# Application Note

## Advantages of LED Lighting in Horticultural Applications

WÜRTH ELEKTRONIK

**ANO003 // Dr. Richard Blakey**

## 1 Introduction

High intensity discharge (HID) lamps are the current industry standard used by the artificial lighting greenhouse industry because of their economic viability and providing a consistent, adequate spectrum for plant growth [1]. Light emitting diodes (LED) provide a multitude of advantages as horticultural lighting sources but early difficulties, primarily cost and intensity, limited their implementation in horticultural applications. However, rapid advances in LED design and manufacture have closed the gap to traditional discharge based lighting technologies and are now becoming an economically viable alternative to HID sources, especially for high-value crops [2], which some have called "a monumental shift" [3]. The following AppNote compares the advantages of LEDs with traditional HID light sources for horticultural applications. Although the properties have been addressed in different sections, they are highly interrelated. Gains in one performance characteristic will compromise others. For an introduction to the use of LEDs in horticultural applications, please refer to ANO002 LEDs - The Future of Horticultural Lighting.

## 2 Output Intensity

Initially, the intensity of LEDs was too low to be of practical use in horticulture, being more suited to indicator lights and control panel backlighting. The intensity of light that can now be generated by LEDs means photosynthetic photon flux (PPF) output is comparable to that of HID sources when used in clusters. The output intensity of lighting is usually expressed in lumens, as humans perceive light, which is biased towards the sensitivity of the eye. However, photosynthesis and plant growth is driven by photons and so is quantified as PPF. This is especially important when comparing LEDs that can generate specific wavelengths of light. As radiant energy is inversely proportional to wavelength, "red photons" have a lower radiant energy content resulting in more photons being generated per unit of input energy. This means that although blue LEDs have higher radiant flux than red LEDs, the difference in PPF is much closer (Figure 1). It is difficult to compare the output intensity of LED and HID sources in a useful way due to a number of factors including, the number of LEDs, the inherent radiation pattern of the devices (LEDs are unidirectional while HID lamps have an omnidirectional broad emission pattern), and the use of reflectors and lenses. The aim is to maximize the transfer of the emitted light from the light source to the plant leaves. It may be therefore, more interesting to consider how light is delivered to the plants. There is no perfect emission distribution pattern but there are some that are more suitable for certain greenhouse configurations. Precision overhead luminaires and lenses can be used to control the emission pattern of HID devices and focus light to the plant growth areas. This is necessary in small greenhouses with widely separated cultivation areas. Canopy photon capture efficiency of above 90% can be achieved in this manner, regardless of the light source. But capture rates near to 100% can be achieved using LED intracanopy lighting [4]. The heat generated by HID fixtures makes intracanopy lighting infeasible.

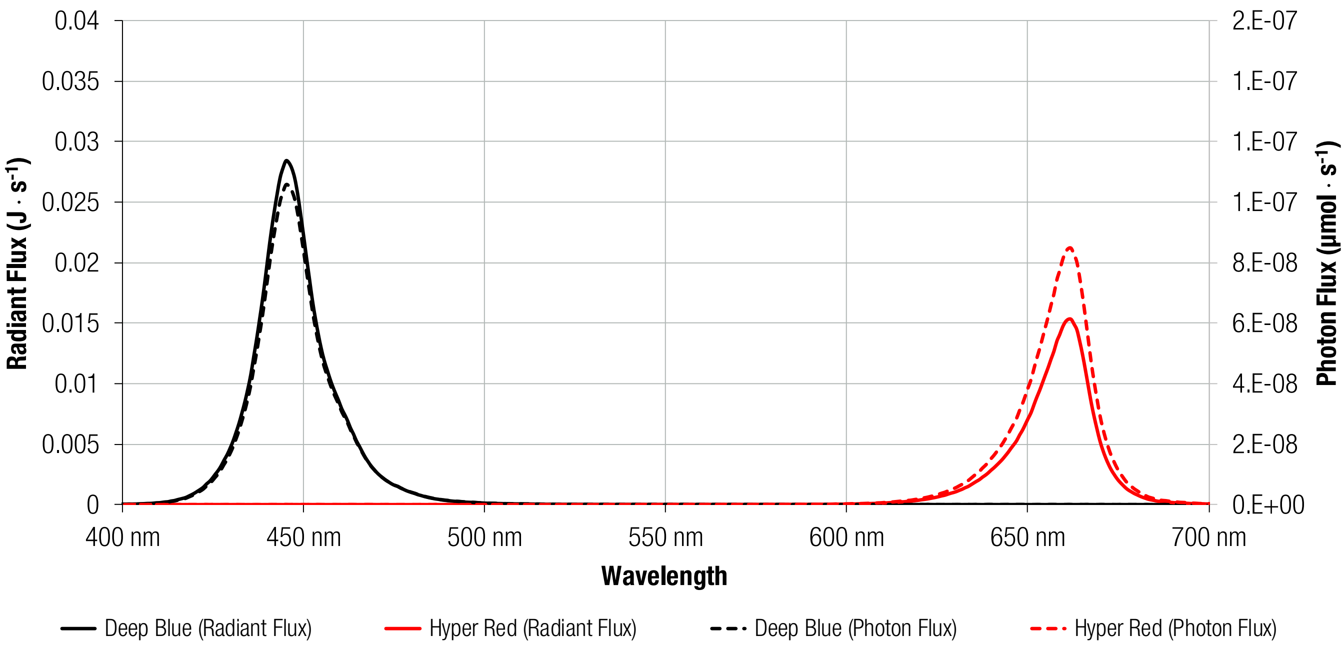


**Figure 1: Comparison of PPF and radiant flux of the WL-SMDC Deep Blue (150 353 DS7 4500) and Hyper Red (150 353 HS7 4500)**

# Application Note

## Advantages of LED Lighting in Horticultural Applications

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## 3 Efficiency

The potential efficiency of LEDs [5] over traditional lighting sources has long been recognized [6]. This is because of their low losses, generated as heat, meaning a greater proportion of the electricity goes towards generating light. Additionally, this means the light source can be placed extremely close or even within the plant canopy. The efficiency (wall-plug efficiency) of light sources is usually expressed as the radiant flux (W) per electrical input power (W) or luminous efficacy, expressed as luminous flux (lm) per electrical input power (W) but for horticulture, photon efficacy is used (µmol $J^{-1}$). This is the output of photosynthetic photons (µmol $s^{-1}$) as a function of the input power (W). As discussed in Section 2, the PPF and radiant flux will vary greatly between different wavelengths of LED. Although blue LEDs have higher wall-plug efficiency than red LEDs, the difference in photon efficacy is much closer (Figure 2).

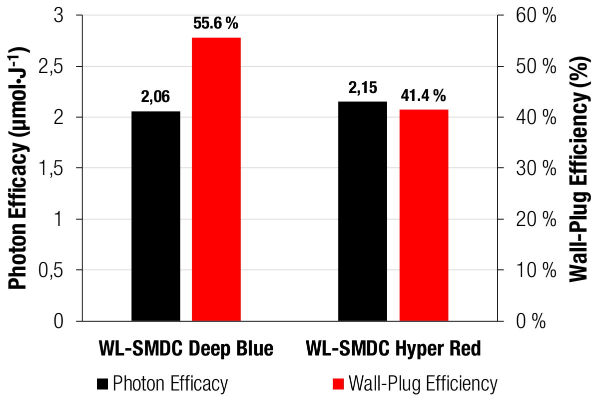


**Figure 2: Comparison of Photon Efficacy and Wall Plug Efficiency of the WL-SMDC Deep Blue (150 353 DS7 4500) and Hyper Red (150 353 HS7 4500)**

This is further complicated by the efficiency of LEDs being different for different materials used to generate different wavelengths in addition to changing as a function of the input current (Figure 3). The most efficient 'colors' of LED, based on photon efficacy, are blue and red.

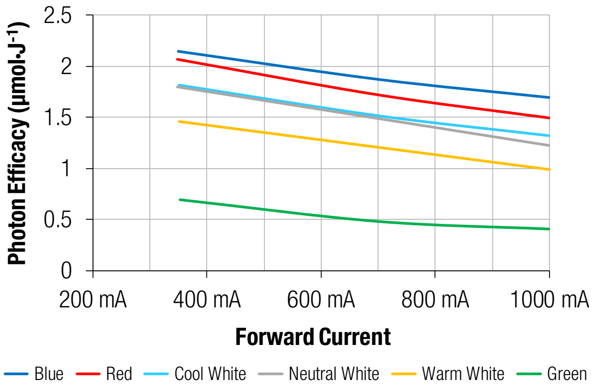


**Figure 3: Typical Photon Efficiency (µmol/J) as a Function of Input Forward Current (mA)**

To compare HID and LED light sources directly, the focus is on the efficiency of the conversion of electrical power to photosynthetic active photons (Table 1).

| Light Source Type | Electrical Input (W) | PPF (µmol $s^{-1}$) | Photon efficacy (µmol $J^{-1}$) |
|---|---|---|---|
| High Pressure Sodium [7] | | | |
| 400 W (Magnetic) | 443 | 416 | 0.94 |
| 1000 W (Magnetic) | 1067 | 1090 | 1.02 |
| 1000 W (Magnetic) | 1024 | 1333 | 1.30 |
| Ceramic Metal Halide [7] | | | |
| 315 W (3100 K) | 337 | 491 | 1.46 |
| 315 W (4200 K) | 340 | 468 | 1.38 |
| Flourescent [7] | | | |
| 400 W (Induction) | 394 | 374 | 0.95 |
| 60 W | 58 | 48 | 0.84 |
| Light Emitting Diode (@350 mA) | | | |
| WL-SMDC Deep Blue (150353DS74500) | 1.12 | 2.31 | 2.06 |
| WL-SMDC Hyper Red (150353HS74500) | 0.84 | 1.81 | 2.15 |
| WL-SMTC Moonlight (158353030) | 1.12 | 1.58 | 1.41 |
| WL-SMTC Daylight (158353050) | 1.12 | 1.69 | 1.51 |

**Table 1: The Most Efficient 'Colors' of LED, Based on Photon Efficacy, are Blue and Red**

The result of this is that the efficiency is highly sensitive to electricity prices (Figure 4). As the price of electricity increases, the savings of implementing an LED lighting system become far more significant.

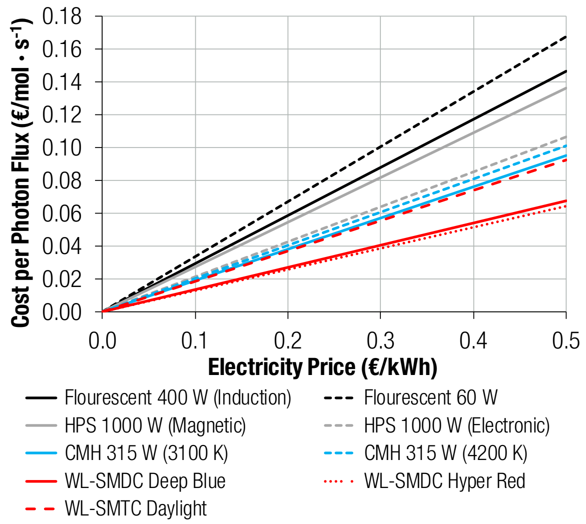


**Figure 4: Cost per PPF as a Function of Electricity Prices in High-Pressure Sodium (Grey), Metal Halide (Blue), Fluorescent (Black) and LED (Red).**

# Application Note
## Advantages of LED Lighting in Horticultural Applications

## 4 Light Quality

The key advantage of LEDs here is the ability to adjust and optimize the total light spectrum. This can be used to enhance and improve photosynthetic efficiency and control developmental phases [8] but also to reduce the amount of wasted light and therefore energy. Because of their monochromatic output, a number of LEDs with different wavelengths can be used to configure light "recipes" specific to species, cultivars and growth phases [9]. This is opposed to HID sources that have a fixed output spectrum, which supply sufficient quantities of light in some wavelengths while providing excessive or deficient quantities at others (Figure 5). Additionally, the light recipe cannot be modified to suit a plants development (Figure 6). There are currently a number of projects that use feedback control to optimize the light recipe (and other parameters) to the growth stage of plant. These systems use cameras, usually in the visible or infrared spectrum.

The ultraviolet region (UVA and UVB, 280 to 400 nm) is currently a very interesting topic in horticulture. Sunlight consists of 9 % UV (percent of PPF) while HID sources emit a fixed level of 0.3 to 8 % UV radiation (percent of PPF) [10]. With LEDs, it is very easy to control the level of exposure. Deficient levels of UV can interrupt development in some plant species [11]. HID sources have minimal far-red radiation (710 to 740 nm), which LEDs are capable of efficiently generating.
The importance of far-red radiation can be found in ANO004. Green LEDs (530 to 580 nm) are not usually directly utilized in LED fixtures as these frequencies were thought to be less important for photosynthesis. However, these wavelengths have better penetration through the canopy and can be important for development and response mechanisms [12]. Light in this wavelength range are usually delivered using white (phosphor) LEDs that also augment blue wavelengths.

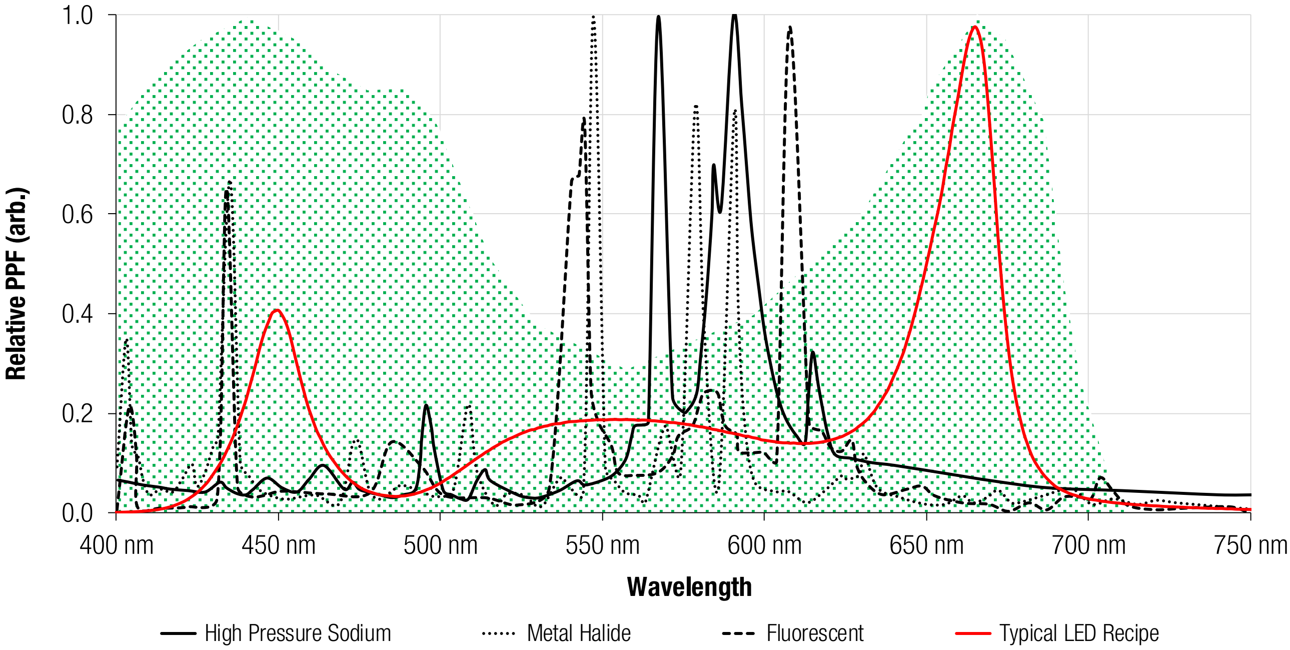


**Figure 5: Typical Emission Spectra of Light Sources used in Horticulture.**
**The green shaded area represents the action spectrum of photosynthesis meaning any peaks outside of this is wasted energy**

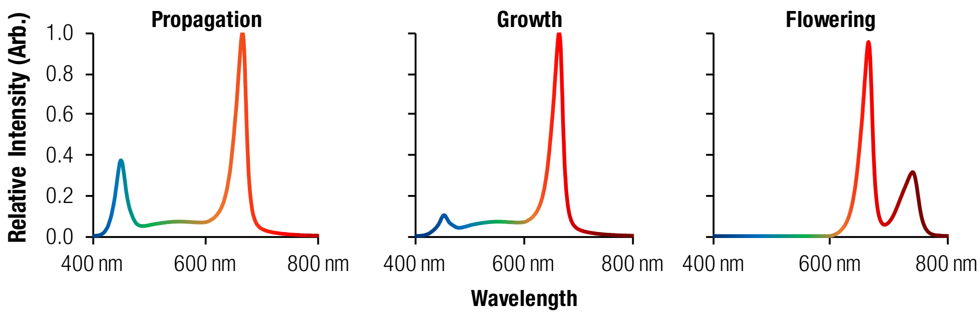


**Figure 6: Possible Light Recipes used in Different Developmental Phases of Plants**

# Application Note

## Advantages of LED Lighting in Horticultural Applications

## 5 Lifespan

When operated at appropriate temperatures, i.e. that well below the maximum operating temperature, LEDs can last for up to 60,000 hours equating to 9.1, 13.7 and 20.5 years when operated for 18, 12 and 8 hours a day respectively. This is greatly reduced when LEDs operate at higher temperatures because of ambient temperature or being driven with higher currents (Figure 7).

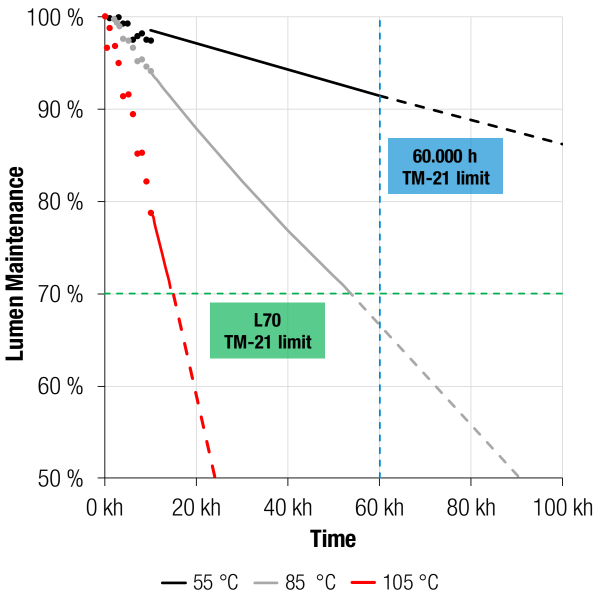


**Figure 7: Typical Lumen Maintenance of One Type of LED at Different Operating Temperatures [13]. Markers Represent Measured Data and Lines the extrapolated Lifespan as per IES TM-21. Dashed Lines Represent Predictions Beyond the Limits of TM-21**

The lower the operating temperature, the longer lifespan LEDs have. In their lifespan, LEDs can drop to around 70 % of their luminous output. However, this is highly dependent upon operating temperature.

Because of the relatively high investment needed to replace LED fixtures, it is thought LEDs will be operated to the limit of their lifespan despite the lower PPF in the end-of-life period (like HID lamps). Replacement of individual LEDs is prohibitively expensive and impractical in the field. However, the LED is often not the limiting factor. Power supplies, fans, and other components (sealings, fixtures, enclosures, etc.) in LED fixtures can fail well before the LEDs themselves. It is therefore important for any LED fixture fabricator to ensure the supporting electronics for the LEDs are designed with reliability in mind, operating well within operating limits to maximize the lifespan of the fixture to match the lifespan of the LEDs. Double-ended high-pressure sodium lamps (1000 W) have a life expectancy of 10,000 to 24,000 hours (based on manufacturer literature), or 3.7, 5.5 and 8.2 years when used an average of 18, 12 and 8 hours per day respectively. However, due to the lumen maintenance performance, it is expected a lamp will be replaced within the first five years. Replacing the bulb increases maintenance costs, due to labor and replacing the bulb. Metal halide lamps have a lifespan between 6,000 and 20,000 while fluorescent (T-5 and T-8) a lifespan of 20,000 to 36,000. Again, due to the lumen maintenance, it is expected that lamps will be replaced before this maximum is reached. A comparison of the lifespan of light sources can be seen below (Figure 8).

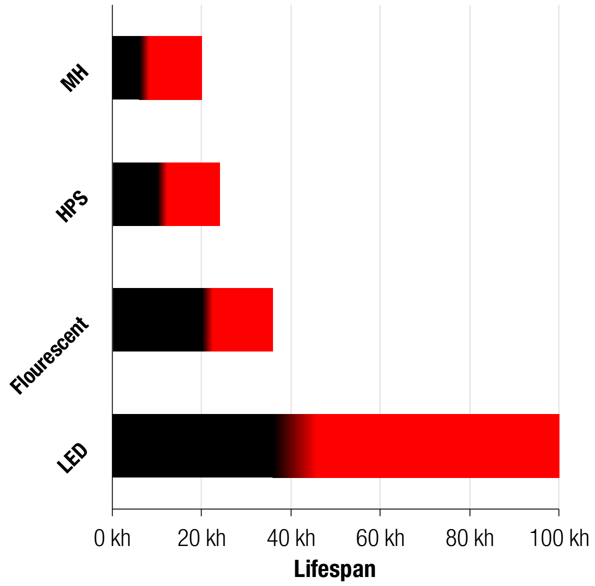


**Figure 8: Comparison of Life Eexpectancy Between Metal halide (MH), High-Pressure S(HPS), Fluorescent and LED Light Sources.**

## 6 Physical properties and environmental impact

The small size of LEDs and their fixtures, in combination with their low operating temperatures, allows them to be positioned in places HID sources cannot such as intracanopy lighting and means there is no risk of burn injuries to operators. Their low operating temperature also allows LED fixtures to be fully or partially encased which can be water and/or dust resistant. Because of their fabrication, LEDs are significantly more resistant to shock meaning less risk when handling or transporting lamps and fixtures. They do not use glass in their fabrication which can be easily damaged and cause injury. Unlike HID light sources, LEDs are RoHS compliant, which means they do not contain mercury that necessitates specialized disposal. In addition, they do not generate UV wavelengths (unless specifically added) as HID lamps can do if damaged. Because LEDs can be operated close to the canopy with a smaller emission pattern, and because they only emit the specific wavelengths used by plants they produce much less wasted light and therefore reduce energy electricity use.

# Application Note

## Advantages of LED Lighting in Horticultural Applications

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## 7 Summary

The performance of LEDs has increased enormously in recent years. When operated at an optimal temperature, with a well-designed power supply, and an optimized spectral output, LED light sources can compete with HID light sources and will surpass them in the near future. Würth Elektronik offers the WL-SMDC SMD Mono-color Ceramic LED Waterclear range of LEDs (Figure 9). The WL-SMDC range has been expanded to include wavelengths of 450 nm (Deep Blue), 660 nm (Hyper Red) and 730 nm (Far Red), which have been optimized to match the absorption spectra of photosynthetic pigments. In addition to the existing products in the WL-SMDC, WL-SMTC, WL-SUMW and WL-SIMW a diverse range of combinations is possible that can be catered to the target cultivar.

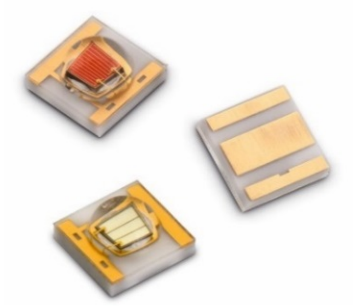

**Figure 9: Würth Elektronik WL-SMDC SMD Mono-Color Ceramic LED Waterclear**

# Application Note
## Advantages of LED Lighting in Horticultural Applications

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## A. Appendix

### A.1. Bibliography


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