CELMA

Federation of National Manufacturers Association for Luminaires and Electrotechnical Components for Luminaires in the European Union

Apples & Pears, a CELMA guiding paper:
Why standardisation of performance criteria for LED luminaires is important

Enabling like-for-like comparison of LED luminaire performance starts with published initial specifications that are in compliance with IEC/PAS performance requirements

CONTENT

1. INTRODUCTION

The rise of LED lighting is driving a significant transformation of our lighting industry. LEDs can provide a palette of millions of colors and dynamic effects that conventional lighting cannot match in terms of design, scene-setting and ambience. Thanks to their miniaturized dimensions and low heat radiation, they can be embedded almost anywhere. And being digital, they are programmable, offering unlimited scope for creative use and effective management. Last but not least, they offer long lifetime and energy and maintenance savings, making them potentially an efficient solution.

There is a catch, however. In recent years the lighting market has been flooded by a vast number of new and unproven entrants. Some are making dubious claims about their products' performance that are too good to be true, and not supported on a technical basis. All stakeholders such as lighting specifiers and designers need to know how long an LED luminaire will retain a meaningful percentage of its initial light output over their years of operation. As things stand, it can be difficult to know who to trust or what to believe.

This guiding paper is intended to help bring clarity by introducing a universal set of quality criteria that are recently described in two IEC/PAS documents. As a user of LED luminaires it is important to apply the same set of standardised and therefore comparable quality criteria when evaluating manufacturer's claims. Users of LED luminaires should always ask for LED luminaire specifications measured in compliance with the new IEC/PAS documents.

In standardisation there are three elements that can be standardised: technical definitions, measurement methods and limiting values. The IEC/PAS performance requirement documents describe the definition of quality criteria and the way to measure them.

This will allow all interested parties to judge comparison claims on an equal, like-for-like basis. Only then will we have a genuinely level playing field for those IEC/PAS elements that truly serves the interests of end-users, specifiers, designers and manufacturers.

2. QUALITY CRITERIA AS MENTIONED IN THE IEC/PAS

The IEC recently published two Public Available Specification (PAS) performance requirement documents:

- IEC/PAS 62717 Performance requirements – LED modules for general lighting
- IEC/PAS 62722 Performance requirements – LED luminaires for general lighting

Both documents have been developed simultaneously to ensure maximum conformity in quality criteria definitions and measuring methods. The testing methods are as much as possible defined in the IEC/PAS for LED modules. Besides this, the luminaire standard IEC/PAS 62722 under certain conditions allows the use of IEC/PAS compliant modules to reduce the number of tests for LED luminaires.

Life time of LED luminaires is in most cases much longer than the practical test times. Consequently, verification of manufacturer's life time claims cannot be made in a sufficiently confident way. For that reason the acceptance or rejection of a manufacturer's life time claim, past 25 % of rated life (with a maximum of 6.000 hours), is out of the scope of both the IEC/PAS documents. In order to validate a life time claim, an extrapolation of test data is needed. A general method of projecting measurement data beyond limited test time is under consideration.

Both IEC/PAS performance requirements documents provide
- *the definition of a set of quality criteria related to the initial specifications of a product;*
- *a standardised description on how to measure these quality criteria.*

This makes manufacturers claims of initial specifications of LED- modules and luminaires comparable. Be aware that the acceptance or rejection of a manufacturers lifetime claim is out of the scope!

The IEC/PAS documents suggest the following list of quality criteria to be considered when evaluating manufacturer's claims:

a) Rated input power
b) Rated luminous flux
c) LED luminaire efficacy
d) Luminous intensity distribution
e) Photometric code
f) Correlated Colour Temperature (CCT)
g) Rated Colour Rendering Index (CRI)
h) Rated chromaticity co-ordinate values both initial and maintained
i) Lumen maintenance code
j) Rated life (in h) of the LED module and the associated rated lumen maintenance (*L*x)
k) Failure fraction (*Fy*), corresponding to the rated life of the LED module in the luminaire
l) Ambient temperature (*tq*) for a luminaire

Find below a brief explanation of the different quality criteria.

a) **Rated input power**
The rated input power shows the amount of energy consumed by a luminaire, including its power supply. It is expressed in watts.

b) **Rated luminous flux**
It corresponds to the light emitted by the luminaire which is expressed in lumen (unit of light output). It is expressed in lumens.

- *For traditional (non LED) luminaires it is not very common to measure and publish the rated luminous flux. This is normally calculated as the lamp flux multiplied by the light output ratio (LOR) of the luminaire;*
- *To make a light technical comparison between 'traditional' and 'LED' luminaires it is recommended to take the actual application into account and compare both lighting designs.*

c) **LED luminaire efficacy**
The measured initial luminous flux divided by the measured initial input power of the same individual LED luminaire. It is expressed in lumens per watt.

d) **Luminous intensity distribution**
The spatial distribution of the luminous flux graphically depicted in a luminous intensity distribution curve, which is usually expressed in a polar coordinate diagram representing the light intensity as a function of angle about a light source. It is expressed in cd = lm × sr-1.

e) **Photometric code**
A six digit photometric code that displays the important 'quality of light' parameters: CRI, CCT, chromaticity co-ordinates and luminous flux.

f) **Rated Colour Rendering Index** (*CRI*)
The colour rendering of a LED module giving white light is the effect on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant.

g) **Correlated Colour Temperature** (*CCT*)
The colour temperature of a LED module giving white light is determined by comparing the light emitted by the LED module with light of an ideal black-body radiator at the given temperature. It is expressed in Kelvin.

h) **Rated chromaticity co-ordinate values** both initial and maintained
The behaviour of the chromaticity co-ordinates of a LED module expressed in two measurement results of both initial and maintained chromaticity co-ordinates.

i) **Lumen maintenance code**
The measured initial luminous flux (initial value) is normalised to 100% and used as the first data point for determining the LED module life. The maintained luminous flux (maintained value) is measured at 25 % of rated life time up to a maximum of 6.000 hours and expressed as percentage of the initial value. The maintained value determines the lumen maintenance code (see table 3).

j) **Rated life** of the LED module and the associated rated lumen maintenance (*Lx*)
The length of time during which a population of LED modules provides more than the claimed percentage (*x*) of the initial luminous flux always published in combination with the failure fraction. It is expressed in hours.

k) **Failure fraction** (*Fy*), corresponding to the rated life of the LED module in the luminaire
The percentage (*y*) of a number of LED modules of the same type at their rated life designates the percentage (fraction) of failures. This failure fraction expresses the combined effect of all components of a module including mechanical, as far as the light output is concerned. The effect of the LED could either be less light than claimed or no light at all.

l) **Ambient temperature** (*tq*) for a luminaire
The ambient temperature around the luminaire related to the specified performance. For a given performance claim the ambient temperature (t_q) is a fixed value. It is possible to specify performance claims at different ambient temperatures. It is expressed in degrees Celsius.

Be aware that you have to make sure that the t_q shall be in accordance with the actual application where the LED luminaire will be used.

When evaluating LED luminaire performance claims from different manufacturers it is important:
- *to compare a standardised set of quality criteria;*
- *that these quality criteria are measured in compliance with the appropriate standard.*

LED luminaire manufacturers should publish product specifications that are in compliance with the IEC/PAS performance requirements.

In the next chapters we will have a closer look at some of the more complex quality criteria, explain the relations and why they are important.

3. PHOTOMETRIC CODE

The six digit photometric code displays the important ‘quality of light’ parameters:

- initial CRI and CCT;
- initial and maintained chromaticity co-ordinates;
- maintained luminous flux.

Color Rendering Index (CRI)
Although light sources may have the same colour appearance, this doesn’t necessarily mean that coloured surfaces will look the same under them. Two lights that appear the same white, may be the result of different blends of wavelengths. As a result a given material may appear differently since the surface may not reflect the constituent wavelengths by the same extent; its colour appearance will change when it is exposed to one or other light. So, colour rendering is an important criterion when selecting light sources for lighting application solutions.

However with the new LED technology coming in, with its narrow spectrum, the CRI index is not in all circumstances giving a fair representation of the colour appearance. New definitions and methods for measuring are currently under development in CIE.

The initial CRI value classification for the photometric code can be obtained by using the following intervals:

Code	CRI range	Colour rendering properties
6	57 – 66	Poor
7	67 – 76	Moderate
8	77 – 86	Good
9	87 – 100	Excellent

Table 1: Colour rendering value intervals

Correlated Colour Temperature (CCT)
Although white light is a mixture of colours, not all whites are the same since they depend on their constituent colours. So a white with a higher proportion of red will appear warmer and a white with a higher proportion of blue will appear cooler. In order to classify the different types of white light, the concept of colour temperature is applied which is described as the colour impression of a perfect black-body radiator at certain temperatures. This concept can be best explained with the help of familiar thermal radiators like the filament of an incandescent lamp or an iron bar.

When these materials are heated to a temperature of 1000 K their colour appearance will be red, at 2000-3000 K they will look yellow white, at 4000 K neutral white, and at 5000-7000 K cool white. In other words: the higher the colour temperature, the cooler the impression of the white light becomes.

The initial CCT value classification for the photometric code can be obtained by taking the initial CCT value divided by 100.

Chromaticity co-ordinates
In the study of color vision, MacAdam ellipses refer to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse. The contour of the ellipse therefore represents the just noticeable differences of chromaticity. MacAdam ellipses are often scaled up to a larger size, perhaps 3x, 5x or 7x the original. This is indicated as a 3-step, 5-step or 7-step MacAdam ellipse.

Mac Adams shows the difference between two light sources and the steps indicate the color variation. Placed in an application where individual light sources are visible, this phenomenon should be taken into account whereas 3-step gives less variation then 5-step.

The initial and maintained chromaticity co-ordinates is measured, for the maintained value at 25% of rated life time up to a maximum of 6.000 hours.

The value classification for the photometric code can be obtained by using the following intervals:

Size of MacAdam ellipse, centered on the rated color target	Color variation category	
	Initial	Maintained
3-step	3	3
5-step	5	5
7-step	7	7
>7-step ellipse	7+	7+

Table 2: Tolerance (categories) on rated chromaticity co-ordinate values

Luminous flux

As the typical life of a LED luminaire is (very) long, it is time-consuming to measure the actual lumen reduction over life (e.g. L_{70} meaning the length of time during which the LED module provides more than the claimed 70% of the initial luminous flux). Also the actual LED behaviour with regard to lumen-maintenance may differ considerably per type and per manufacturer. It is not possible to express the lumen-maintenance of all LED's in simple mathematical relations. A fast initial decrease in lumen output does not automatically imply that a particular LED will not make its rated life.

In order to validate a life time claim, an extrapolation of test data is needed. In IEC a general method of projecting measurement data beyond limited test time is under consideration. In the US an extrapolation based on LM-80 test data will be described in IES TM-21.

Instead of life time validation, the IEC/PAS has opted for lumen maintenance codes at a defined finite test time. Therefore, the code number does not imply a prediction of achievable life time. The categories are lumen-depreciation character categories showing behaviour in agreement with manufacturer's information which is provided before the test is started.

The maintained luminous flux is measured at 25% of rated life time up to a maximum of 6.000 hours. The value classification for the photometric code is obtained by using one of the following 'lumen maintenance categories':

Lumen maintenance (%)	Code
≥90	9
≥80	8
≥70	7

Table 3: Lumen maintenance code at an operational time

To find out to what extend a photometric code makes sense, we are going to decode 830/359:
- *initial CRI value of 84 – code 8;*
- *initial CCT value of 3000K – code 30;*
- *initial spread of chromaticity co-ordinates within a 3-step MacAdam ellipse – code 3;*
- *maintained spread of chromaticity co-ordinates within a 5-step MacAdam ellipse – code 5;*

- *maintained luminous flux of 91% – code 9.*

The photometric code of the LED module has to be published on the packaging of the product and in the product leaflet.

4. QUALITY CRITERIA OVER TIME

We have seen that most of the IEC/PAS quality criteria are linked to the initial performance requirements of LED modules and LED luminaires. In case of maintained values we speak about 25% of rated life time up to a maximum of 6.000 hours, the time until which the approval tests are carried out. There is no lifetime validation above 6.000 hours; accelerated test methods providing more advanced insight in lumen depreciation over LED module and/or LED luminaire life are under consideration.

However it is important to keep in mind that lifetime claims based on lumen maintenance and luminaire life are two very different things. The lifetime claims based on lumen maintenance refers to the lumen maintenance projections of the LED light sources integrated into that luminaire in simple Dutch, the number of hours that a LED luminaire will deliver a sufficient amount of light in a given application.

Lumen maintenance claims

Currently many LED luminaire manufacturers use test results typically provided by LM-80 (for explanation see Annex 2) as the L_{90}, L_{70} and L_{50} lumen maintenance thresholds of LED luminaires. But there is a disconnection between the LM-80 test results usually made by the LED manufacturer and the results on a LED luminaire where for example the thermal management can change the actual performance.

LM-80 requires testing of LED light sources for 6.000 hours, and recommends testing for 10.000 hours. It calls for testing at three surface 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.

In practice, leading LED light source manufacturers test their products to the LM-80 minimums of 6.000 or 10.000 hours, and then apply extrapolation methodologies as described in TM-21 (see Annex 2) to arrive at L_{90}, L_{70} and L_{50} figures. Luminaire manufacturers translate these curves into LED luminaire specific curves.

There are two constraints in translating these test results into LED luminaire performance:

- First: catastrophic failures of individual LEDs and other failure modes participate to the light output depreciation of a population of LEDs in a LED-luminaire are not taken into consideration;
- Second: there is no validated way to translate the lumen maintenance curve of an individual LED-light source into a curve for the LED-luminaire.

Luminaire life claims

Luminaire life, on the other hand, has to do with the reliability of the components of an LED luminaire 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, an electronic control gear circuit 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 in the whole lighting system.

One remark. If an LED luminaire is equipped with a replaceable LED module, luminaire life can be decoupled from the LED module and its life. This brings luminaire life closer to the current definition of luminaire life for conventional light sources. For instance, the life of road lighting luminaires is often 30 to 40 years. However it is preferable to publish the LED module life as the LED luminaire life.

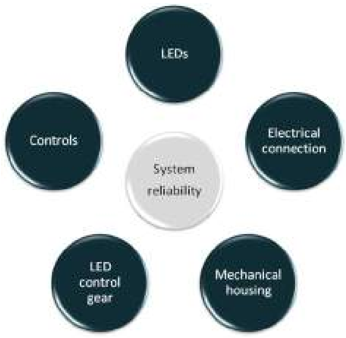

Figure 1: Luminaire life is about system reliability

Reputable LED luminaire 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 luminaire design is then typically validated through a series of laboratory tests to verify that the luminaire is meeting the expected performance levels for heat dissipation, light output, and so on. Since all the aspects of an LED luminaire are interdependent, operational performance can be determined only by testing the luminaire as an integrated system.

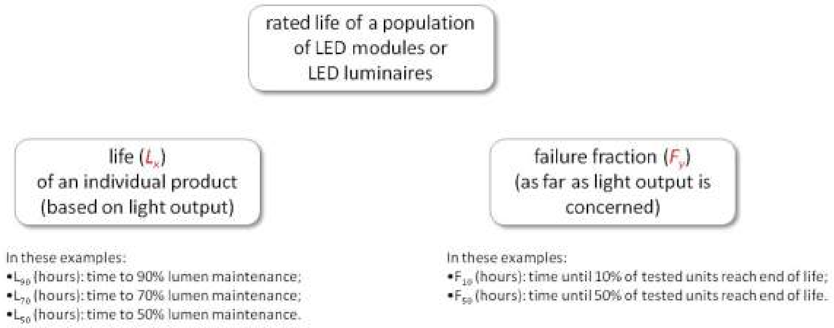

Figure 2: LED luminaire life according to IEC

LED luminaire life according to the IEC/PAS 62722 should always be published as a combination of life at lumen maintenance (L_x) and failure fraction (F_y). The failure fraction expresses the combined effect of gradual and abrupt failure of all components of a luminaire, including mechanical, as far as the light output is concerned. This means that the LED luminaire could either emit less light than claimed or no light at all.

Luminaire lifetime claims based on lumen maintenance and luminaire life are two very different things:

- *Luminaire lifetime claims based on lumen maintenance refers to the lumen maintenance projections of the LED light sources integrated into that luminaire, the number of hours that a LED luminaire will deliver a sufficient amount of light in a given application;*
- *Luminaire life has to do with the reliability of the components of an LED luminaire as a system, the entire system lasts as long as the critical component with the shortest life. From this point of view LED light sources are simply one critical component among many.*

5. GETTING DEPENDABLE ACCURATE INFORMATION

Reliable information on catastrophic failure rates of individual components is hardly available due to the relatively new technology and long expected life. Then there is the lack of transparency of the lumen maintenance projections of both LED light source manufacturers and luminaire manufacturers. The question is how specifiers, lighting designers, technical engineers and policy makers can evaluate whether a manufacturer's LED luminaire life or lumen maintenance figure is accurate?

We have seen that when evaluating LED luminaire performance claims from different manufacturers it is important to compare a standardised set of quality criteria measured in compliance with the appropriate standard. These quality criteria are designed to ensure that performance claims can be matched against traceable data.

Typical quality criteria a user should look for:

1. Rated input power (*in W*);
2. Rated luminous flux (*in lm*);
3. LED luminaire efficacy (*in lm/W*);
4. Luminous intensity distribution;
5. Photometric code:
6. Correlated Colour Temperature (CCT *in K*);
7. Rated Colour Rendering Index (CRI);
8. Rated chromaticity co-ordinate values (initial and maintained);
9. Maintained luminous flux.
10. Rated life (in h) of the LED module and the associated rated lumen maintenance (*L*x)
11. Failure fraction (*Fy*), corresponding to the rated life of the LED module in the luminaire
12. Ambient temperature (*tq*) for a luminaire

In short, always look for a reputable LED luminaire manufacturer that publishes product specifications that are measured in compliance with the IEC/PAS performance requirements.

ANNEX 1 – LED TERMS

Following three terms are used in this guiding document:

LED light source
The LED die (or chip) is contained in a suitable package allowing simplified electrical connection or assembly;

Examples:

LED module
The LED die (or chip) together with mechanical and optical components making a replaceable item for use in a luminaire;

Examples:

LED luminaire
The complete system consisting of the LED light source or LED module including the electronics, materials, housing, wiring, connectors, seals, and so on.

Examples:

ANNEX 2 – SUMMARY OF EXISTING IEC & UL/IES STANDARDS

Shown below is an overview of the most relevant LED-related IEC standards on both safety and performance, including the ones that are currently in progress.

Product Type	Safety Standard	Performance Standard
LED control gear	**IEC 61347-2-13** Publication 2006	**IEC 62384** Publication 2006
LED lamps	**IEC 62560 Edition 1** Publication 2010 (expected)	**IEC/PAS 62612** Public Available Specification
LED modules	**IEC 62031 Edition 1** Publication 2008	**IEC/PAS 62717 Edition 1** Public Available Specification
LED luminaires	**IEC 60598 Edition 1&2** Publication 2008	**IEC/PAS 62722-2-1** Public Available Specification
LED products	**IEC TS 62504 Edition 1** Terms and definitions for LEDs and LED modules in general lighting.	

Table A1: Overview of LED-related IEC standards

Informative annex B of IEC/PAS 62722 explains the current view on recommended life time metrics related to LED luminaire life. The aim is to come in the end to an international recognised standard.

Additional standards which may be taken in consideration:

Product Type	Safety Standard	Performance Standard
LEDs	**n/a**	**IES LM-80-08 &** **IES TM-21-11**
LED control gear	**UL 1012** (UL Class 1) & **UL 1310** (UL Class 2)	
LED lamps	**UL 8750**	
LED modules	**UL 8750**	
LED luminaires	**UL 8750**	**IES LM-79-08**
LED products	**ANSI / IESNA RP-16-10** Nomenclature and Definitions for Illuminating Engineering.	

Table A2: Overview of LED-related UL and IES standards

IES LM-79-08. *Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products* – Illuminating Engineering Society of North America, 2008

LM-79 prescribes uniform test methods under controlled conditions for photometric and colorimetric performance as well as electrical power measurements for LED-luminaires manufactured for production. This can be used to measure the initial electrical and photometrical specifications of a LED-luminaire.

IES LM-80-08. *Approved Method: Measuring Lumen Maintenance of LED-Light Sources* – Illuminating Engineering Society of North America, 2008

LM-80 is about the measuring lumen maintenance of LED-light sources (package and array). It consists of a real measurement over the first 6000 hours combined with an extrapolation out to end of life. Many luminaire manufacturers will translate the maintenance curve of the LED-light source into a maintenance curve of the LED-luminaire using the TM-21 recommendations.

There are two constraints in doing this:

- First: catastrophic failures of individual LEDs and other failure modes participate to the light output depreciation of a population of LEDs in a LED-luminaire are not taken into consideration.
- Second: there is no validated way to translate the lumen maintenance curve of an individual LED-light source into a curve for the LED-luminaire.

IES TM-21-11. *Projecting Long Term Lumen Maintenance of LED Packages* – Illuminating Engineering Society of North America, 2011

TM-21 provides recommendations for projecting long term lumen maintenance of LED packages using data obtained when testing them per IES LM-80-08.