Dextra GROUP PLC

CPD LED Course Notes

LED Technology, Lifetime, Efficiency and Comparison

CIBSE CPD

INNOVATE to ILLUMINATE

LED SPECIFICATION OVERVIEW

Not all LED's are alike

- During Binning the higher the flux and lower the forward voltage the more efficient the LED.

Specify "Hot Binned" premium LED's

Quality of Light

- Colour Temperature suitable for the environment

Specify required colour temperature: eg 4000K for offices, 3000K for hospitality etc.

- MacAdam's Ellipse / Standard Deviation Colour Match

Specify maximum acceptable Chromaticity Tolerance (MacAdam) e.g. <3 SDCM from initial LED source.

- Colour Rendering Index

Specify Colour Rendering Index e.g CRI>80 generally or CRI>90 for specialist tasks.

LED Lifetime

- LM80 Tested, Lifetime & Lumen Maintenance Data
- L70 (50,000 hrs) Industry Norm / L90 (60,000 hrs) for premium LED's

Example: Specifying L90 (60,000hrs) means the LED's are rated to maintain >90% of the original light output over 60,000 hours of operation.

Luminaire Comparisons

- Same chip, different package.

The LED Array Optics & Control gear all contribute to the performance of the luminaire.

- Wattages count for little given variations in efficiency of LED's & Optical Design.
- (LLM/W) Luminaire Lumens per Circuit Watt should always be used to compare efficiency.

Specify minimum llm/w e.g. Luminaire Efficiency >100 llm/w

- Manufacturer Warranty

Specify minimum duration of Manufacturer warranty e.g. 5 years.

History of LED

1. Electro-luminescence is a characteristic of a material, typically a semi-conductor, that enables it to release photons (emit light) in response to a small electrical current.

2. Oleg Vladimirovich Losev researched semi-conductors that emitted light (LED's).

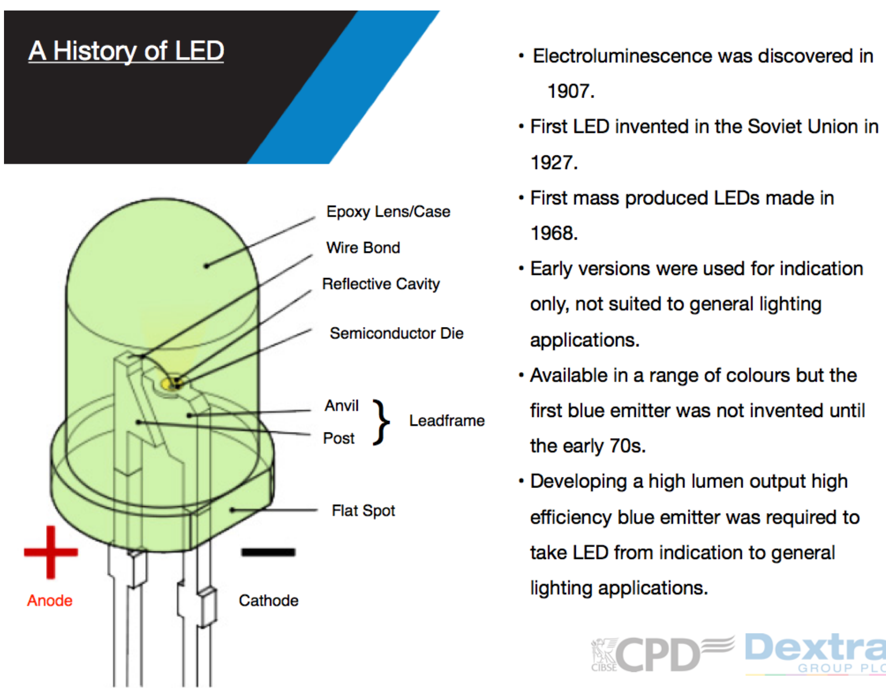
3. Prior to mass production LED's were in the order of $200 per unit.

4. Originally low intensity Infrared for remotes. Then low intensity red and green for indicators.

5. The illusive Blue LED was created in the 70's but only in the 90's high output blue emerged.

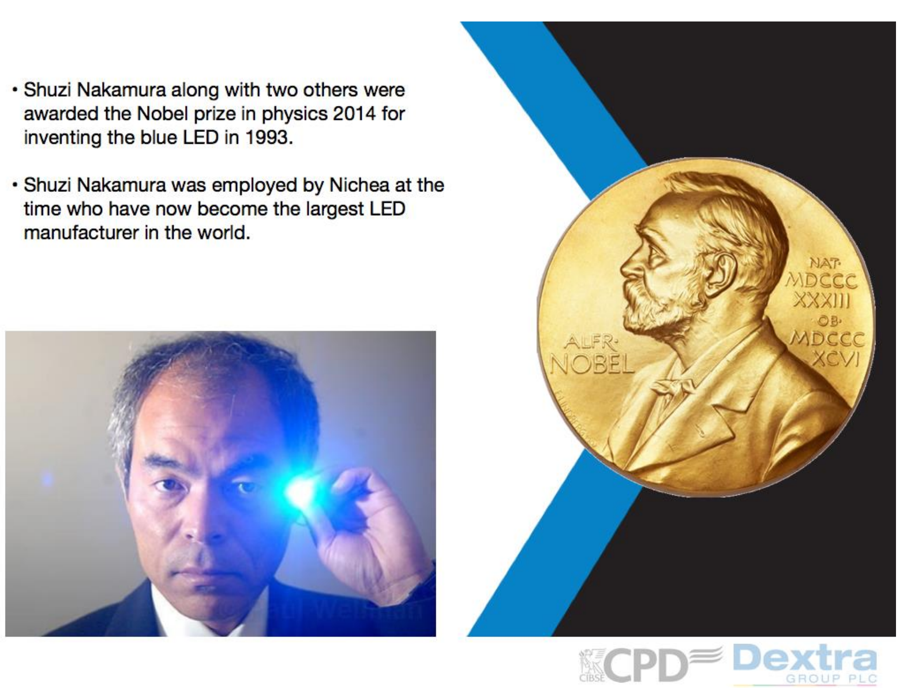
6. This could then pave way for blue, green and red light to combine with different phosphors to create the all important high output white light.

7. The diagram is indicative of a low intensity indicator LED only.



Notes:

1. It was the fact that this was the first high out put blue that set it apart from the earlier versions and opened up the possibilities for its use in general lighting.



Notes:

How LED's Work

1. A sample array of the 3 LED categories will be available at each presentation.

2. The diagram is indicative of a high power LED only.

3. High Power Chips   -floodlights, street lights and high level pendants.

4. Mid Power Chips   -most commercial lighting products.

5. Low Power Chips   -for indication purposes or colour specific.

6. Different terminology of Blue pump - emitter, diode, LED, semi-conductor, chip etc.

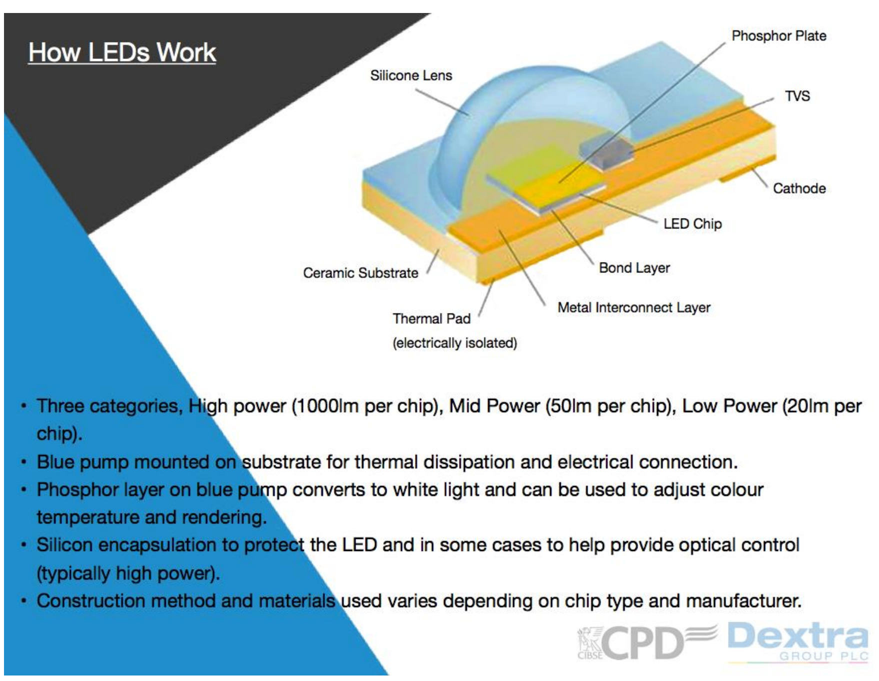
7. The silicone lens protects from chemical attack especially sulphur that degrades quality. It also provides a more directional light and prevents a completely flat lambertian distribution.

8. Secondary optical control can be added e.g. asymmetric, wide beam, narrow beam etc.

9. LED structure and Phosphor layer are a highly protected formula by the manufacturer.

10. TVS - Transient Voltage Suppressor to protect against static charge.

11. The Thermal pad is bonded to the circuit board which is typically aluminium with high power LED's allowing for greater thermal dissipation, the circuit board is then mounted on a heat sink.



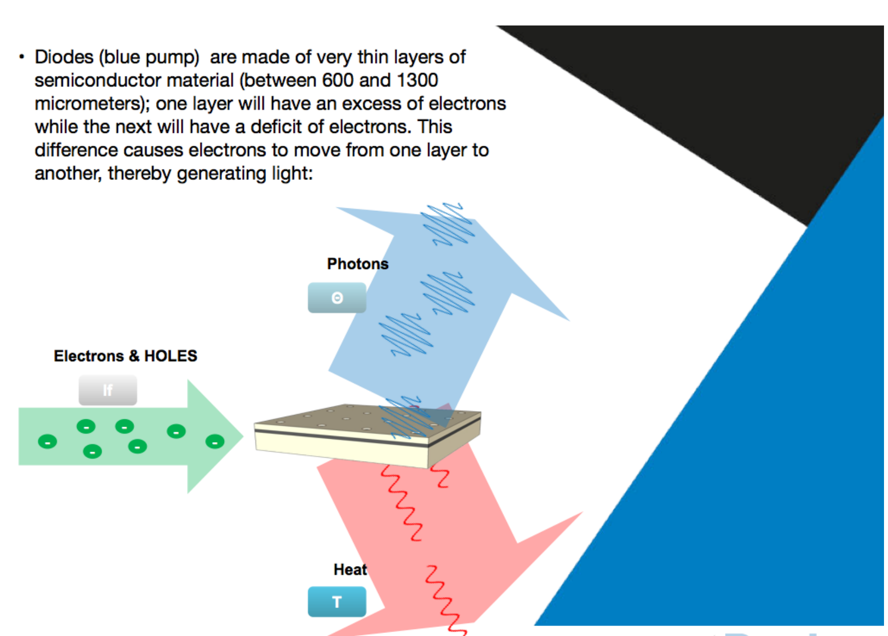
Notes:

1. Process of Electro-luminescence enables the release of photons that are visible as light.

2. This light is then converted by the phosphor layer that will be above the blue pump.

3. A side effect of this process is heat that needs to be managed to prolong LED life.

4. A strand of hair is typically 100 microns.



Notes:

How LED's are made

1. The photo shows an LED reactor that grows the LED's. These are 10ft across and £5m each.

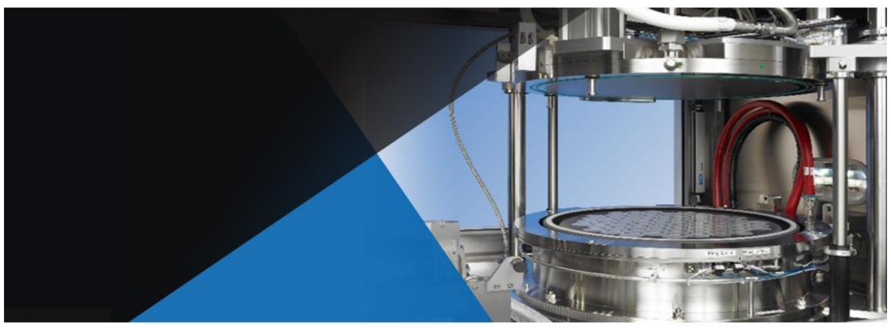
2. The reactors are housed in clean room environments. Crystal growth system is very sensitive to changes in temperature and pressure.

3. Even with very close supervision variations occur and efficiency across the wafers.

4. The process is being improved all the time but the yield across a batch is still not all the same colour of efficiency. Hence the dies need to be binned with like dies.

How LEDs are made

- The wafer is manufactured in a reactor, typically on 12 inch substrates made from silicon or sapphire.
- Wafer growth takes up to 6 weeks at high pressures and temperature, typically 850°C



- Minute variations in temperature across the wafer or impurities cause variations in wafer growth hence the need to bin LEDs post production.
- Each wafer is inspected and separated into individual dies, the size of which varies depending on the type of LED to be made.

Notes:

1. This slide demonstrates the process from substrate to Binning.

2. Epitaxy Growth - Positive and Neutral layers are created in the reactor.

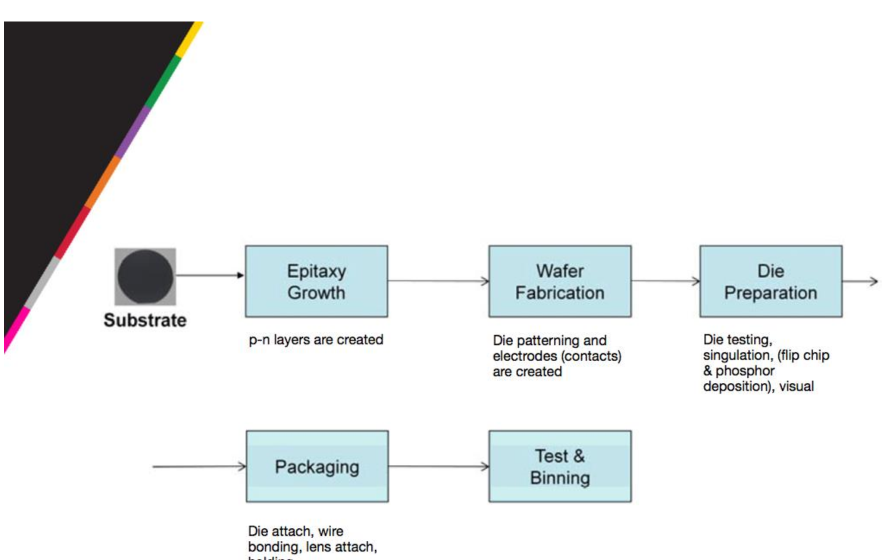
3. Wafer Fabrication - the wafer on the 12" substrate is subdivided into dies.

4. Die preparation - each die is separated, tested and the appropriate phosphor applied.

5. Packaging - NOT a box but electrical connection, phosphor application, optics and assembly.

6. Test & Binning - Colour, CRI and efficiency established and like dies are binned.

7. Phosphor are optimised to produce high yields of the most popular dies e.g C84. Therefore less popular colours and performance criteria are far less plentiful e.g. C95



Notes:

Not all LED's are alike

1. Sapphire substrates grow the highest quality and most efficient LED's. They are only used once but processes are being developed to re-use the substrate e.g. Sapphire glass is used in the production of high quality anti-scratch watch faces.

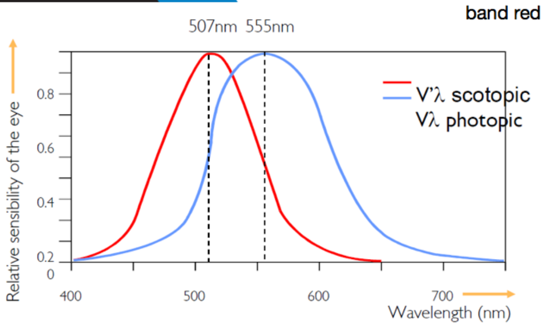
2. Silicon substrates are cheaper to make and hence reduce production costs but can't match Sapphire on quality. Silicon produces lower efficiency LED's.

3. The most efficient LED's focus on visible wavelengths between 507 and 555nm. Visible light is from approximately 400-700nm.

4. The most efficient LED's use "narrow band red phosphor" developed in the last 2 years.

Not all LEDs are alike

- Efficiency of blue pump.
- Substrate material (silicon, sapphire etc) used in wafer production defines the structure of the die and therefore alignment of apertures for electrons to pass through.
- Sapphire tends to give the most efficient blue pump but at additional cost compared to silicon.
- Phosphor development, eliminating wasted energy on non visible wavelengths that fall outside the lambda curve, for example narrow band red phosphor.



Notes:

LED Variation and Binning

1. This process is done incredibly quickly and is fully automated.

2. The chart shows the method adopted by Lumileds/Philips. Other manufacturers would adopt similar methods to communicate the efficiency of their chip types.

3. Each Bin letter is again subdivided into 1 and 2 e.g. R1 would be 48-50 and R2 would be 50-52.

4. The Best mass produced LED's in this table would be R and S.

5. Bins between J and Q are available but in lower volumes and at a reduced price.

6. Bin T is available in very low volumes and at a high price but indicates future efficiency gains.

7. 100% difference between the least and most efficient LED from the same manufacturer.

LED Variation and Binning

- Three key variables by which LED are binned:
  - Flux: Photometric Luminous Flux (lm)
  - Colour: Correlated Colour Temp (K)
  - Forward Voltage (Vf)
- The higher the flux and lower the forward voltage the more efficient the LED.
- Colour ought to be limited to three step Macadams Ellipse.
- Table below shows variation in flux bins within an identical chip >100% efficiency difference:

BIN	LUMINOUS FLUX (lm)	
	MINIMUM	MAXIMUM
J	24	28
K	28	32
L	32	36
M	36	40
P	40	44
Q	44	48
R	48	52
S	52	56
T	56	60

Notes:

Hot Binning

1. Hot Binned data is far more accurate for LED's in real environments.

2. Hot Binning is more expensive due to additional energy and time required.

3. Cold Binned data may not be as good in real environments.

Hot Binning

- Premium LEDs are typically "Hot Binned" to ensure that colour and performance is grouped according to real life performance within the luminaire:

- At 85^{0}C
- 700 mA drive current
- Applied in DC (100 mS)

Notes:

Macadam's Ellipse

1. A single step Macadam's Ellipse defines a spectral area in which the average person can only discern a single colour.

Macadam's Ellipse

"Thus, a human observer should not reliably detect a colour difference between a reference light having a chromaticity at the centre of the ellipse and any other light within the elliptical pattern of constant discriminability." (MacAdam, 1942)

- A single step Macadam's Ellipse defines a spectral area in which the average person can only discern a single colour.
- The size of the ellipse varies depending on the colour due to variations in the sensitivity of the human eye to different colours.

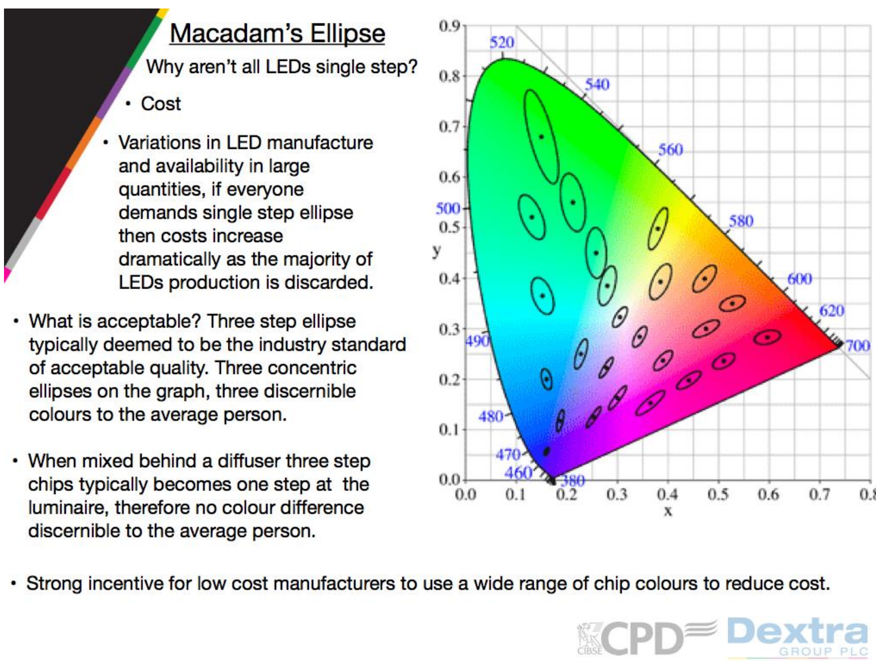
Notes:

Macadam's Ellipse

1. The CIE 1931 xy Chromacity diagram demonstrates ellipses that are magnified x 10. It shows how relative ellipse sizes vary depending on colour and sensitivity of the human eye.

2. It also shows how very sensitive the human eye is to colour changes in white light as the demonstrated in the small size of the ellipse in the centre.

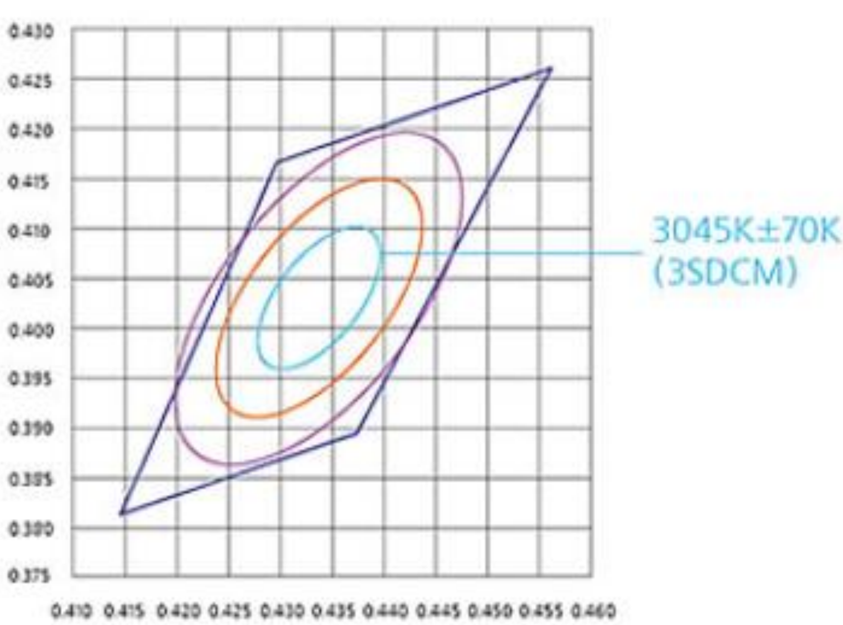
3. Three step essentially allows the selection of chips in three concentric ellipses. This is often communicated as 3SDCM - 3 Standard deviation colour match.



Notes:

1. In reality and with the yield rates of LED manufacturing, it is not currently possible to accommodate the global lighting market with single colour bins that sit in one Ellipse.

2. Most luminaires introduce a diffuser so colour matching is far better than 3 step.



Notes:

Quality of Light

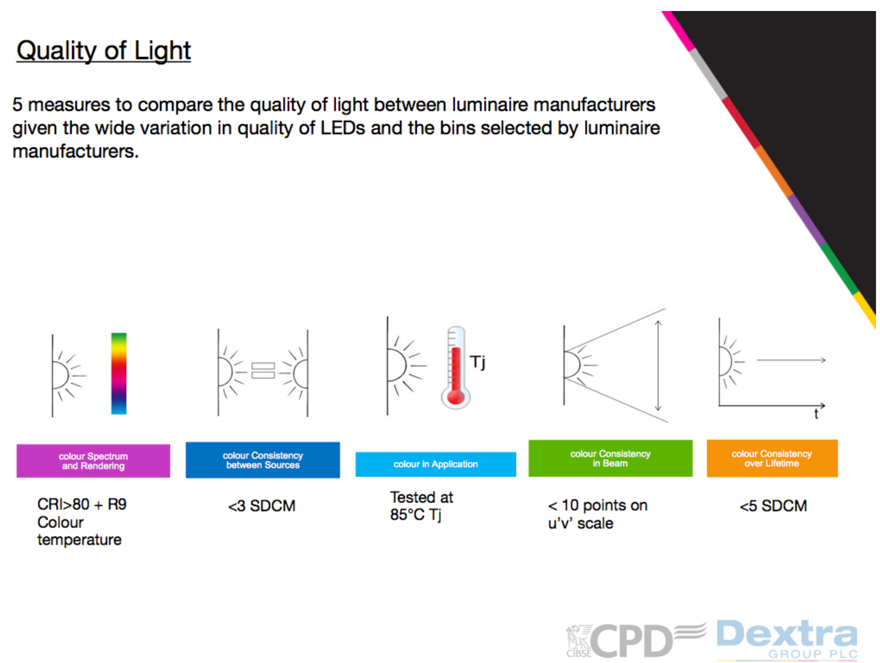
1. Good quality of light. CRI-Colour Rendering Index - measures the ability of light source to reveal colours faithfully in comparison to a natural light source. 100 is perfect however >80 is good and some LED’s are available >90 or higher.

2. Good colour consistency between chips - <3 Standard Deviation colour match i.e <3 step Macadam’s Ellipse.

3. Hot binning at 85 degree C provides more accurate performance data, replicating real life.

4. Good colour consistency across the width of the desired beam angle.

5. Good colour consistency over the life time of the product i.e. 5 step Macadam’s Ellipse at end of life.



Notes:

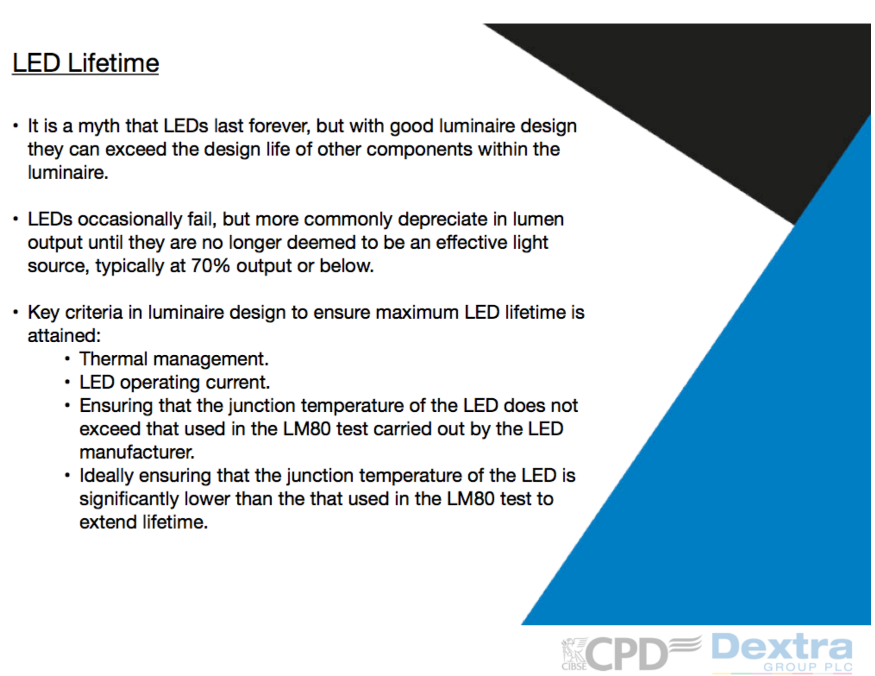
LED Lifetime

1. Typically manufacturers declare life at 50,000 hours at L70. this means that after this time the LED’s should be no worse than 70% of their actual output, 0-69% is a fail. Others declare 60,000 hours L90 and sometimes longer for specific environments like tunnel lighting.

2. Drivers are often rated at 100,000 hours.

3. Over population of the lED and running them at a lower operating current will extend life.

4. The junction temperature is measured inside the LED between the pump and the substrate.



Notes:

LED Lifetime

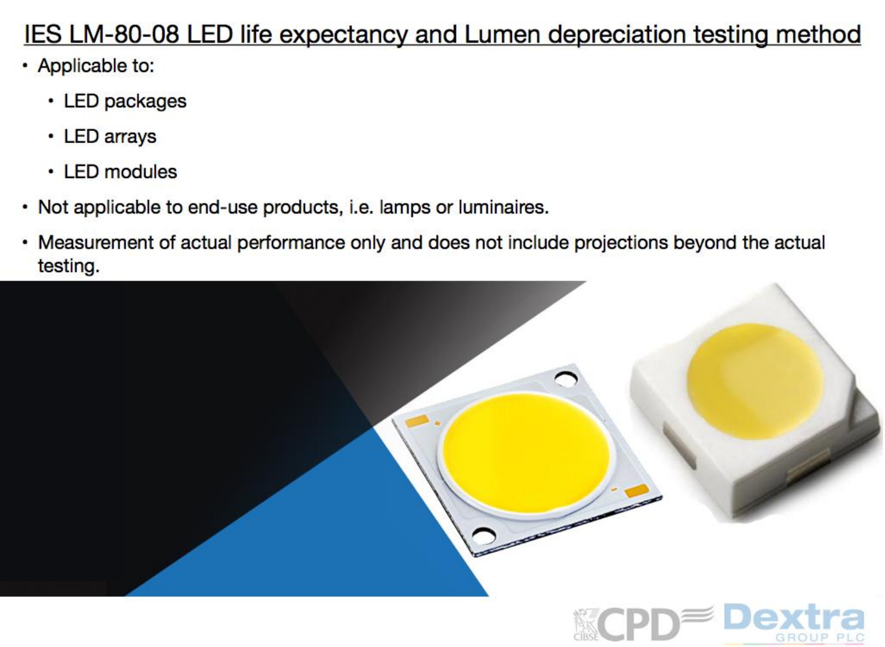
1. Long LED life and performance is all about keeping temperature under control.

Notes:

IES LM-80-08 LED life expectancy and Lumen depreciation testing method

1. LM-80 measures actual performance of LED packages, arrays and modules.

2. However it is an essential tool for the design of light fittings.



Notes:

IES LM-80-08

1. The manufacturers selected case temperature should be high to replicate a reasonable worst case. Lumileds test at 105 degree C.
2. Power conditioning means a clean power supply through a monitoring device.
3. The tests duration is 6000 hours +
4. Over this period the test cards are placed in an integrating sphere to measure lumen output and colour. These tests are at rapid intervals to start with decreasing into the mid term.

IES LM-80-08

- Environmental, electrical and thermal conditions:
  - Minimum of three controlled case temperatures:
    - 55°C
    - 85°C
    - xx°C (manufacturer's selection – can be any temperature)
  - LED case temperatures monitored with thermocouples.
  - Heat sinking as needed and recommended by LED manufacturer.
  - Airflow minimised around devices under test.
  - No excessive vibration.
  - Power conditioning required for input to devices under test.
  - Measurements taken periodically through the test to measure lumen depreciation.

Notes:

1. All LED products should state a rated lumen maintenance. Anything less than L70 for LED is usually deemed as a failure.
2. These LED products should state the failure fraction. B10 is considered as being good. Some product are as high as B50 at some elapsed operating times.
3. The C value describes the expected percentage of catastrophic failures i.e. when an LED produces no light this is generally not published for indoor use.
4. Many quality luminaires compensate for spot lED failures within an array by driving remaining LED's slightly harder.

IES LM-80-08

- Lumen maintenance (IES LM-80-08): the luminous flux output remaining (typically expressed as a percentage of the maximum output) at any selected elapsed operating time. Lumen maintenance is the converse of lumen depreciation.
  - Example: after 10,000 hours, LED lumen maintenance is 98.7%
  - Example: after 50,000 hours, LED lumen maintenance is 72.3%
- Failure Fraction: the variation in the expected Luminous flux output (expressed as a percentage of the number of LED's).
  - Example: after 50,000 hours, LED failure fraction is 10%.

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IES LM-80-08

- Rated lumen maintenance life (IES LM-80-08): The elapsed operating time over which the LED light source will maintain the percentage, p, of its initial light output, e.g.
  - L70 (hours): time to 70% of lumen maintenance (Industry Standard).
  - L90 (hours): time to 90% of lumen maintenance (Premium LED and Luminaire design).
  - Example: L90 (60,000) means the product is rated to maintain > 90% of original light output prior to 60,000 hours of operation (10% lumen depreciation).
- Life for incandescent, HID and Fluorescent sources typically published lifetime hours at 50% failure rate (B50), because LEDs can't be replaced over the course of the luminaire lifetime they are typically deemed to have failed when they produce less than 70% of initial luminous flux.

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Notes:

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IES TM-21-11 Extrapolation Method

1. TM-21 is the recognised calculation method to project LED’s lumen maintenance beyond the 6000 hour + LM-80 data.

IES TM-21-11 - Extrapolation Method

- With LM-80 we measure actual light output for a minimum of 6,000 hours.
- With TM-21 we can project lumen maintenance performance beyond the tested hours (e.g. to 25,000 or 50,000 hours).
- TM-21 is not a test method , it is a calculation only.
- Scope:
  - LED packages / arrays / modules tested per IES LM-80.
  - Not intended for end-use products (lamps, luminaires).

Notes:

IES TM-21-11

1. TM-21 data can only project a maximum of 6 times the LM-80 test duration e.g. 6000 hours can be projected to 36000 hours. So to claim 50,000 hours you must have over 8000 hours of test data.

2. LM80 tests are very expensive to undertake especially for long durations in excess of 6000 hours so only best quality LED’s will have data available to LM80 10,000 hours and TM21 to 60,000 hours.

IES TM-21-11

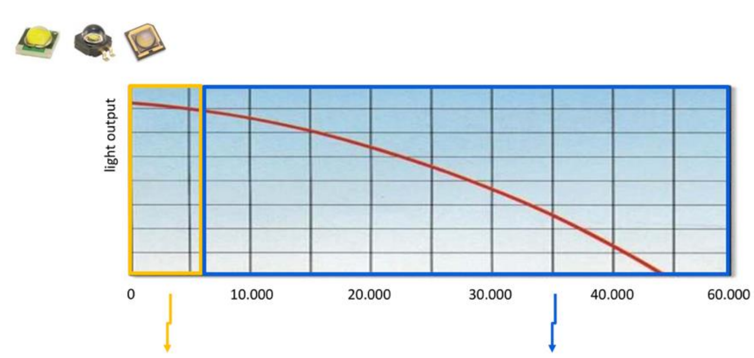
Projection method overview:

- Data for one LM-80 temperature is used.
- Each tested unit’s output is normalised to 1 at zero hours.
- All data (for the selected temperature) is averaged together.
- For data ≤ 10,000 hours, only the last 5,000 hours of data are used – the first 1,000 hours are disregarded (generally too noisy).
- For data ≥ 10,000 hours, the last 50% of time points are used.

$$\Phi(t) = B \exp[-\alpha t]$$

$$L70 = \frac{\ln\left(\frac{B}{0.7}\right)}{\alpha}$$

Lumen Maintenance of LEDs



LM-80: 6-10K hrs real measurement.

TM-21: extrapolation 6x measurement.

Notes:

IES LM-79 Luminaire life expectancy and Lumen depreciation testing method

1. LM-79 measures the whole product with LED's built in for 6000 hours. Hence in the rapidly developing world of luminaires and LED's, this is impracticable in most cases. Specialist areas may demand this information such as tunnels/oil rigs etc.

IES LM-79 - Luminaire life expectancy and Lumen depreciation testing method

- Lamp / luminaire testing:
  - Measure light output of whole product at zero hours (LM-79 using an integrating sphere or goniophotometer).
  - Operate product for 6,000 hours as per UL 1993 (lamps) or UL 1598 (luminaires).
  - Remeasure light output of whole product at 6,000 hours (LM-79).
  - Calculate lumen maintenance at 6,000 hours.

Notes:

Is LM-79 required for all luminaires?

1. For most environments manufacturers demonstrate operation within LM-80 test parameters.

Is LM-79 required for all luminaires?

- This is not a mandatory test required under CE mark standards.
- It is an optional test to demonstrate estimated luminaire lifetime.
- Where luminaire manufacturers can demonstrate that the LED is being operated within the parameters of the LM80 chip level test when installed within in the luminaire it is typically not necessary to duplicate the test within the luminaire also.
- Impractical for most luminaire manufacturers to carry out 6000 hours of testing on all luminaire variants given the large number of products manufactured.
- Most applicable to specialist luminaires for arduous applications where long lifetime of entire product must be demonstrated.

Notes:

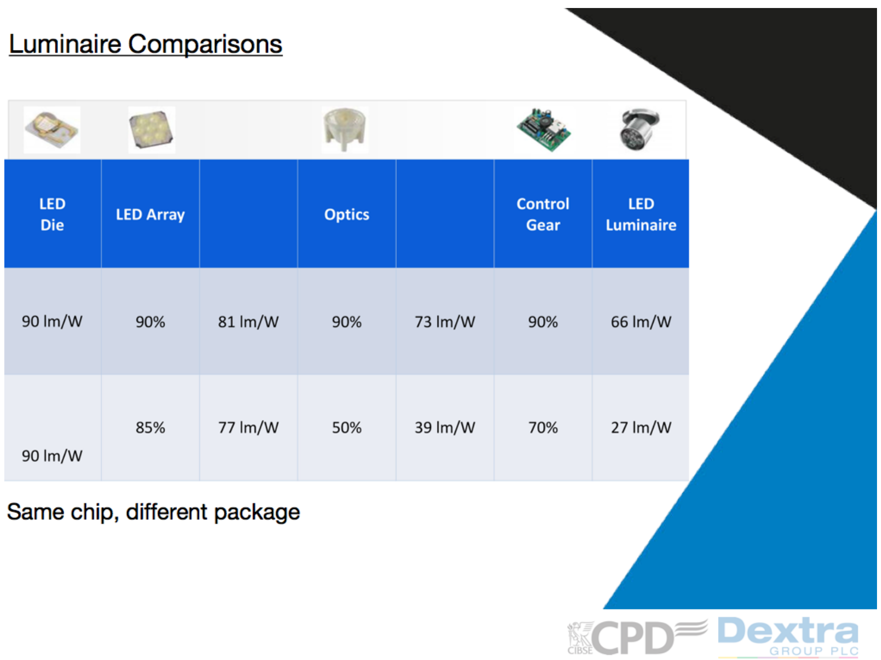
Luminaire Comparisons

1. Criteria that effect the LED array are Temperature, Circuit configuration and Thermal design.

2. Criteria that effect the Optics are Material, Lens quality, Tooling and Design.

3. Criteria that effect the Control gear are Gear losses, Optimised selection and Pairing.

4. Seek driver efficiencies of 90% +



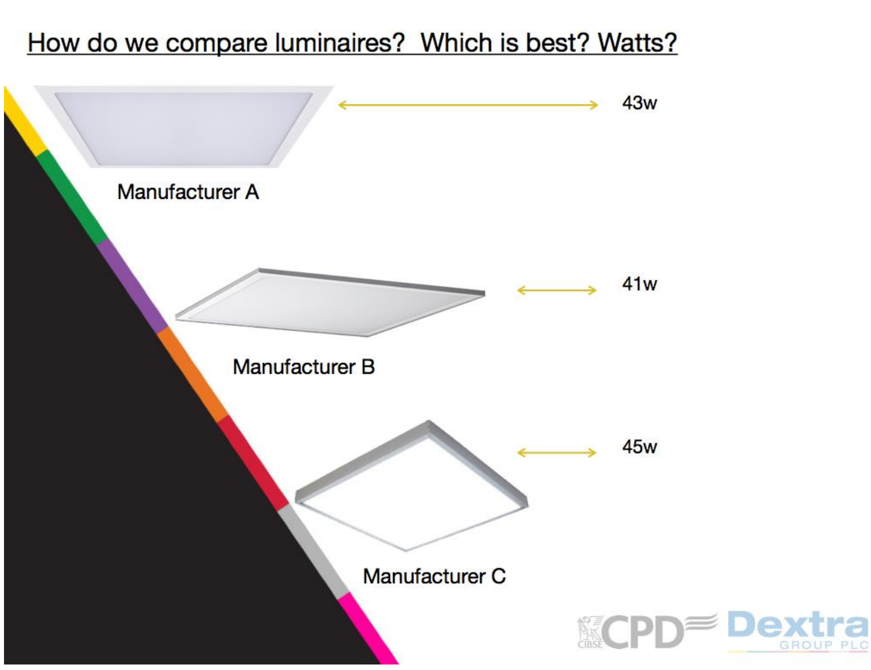
LED Die	LED Array		Optics		Control Gear	LED Luminaire
90 lm/W	90%	81 lm/W	90%	73 lm/W	90%	66 lm/W
90 lm/W	85%	77 lm/W	50%	39 lm/W	70%	27 lm/W

Notes:

How do we compare luminaires? Which is best? Watts?

1. Selecting ONLY POWER as the point of comparison is not the right path.

2. If you do this Manufacturer B looks the most efficient while A and C “look” less efficient?

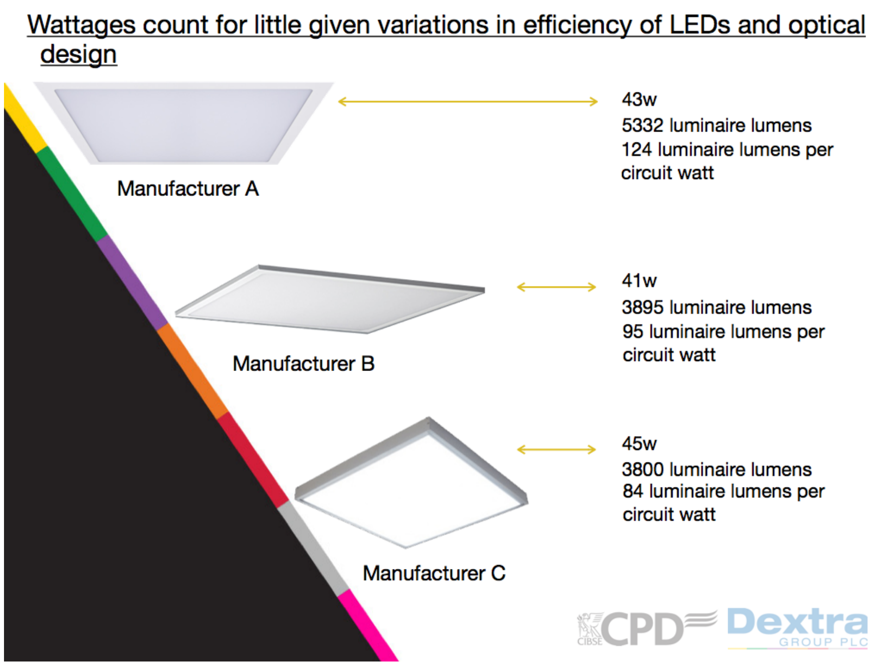


Notes:

Wattages count for little given variations in efficiency of LED's and optical design

1. However selecting on Luminaire Lumens per Circuit Watt, Manufacturer A is most efficient.

2. Luminaire Lumens per Circuit Watt is the best benchmark with which to compare efficiency.

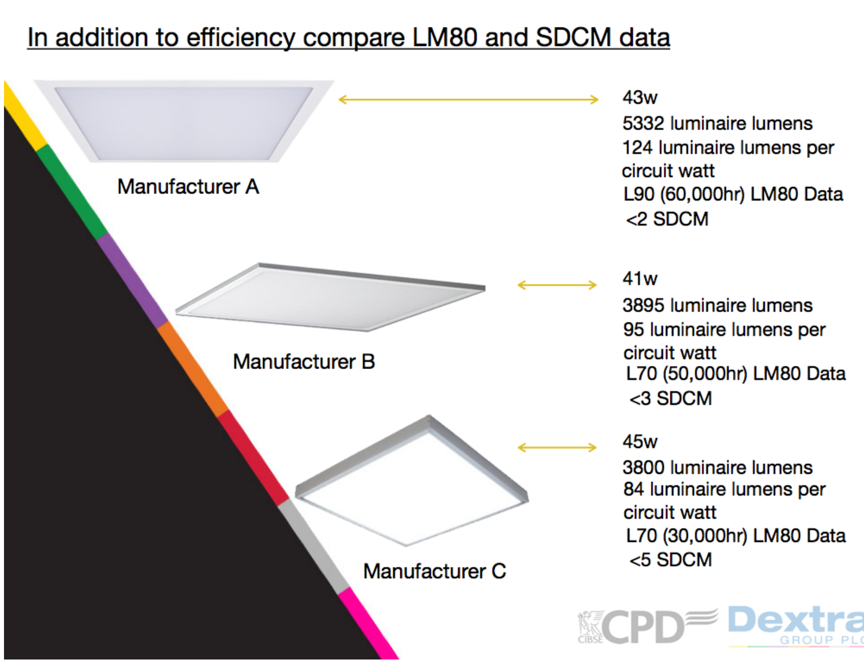


Notes:

In addition to efficiency compare LM80 and SDCM data

1. If efficiency alone is not enough, compare published LM80 and Macadam's Ellipse data.

2. ALSO if there is an opportunity to select a lower lumen package from Manufacturer A to maximise energy saving potential further?

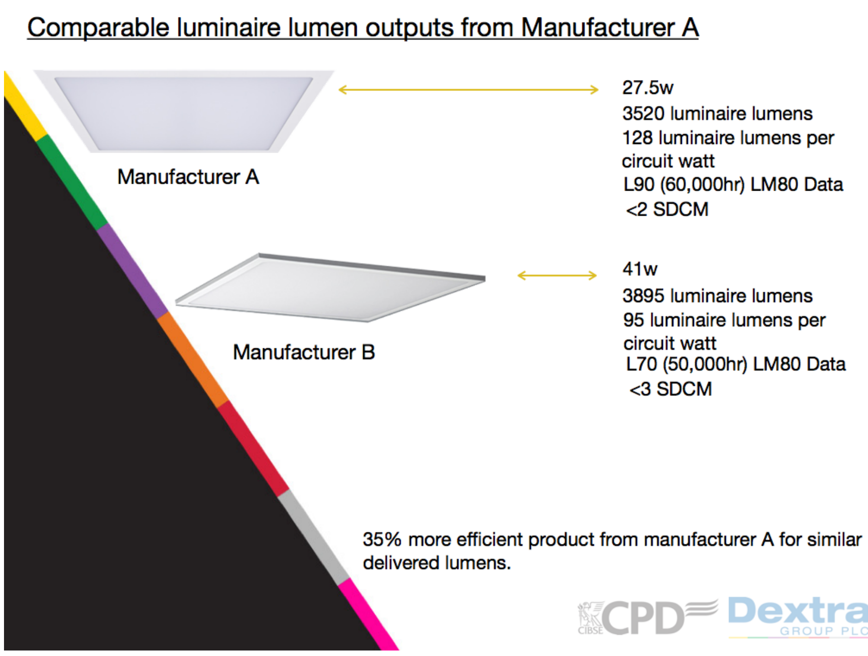


Notes:

Comparable luminaire lumen outputs from Manufacturer A

1. YES. By selecting Manufacturer A's model at a reduced 3520 Lumens you can further reduce consumption by 35% and achieve a similar light level.

2. Recessed Opal LED's were selected for demonstration purposes, however this process is equally valid for other styles of luminaires when you have lumen, power, Llm/cw and LM80 data.



Notes:

How do we compare like for like?

How do we compare like for like?

- Chip manufacturer, chip binning, quality of light source, colour temperature and rendering Macadams Ellipse.
- Substantiated test data, LM80 and TM21.
- Luminaire design, thermal management and thermal testing data, CE mark.
- Photometry, efficient optical design.
- Luminaire lumens per circuit watt gives the most simple comparison of luminaire efficiency as it compares chip, driver and optical efficiency with a single figure.
- Other key comparisons; warranty and ability to support warranty over the promised period, service, delivery and ability to deliver a wide range of variants and customised product at short notice, on site survey and schemes, aesthetic considerations, options for control integration, compliance of installation, ROI calculations and WEEE disposal.

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David Jenner - National Specification Director

Dextra Lighting Ltd

Telephone: 01747 858100

Mobile: 07795 846627

Email: djenner@dextragroup.co.uk

Web: dextragroup.co.uk

Gosia Skop – External Sales Representative

Dextra Lighting Ltd

Telephone: 01747 858100

Mobile: 07779 260909

Email: mskop@dextragroup.co.uk

Web: dextragroup.co.uk

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