved method for measuring lumen maintenance is just the opposite: It calls for the testing of LED *light sources*, not complete LED lighting fixtures. LM-80 explicitly defines light sources as "packages, arrays, and modules only." This means that LED fixture manufacturers must define their own methods of calculating lumen maintenance for their LED lighting fixtures. As with L_{70} and L_{50} figures provided by LED source manufacturers, lumen maintenance figures provided by LED fixture manufacturers may *use* LM-80 test data and lumen maintenance extrapolations based on them, but they are *not* LM-80 measurements.



Left, an LED package consisting of a single LED chip, lens, and substrate. Right, an LED array (module), incorporating multiple LED packages. LM-80 applies to packages, modules, and arrays only, not to complete lighting fixtures.

Ambient and internal operating temperatures and drive currents have a significant effect on the lumen maintenance of LED light sources integrated into lighting fixtures, but so do many features of LED lighting fixtures themselves, including lensing, housing color, quality of components, and thermal design. Operational factors such as power surges, static discharge, vibration, and moisture infiltration can also have a significant effect. LM-80 testing for complete LED lighting fixtures would be prohibitively complex and expensive for manufacturers, as they would have to test every different version of their fixtures to account for the effect of each feature or combination of features.

In practice, therefore, reputable LED fixture manufacturers ensure that their fixture drive currents and operating temperatures (especially junction temperatures) fall within the ranges specified by the LED source manufacturers in their lumen maintenance reports. The fixture manufacturers then make their own calculations of the useful life of the LED sources integrated into their lighting fixtures, based on their understanding of the effects of specific physical and operational features.

LED fixture manufacturers make their own useful life calculations, accounting for specific physical and operational features of their lighting fixtures.

Useful Life Is Not Fixture Lifetime

It's important to keep in mind that *useful life* and *fixture lifetime* are two very different things. The useful life of a fixture refers to the lumen maintenance projections of the LED sources integrated into that fixture — in plain English, the number of hours an LED lighting fixture will deliver a sufficient amount of light in a given application.

Fixture lifetime, on the other hand, has to do with the reliability of the components of an LED lighting fixture as a system, including the electronics, materials, housing, wiring, connectors, seals, and so on. The entire system lasts only as long as the critical component with the shortest life, whether that critical component is a weather seal, an optical element, an LED, or something else. From this point of view, LED light sources are simply one critical component among many — although they are often the most reliable component of the whole lighting system.

Reputable LED lighting fixture manufacturers spend a great deal of time and effort designing and developing all aspects of a lighting system, including control algorithms, board layouts, component quality, thermal management features, optics, and mechanical design. The LED lighting fixture design is then typically validated through a series of in situ tests to verify that the fixture is meeting the expected performance levels for heat dissipation, light output, and so on. Since all the aspects of an LED lighting fixture are interdependent, operational performance can be determined only by testing the fixture as an integrated system.

Photography: George Fischer

The long useful life of LED sources allow the use of white and color-changing light fixtures in locations where lamp maintenance may be problematic or impossible. Unusual exterior architectural installations, such as the 1,815 ft (553 m) high CN Tower in Toronto, Canada, use LED lighting fixtures to dramatically reduce maintenance labor and costs. The ColorBlast 12 fixtures in use today can natively produce millions of colors, and will maintain 50% of their original lumen output over 50,000 hours or more of use.

Because conventional lamps typically fail before reaching L_{70}, their rated life is effectively their useful life.

Comparing the rated life of a conventional lamp with the lumen maintenance projections of an LED lighting fixture can determine how many relampings the LED fixture will help you avoid.

Comparing the Useful Life of Conventional Lamps and LED Lighting Fixtures

Since all electric light sources experience lumen depreciation, it ought to be possible to extrapolate rated life and lumen depreciation figures for conventional light sources to arrive at L_{70} (and L_{50}) figures. This would allow lighting designers and specifiers to compare apples with apples — that is to say, the useful life of LED sources as incorporated in lighting fixtures with the useful life of incandescent or fluorescent lamps.

- **Incandescent Comparison**
  A 60-watt incandescent lamp has a rated average life of 1,000 hours. If we assume typical light loss of 10% – 15% over its life, the lamp will fail before reaching the L_{70} threshold. Therefore, its rated life is effectively its useful life.
- **CFL Comparison**
  An 18-watt CFL lamp has a rated life of 15,000 hours, 1,250 initial lamp lumens, and 1,125 design lumens, which represents a 10% loss after 6,000 hours of operation. The lamp will therefore reach L_{70} after 18,000 hours. But since the lamp is expected to fail after 15,000 hours, its rated life is effectively its useful life.
- **Fluorescent Tube Comparison**
  High-performance fluorescent lamps are now available with significantly extended rated lives. For example, a 48-inch, 32-watt T8 with an average rated life of 33,000 hours loses 5% of its initial light output after 13,200 hours, or 40% of its rated life. At a constant rate of lumen depreciation, the lamp would reach L_{70} at 79,200 of operation — a figure that rivals the useful life of many LED light sources. Still, the lamp is expected to fail after 33,000 hours, long before it reaches the L_{70} threshold. Therefore, its rated life — not its estimated L_{70} threshold — is effectively its useful life.
- **HID Lamp Comparison**
  A high pressure sodium lamp, used for streetlighting and outdoor area illumination, lists a rated average life of 24,000 hours. Unlike rated life for the fluorescent and incandescent examples above, rated life for this lamp is based on survival of 67% of the tested lamps (instead of 50%). At 9,600 hours of operation, the lamp maintains 90% of its initial lumen output, which puts its L_{70} threshold at 28,800 hours. While the lamp's rated life and L_{70} measurements are roughly equivalent, the rated average life is still slightly lower. Again, its rated life is effectively its useful life.

As these examples demonstrate, rated life is generally equivalent to useful life for conventional light sources, since conventional light sources typically fail before they reach the relevant lumen maintenance thresholds. Comparing useful life figures for LED lighting fixtures with rated life figures for conventional lamps, then, affords a valid evaluation of how many relampings you can avoid by using LED-based alternatives to conventional lighting solutions. This evaluation in turn offers important information for total cost of ownership comparisons.

For example, eW Cove Powercore, a linear LED cove light from Philips Color Kinetics, reports an L_{70} figure of 60,000 hours. Using eW Cove Powercore instead of the T8 fluorescent fixture in the example above avoids two relampings, four relampings if used instead of the CFL lamp, and 60 relampings if used instead of the incandescent lamp. A Philips Gardco Radiant LED area luminaire, with energy consumption and light output similar to the high pressure sodium streetlamp in the example above, reports L_{70} figures ranging from 50,000 to 100,000 hours, depending on ambient operating temperature and drive current. The LED alternative in this case, therefore, offers a useful life two to four times longer than the HID source.

Getting Dependable, Accurate Information

Given the lack of transparency in the lumen maintenance projections of both LED source and fixture manufacturers, how can lighting specifiers and designers evaluate whether a fixture manufacturer's useful life figures are accurate?

To begin with, always look for a reputable fixture manufacturer with a proven track record, and make sure that the manufacturer offers a comprehensive set of published specifications, photometric data, and related information. But remember that you can't simply ask an LED fixture manufacturer for its LM-80 data: As we've seen, only LED *source* manufacturers obtain LM-80 data, and only for a period of operation significantly shorter than accepted useful life thresholds.

Nevertheless, you can increase your confidence in an LED fixture manufacturer's useful life figures by making sure that:

- The manufacturer of the LED sources incorporated in an LED lighting fixture were tested in accordance with LM-80
- The LED source manufacturer uses a valid method of projecting LM-80 test results to L_{70} and L_{50}, based on recommended operating conditions
- The LED lighting fixture manufacturer performs their own measurements of junction temperature, drive current, and other relevant factors, and bases their fixture's L_{70} and L_{50} figures on LM-80 extrapolations provided by the LED source manufacturer
- The LED fixture manufacturer bases its published photometric data on test results from an independent NIST-traceable testing lab, using absolute photometry in accordance with methods and conditions spell out in LM-79

Leading LED fixture manufacturers design their fixtures to ensure that they are as durable and reliable as possible. Although fixture failures do sometimes occur, well-designed LED lighting fixtures can perform reliably for many thousands of hours, often until the LED sources within them have reached the end of their useful life.

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