COLOUR CONSISTENCY AND MACADAM ELLIPSE

Due to the method by which LEDs are manufactured variations occur within batches of chips. Significant progress has been made in this area over the last few years and production variations within batches of LEDs are generally smaller, however such variations are an inevitable part of LED manufacturing which will likely never be completely eliminated.

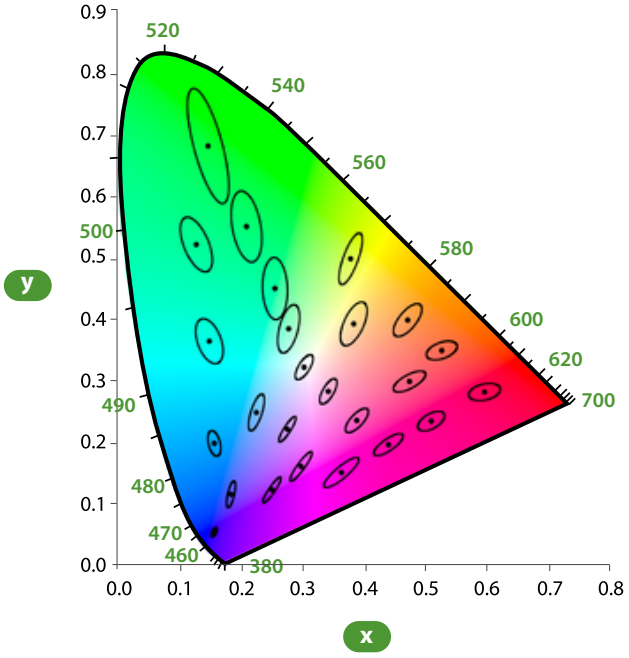
LEDs are manufactured in reactors which create high pressure and temperature environments within which semi-conductor wafers are grown on substrates of gallium or sapphire over a period of weeks. Slight variations in temperature over the wafer during this time can cause variations in the semi-conductor growth resulting in changes to the performance of the LEDs across a single wafer.

To minimise the effects of these variations LEDs are binned post production so that luminaire manufacturers can produce luminaires with consistent light sources. LEDs are binned by three factors, Forward Voltage, Flux and Colour. The first two factors effect the efficiency of the chip and therefore the luminaire, the Flux and Forward Voltage bins selected by luminaire manufacturers are less relevant to users as the efficiency of the luminaire is always published as a simple luminaire lumens per watt figure so the exact bin detail is not required by end users. The colour bins selected though can have a direct effect on the quality of light that the customer is purchasing and ought to be considered in your purchase.

MacAdam Ellipse

Colour consistency is defined using MacAdam Ellipses. A one step MacAdam Ellipse defines an area of a chromaticity diagram where the average person is only able to distinguish a single colour. The diagram below shows examples of one step ellipses on a chromaticity diagram where only a single colour can be distinguished by the average observer. Note that the human eye is more sensitive to wavelength changes in the blue and red spectrums than green, hence the differing size of the ellipse between these colours.

In a single production batch of LEDs the majority will typically fall within a five step MacAdam Ellipse with a small proportion falling outside this with greater colour variation. If LED manufacturers were to discard LEDs outside of a one step Macadam Ellipse to give perfect colour consistency it would mean the majority of LEDs would be wasted making production costs prohibitive. Instead LEDs are measured on the production lines to determine their colour and then batched together into colour bins so that luminaire manufacturers can select those most suitable for their products. The wider the colour bin that a luminaire manufacturer is willing to accept the lower their cost becomes as the LED manufacturer is able to sell a greater proportion of the yield from each production run. The lowest cost colour selection is typically “Full Yield” in which the luminaire manufacturer purchases the entire production run of LEDs regardless of variations in colour, although this reduces cost it inevitably results in a colour variation between luminaires, and between chips within a single luminaire, that most clients would be unwilling to accept. At the other end of the cost spectrum a luminaire manufacturer can order one step MacAdam Ellipse colour bins however such a narrow and expensive colour selection would be unnecessary in the vast majority of applications.



3 Step vs 5 Step

LED colour bin choice therefore typically involves making the best possible selection with consideration for both cost and colour consistency. For this reason the majority of manufacturers select either a three step or a five step MacAdam Ellipse for their colour bin selection. It is important to consider the luminaire design and the application for which the product is intended, for example greater colour variation may be tolerated in applications such as industrial or warehousing projects than would deemed acceptable by high end retail customers.

Some luminaire designs have greater visibility of individual LEDs so LED colour variation is more apparent, where others use an opal diffuser which mixes the chip output together, such luminaire designs often allow a three step colour bin to create a single step colour on the diffuser of the luminaire negating the colour difference at chip level. As a general rule three step MacAdam Ellipse is considered to be a high quality colour bin selection suitable for the vast majority of applications and luminaire designs and will provide a light output with little if any discernible difference in the colour of light the vast majority of the time. A five step MacAdam Ellipse is more often used in lower cost products where clients are willing to accept a compromise on colour consistency for the sake of cost.

Beginning and end of life colour consistency

As with all electrical components degradation occurs over the lifetime of LEDs. Lumen depreciation is most commonly discussed when changes over lifetime are considered, however there is typically a small shift in colour as well as LEDs age. The rate and extent of changes in LED chips is largely dependent on the temperature and current at which they are operated, although it is worth noting that exposure to some chemicals can cause very rapid and significant changes in colouration.

Good quality LEDs operated at moderate currents and temperatures will typically degrade by no more than two steps over their lifetime, and often less given this would only occur when the luminaire was consistently operated at its maximum permissible temperature. Therefore a common colour consistency over lifetime for a high quality luminaire will be three step beginning of life, five step end of life. A lower quality luminaire might offer a colour consistency over lifetime of five step beginning of life, seven step or greater at end of life.