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LEDs are the panacea – and other fairy tales

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Abstract

Recently, there has been an explosive growth in the popularity of LED luminaires. Like all markets experiencing such expansion, it has attracted many new manufacturers. Some of these have a reputation to uphold, but many do not. As such, it can be difficult for designers to differentiate good quality products from bad quality products. This paper explores a set of standardised test methods and performance criteria associated with LED luminaires. Moreover, it proposes a set of questions for discussion within the lighting community. These questions would be used to interrogate manufacturer data and aid with the determination of product quality.

Key Words:
LED, specification, questions, manufacturers.

Introduction

Once upon a time there were three lighting designers with a small practice in Dublin. They weren't rich, but they worked hard and made a living by offering their clients up-to-date, innovative and honest advice about all aspects of lighting. On the back of this, they had built a commendable reputation and thoroughly enjoyed their occupations. However, in the present day, they approach their work with angst and fear. You see, in recent years, they have endorsed LED products with much excitement, but failed to properly interrogate manufacturer claims. The consequences of their actions have begun to surround them. Client complaints – failed fittings, insufficient light, noticeable colour shift, rapid lumen depreciation, extreme flicker, to name but a few. In short, their clients' complaints highlight broken promises and demonstrate disappointment. For our designers, this is unfamiliar territory. They are competent, experienced and have always made decisions with their clients' best interests in mind, yet they suddenly find themselves the focal point of many justifiable complaints. Where did it all go wrong? It's obvious; they took a step into the unknown and placed their reputation in the hands of others, purely to keep up with the Joneses.

This paper examines reasons behind client complaints, discusses quality criteria associated with LED luminaires and ultimately, proposes a draft set of questions that designers should ask manufacturers of LED luminaires to help differentiate good quality from poor quality products. Construction and operation of LED luminaires is explained in great detail elsewhere[1] – [10] and will not be covered here.

The growth of LED

Boyce suggests[11] that the growth of LEDs has happened for three reasons. The first is the immense quantity of money invested in LEDs by organisations and the consequent rapid development in their capabilities. The second has been the enthusiasm of regulators who see LEDs as the ultimate replacement for incandescents. The third is fashion. At present, opting for LEDs is considered progressive and enlightened. As a result of these factors, the market is now saturated with new, and unfamiliar, LED products. This raises an issue for designers: how can they distinguish good equipment from bad?

A level playing field

Traditionally, not many standards have been in place to aid designers in the selection of LED products, but in recent years, this has improved somewhat with the introduction of *IESNA LM-79-08, IES Approved Method for the Electrical and Photometric Measurement of Solid-State Lighting Products*[12] and *IESNA LM-80-08, IES approved Method: Measuring Lumen Maintenance of Light Emitting Diode Light Sources*[13]. Both of these test methods allow manufacturers to have their products tested in an independent laboratory, to a standard set of testing procedures that have been devised to examine particular qualities associated with LED products. The International Electrotechnical Commission (IEC) has also produced two publicly-available standards (PAS) that detail performance requirements for LED products; *IEC/PAS 62717 Performance requirements – LED modules for general lighting*[14] and *IEC/PAS 62722 Performance requirements – LED luminaires for general lighting*[15]. These documents deal with LED modules and LED luminaires separately, but both bring clarity to the manner in which LED data should be measured and presented by introducing a universal set of quality criteria. Details of the quality criteria should be displayed on LED product datasheets. This information offers designers an equal platform where they can evaluate products from different manufacturers. The quality criteria described within the IEC/PAS documents are: input power, luminous flux, luminaire efficacy, luminous intensity distribution, correlated colour temperature (CCT), colour rendering index (CRI), chromaticity co-ordinate values (initial and maintained), lumen maintenance code, photometric code, life in hours and the associated rated lumen maintenance (Lx), failure fraction (Fy), ambient temperature (tq), power factor and drive current. Some of these will be familiar terms, as they are commonly employed to describe features of traditional source luminaires. Nonetheless, a number of these will be less recognisable or their significance may be greater with LED sources. These are explained and briefly discussed in the following sections.

Colour rendering index (CRI)

Despite the prominence of CRI, it has several shortcomings and problems[16]–[19]. Two luminaires that have the same white colour appearance may be the result of various blends of wavelengths[4][20]. Consequently, a given material may project dissimilar appearances, since the material surface will reflect the constituent wavelengths by varying extents – i.e. its colour appearance will change when it is exposed to one or other luminaire. The Commission Internationale de l'Eclairage (CIE) is currently in the process of revising the metric and recommends that it is not suitable for quantifying the colour rendering capabilities of white LED light sources[21]. As such, and for other reasons stated later in this paper, samples of LED luminaires should always be viewed before specification. The IEC/PAS documents specify CRI as a code and this code is given as indicated in Table 1.

Table 1 – IEC/PAS colour rendering index codes

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

Rated initial and maintained chromaticity coordinates

In the study of colour vision, MacAdam ellipses refer to the region on a chromaticity diagram that contains all colours which are indistinguishable to the average human eye, from the colour at the centre of the ellipse[23] – [26]. Therefore, the contour of the ellipse represents the just-noticeable differences of chromaticity. The scale of a single MacAdam ellipse is extremely small and, as such, they are usually scaled up to a larger size. This is represented by a 3-step, 5-step or 7-step MacAdam ellipse, where a 3-step is three times greater than a standard MacAdam ellipse, and so forth. When products are tested in accordance with the IESNA test methods quoted previously, initial and maintained chromaticity coordinates are measured, where the maintained value is recorded at 25% of rated life, but a maximum of 6,000 hours. The relevant IEC/PAS code can be obtained using Table 2.

Table 2 – IEC/PAS initial and maintained colour variation codes

Size of MacAdam ellipse,	*Colour rendering properties*	
centred on the colour target	*Initial*	*Maintained*
3-step ellipse	3	3
5-step ellipse	5	5
7-step ellipse	7	7
> 7-step ellipse	7+	7+

Lumen maintenance code

The life of LED luminaires is typically very long. It is therefore impractical to measure the actual reduction in lumen output over entire luminaire lifetime. Instead, validation of lumen maintenance at finite test times is specified by the IEC/PAS documents[14][15]. The maintained luminous flux is measured at 25% of rated lifetime up to a maximum of 6,000 hours. Therefore, the code numbers assigned do not imply a prediction of achievable life; they simply declare the quantity of luminous flux still emitted at 25% of rated life or 6,000 hours. The IEC/PAS code can be obtained using Table 3.

Table 3 – IEC/PAS Lumen Maintenance Codes

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

In order to generate a lifetime claim, an extrapolation of test data is necessary. At present, the IEC has no standardised methodology for the extrapolation of lumen maintenance data[27]. However, if a product has been tested in accordance with IESNA LM-80-08[13], a standard extrapolation method *IESNA TM-21-11, IES Approved Method: Making Useful LED Lifetime Projections* is used to make extrapolated predictions[28]. This offers a standardised platform from which a designer can independently compare lifetime claims from various manufacturers.

Photometric code

The IEC/PAS photometric code is a six-digit code that displays the important "quality of light" parameters of an LED luminaire[14][15].

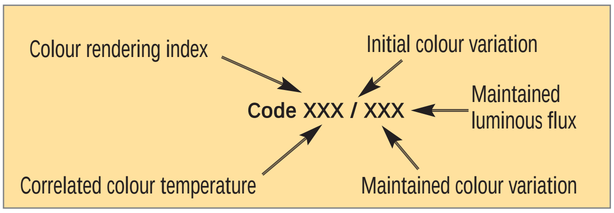

Figure 1 – IEC/PAS photometric code breakdown

It states initial CRI, initial CCT, initial and maintained colour coordinates and lumen depreciation code. Figure 1 above indicates in more detail what each digit signifies.

As an example, consider an LED luminaire with the following properties and the corresponding photometric code indicated in brackets; initial CRI value of 83 (code 8), initial CCT value of 4000K (code 40), initial spread of chromaticity coordinates within a 3-step MacAdam ellipse (code 3), maintained spread of chromaticity coordinates within a 5-step MacAdam ellipse (code 5) and maintained luminous flux of 92% (code 9). The photometric code for this luminaire would be 840/359.

Rated life and associated lumen maintenance (Lx)

Rated life is the length of time during which an LED module provides more than the claimed percentage of the initial luminous flux. This is stated in hours and represented in terms of Lx, where x is the percentage of lumen depreciation and should always be published along with the failure fraction (Fy). The recommended series of values for x is 70, 80 and 90[14][15].

It is important to note the limitations of LED lumen maintenance measurements. As briefly discussed previously, many LED manufacturers use test results provided by IESNA LM-80-08 to obtain lumen maintenance thresholds of LEDs, but there is a distinct disconnection between the results found by the LED manufacturer and the results for an LED luminaire. The performance of an LED module will vary within different luminaire housings and with varying thermal management systems[27]. In practice, LED manufacturers test their products to IESNA LM-80-08 and then apply extrapolation procedures as detailed in IESNA TM-21-11 to arrive at L90, L70 or L50 figures[27][29]. Luminaire manufacturers then translate these curves into LED luminaire-specific curves. There are two constraints with interpreting data in this manner. The first and most crucial is that there is no validated method for translating the lumen maintenance curve for an individual LED into a curve for an LED luminaire. The second is that catastrophic failure of individual LEDs and failure of other critical luminaire components is not considered.

Failure fraction (Fy)

Failure fraction is the percentage of a number of LED modules of the same type at their rated life that have failed. The failure fraction expresses the combined effect of all components of a module including mechanical, as far as the light output is concerned. The recommended series of values for y is 10 and 50[14][15].

Ambient temperature (tq)

For a given performance claim, the ambient temperature is a fixed value. The ambient temperature is important as it affects junction temperature, which affects lumen output, efficacy and luminaire life[1][5][6]. It is possible to specify performance claims at different temperatures and reputable manufacturers should be able to provide this. Temperature should be given in degrees Celsius[14][15].

Drive current

Drive current affects LED junction temperature, which affects lumen output, luminous efficacy and luminaire life[1][5][6]. Typical drive current values are between 350mA and 700mA, but this can be higher if the thermal management of the luminaire is good enough to keep the junction temperature below critical failure temperature. In general, as drive current increases, lumen output will increase, efficacy will decrease, as will luminaire life. Reputable manufacturers will be able to provide a graphic demonstrating how life and efficacy vary with alternative drive currents.

Interrogating manufacturer data

While the aforementioned documents offer the prospect of equality between manufacturers, it will be evident to those working in lighting that this information is not yet freely available on data sheets as the IEC/PAS standards advocate it should be. Boyce has suggested[11] that a valuable contribution to the lighting community would be a set of simple questions to ask the LED supplier, whereby any supplier that is unwilling, or unable, to answer these questions should be treated with caution. This section proposes a draft set of questions that could be put to manufacturers of LED luminaires in order to determine the quality of the product that they are supplying. The questions are derived partly from the IEC/PAS performance requirements and partly from the experience of the authors. They are worded in a manner that indicates to suppliers and manufacturers exactly what is required from their response. In the paragraph following this, a short explanation of expected responses is detailed.

Questions for manufacturers and suppliers of LED luminaires

i. Is this LED luminaire tested in accordance with *IESNA LM-79-08, IES Approved Method for the Electrical and Photometric Measurement of Solid-State Lighting Products*? If so, please provide a results certificate.

ii. Are the LEDs within this luminaire tested in accordance with *IESNA LM-80-08, IES approved Method: Measuring Lumen Maintenance of Light Emitting Diode Light Sources*? If so, please provide a results certificate.

iii. Is luminaire life extrapolated in accordance with *IESNA TM-21-11, IES Approved Method: Making Useful LED Lifetime Projections*? If it is not, is it estimated in accordance with any other standard procedure or extrapolation method?

iv. Is the data in your product specification sheet presented in accordance with *IEC/PAS 62717 Performance requirements,*

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LED modules for general lighting' and *'IEC/PAS 62722 Performance requirements, LED luminaires for general lighting?*

v. Who supplies the LEDs within your LED luminaires?

vi. What is the rated Luminaire Lifetime? Provide an answer in terms of hours at LxxFxx, where Lxx represents parametric failure rate and Fxx represents the catastrophic failure rate.

vii. State the luminaire photometric code, as defined within IEC/PAS 62722 and IEC/PAS 62717, where the six-digit code displays the important "quality of light" parameters of an LED luminaire. It should state initial CRI, initial CCT, initial and maintained colour variation and lumen depreciation code. Please provide a lumen depreciation curve.

viii. What is the driver power factor and is the driver replaceable?

ix. What is the total luminaire wattage, including control gear?

x. What is the ambient temperature for which the luminaire performance is rated? Please provide information on how at least three ambient temperatures will affect the performance and lifetime of the LED luminaire.

xi. What is the initial luminaire lumen output, for the specified driver current? If the luminaire is to be driven at a current that is not the standard, please provide information on how this will affect luminaire performance and life.

xii. What length of time is the complete luminaire warrantied for? Please supply a copy of the warranty.

Acceptable responses?

Now that we have a grasp of the questions we should be asking, what are the responses that we will consider acceptable or unacceptable? The following is merely the opinion of the authors, but has been formed through extensive discussion with noteworthy lighting designers, engineers, through social media, internet forums and interaction with very reputable manufacturers of LED luminaires.

All LED modules and LED luminaires should be tested in accordance with IESNA testing methods and have product information displayed in accordance with IEC/PAS requirements. The cost of these tests is relatively low, so there is no justifiable reason why manufacturers would not test to IESNA standards and present data in accordance with IES/PAS requirements. It is preferable that all luminaire lifetimes are extrapolated in accordance with IESNA TM-21-11, but this will not always be the case, particularly with manufacturers that do not retail in the USA.

Some reputable suppliers of LED chips and modules are: Cree, Sharp, Philips, Osram, Epistar/Intermolecular, Nichia, Xicato, Citizen, Bridgelux and ASM Pacific, but this list is not exhaustive. LED luminaire manufacturers that refuse to disclose the manufacturer of the LED chips within their luminaires should be dismissed quickly. Luminaire lifetime with good quality products for general lighting is typically L70F10 for 50,000 hours. This may shorten or be stated as L70F50 for decorative or some architectural type luminaires and may lengthen for luminaires in cooler ambient temperatures. The first half (CRI and CCT) of the IEC/PAS photometric code will differ on a project-specific basis, but the latter half, for good quality products, should be within a 3-step MacAdam ellipse initially and within a 3-step Macadam ellipse through lumen maintenance (for white light), combined with a lumen maintenance of Code 9 or better. Again, this may shift for decorative, external and architectural applications and products of lesser quality will generally show larger colour shift and greater lumen depreciation.

This may be acceptable for some applications and not for others, but at least the designer and client will be aware of probable issues. Care should be taken with replaceable drivers, as by law and in accordance with European Commission Electro-magnetic Compatibility Directive 2004/108/EC and all associated modifications[30], they cannot simply be replaced on-site in a plug and play manner. This is currently not enforced, but if an LED module or driver fails, the entire fitting should be replaced or a single component replaced and the fitting re-tested with the new component installed[30]. Combine this with the fragile nature of electronic components within an LED luminaire and the wide range of replacements available, and the authors believe that replaceable drivers should be avoided when possible as they are likely to cause unforeseen compatibility issues. The quoted total wattage should be given inclusive of control gear losses.

Driver current affects lumen output, efficacy and luminaire life. Typically, increased drive currents will increase lumen output, but reduce efficacy and decrease life[1][5]. Similarly, increased ambient temperatures will generally decrease lumen output and luminaire life[1][5]. Reputable manufacturers will be able to supply information about how drive current and ambient temperature affect all of these parameters.

For most of the better manufacturers of LED luminaires, their standard product warranty will be five years. It should be noted that some of the best LED manufacturers now offer a 10-year warranty, as standard, on their external LED luminaires, inclusive of all luminaire components. A copy of all product warranties should be obtained and examined, as they can often be misleading. Ensure that the warranty states very clearly what parameters will need to have drifted and how much they will need to have drifted by before the luminaire is replaced. Also be sure that all components are covered in the event of failure, i.e. the warranty should cover driver, heat sink, LED module, housing, etc.

The role of mock-ups

Despite the quality criteria outlined, there are some aspects of LED quality which are best assessed using first-hand experience. Flicker and dimming are not discussed above. A combination of percentage flicker and flicker index can be used to estimate the stroboscopic effect of a luminaire[31]. Dimming is frequently specified by the protocol selected, but a common complaint is that LED luminaires will not dim to 1% of full lumen output. Both of these issues are effortlessly solved with a simple, real life mock-up. Aside from resolving these issues, when multiple luminaires are included in the mock-up, the designer and client can obtain personal experience of initial colour variation in the luminaire batch and compare this with colour variation between surrounding traditional source luminaires. This should leave the client and designer with few surprises when the product is finally installed on site.

Conclusion

This paper has shown how fair comparison between LED products is possible using internationally-recognised test methods and performance standards. It has also applied the experience of the authors and opinions of many within the lighting community to devise a draft set of questions and acceptable responses that can be put to manufacturers of LED luminaires to assist with determining the quality of an LED product. This list is not intended to be definitive, but rather to stimulate discussion within the lighting community and familiarise readers with what is required to differentiate between good and bad quality LED products.

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