

AHDB Fellowship CP 139
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Lighting: In practice







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INTRODUCTION

New lighting systems, especially Light Emitting Diodes (LEDs) have received significant interest from growers in recent years. They promise increased productivity and reduced energy use. This has driven many growers to carry out trials with commercially available lights.

This guide provides impartial information to growers about the technical specifications of horticultural lighting equipment including:

- How to compare the efficiency of different horticultural lamps.
- The installation factors that need to be considered in a commercial installation.
- The key features to consider when choosing new lighting systems.

The information in this guide is based on the results of AHDB Horticulture Project CP 139, which compared the performance of a selection of example horticultural lights. Tests were done in a UKAS accredited independent test laboratory and are described in detail in the project report.

An accompanying guide written by Dr Phillip Davis of the Stockbridge Technology Centre (Lighting: The principles) provides an insight into plant responses and complements the technical guidance provided here.

For many years, High Pressure Sodium (HPS) was considered as the best available solution for horticultural lighting. Users accepted that it had limitations, but it gives commercially acceptable performance, both in terms of plant growth and energy consumption. However, because of the limitations of HPS, there has long been a desire to develop new lamp designs that can provide superior performance.

LED is one of several technologies that promise to provide better performance. This is because:

- LEDs are viewed as being highly electrically efficient.
- They can produce light in defined spectral outputs to elicit specific plant responses.
- The heat produced by LEDs is less likely to cause environmental control problems in greenhouses.

A number of new lighting products have been made commercially available to growers. Some of these come from internationally renowned lighting companies, whilst others have come from new companies that have been set up to develop products for the horticultural market. One problem faced by growers is that there is no comparative information on these new products and how performance factors such as electrical efficiency or spectral output differ between the various designs. Therefore, making simple informed decisions on lamp selection for horticultural applications can be problematic.

This guide provides information about the current range of lights available to growers including LED, plasma and HPS. The information gives users a better insight into how the efficiency and output of the various designs differs and which features to consider when choosing a system, taking some typical units as examples. It is not designed to give comparative performance information between different systems or manufacturers.





SECTION ONE

Measuring light performance

When a grower is choosing a lighting system, the aim is to produce a more profitable crop. This might either be one with higher quality or a greater yield, and to achieve this there is a need to keep the cost of production under control.

Therefore, to be most useful, performance should be measured as **'production efficiency'**.

For a tomato grower this might be:

Yield (kg)/electricity use (kWh).

Whereas for an ornamentals grower it could be:

Number of units produced to specification/electricity use (kWh).

Unfortunately, with our current knowledge, production efficiency cannot be adopted at the present time. This is because we do not yet fully understand how different plants respond to different light sources and the specific impact of their spectral outputs.

This means that light energy efficiency is the only useful measure we currently have for comparing lamps. Further research is required to understand fully which optimal spectral outputs best drive plant growth. Until this research is conducted, growers will need to test a number of lamps under their own circumstances to determine if they have the optimal solution. As a result, most of the information in this guide focuses on energy efficiency. This approach allows a grower to choose a system that efficiently converts electricity into light.

In practice, no two lights give precisely the same spectral output, so data of the type included here will only ever be useful as guide to system selection. It cannot be over emphasised however, that response of the crop to light spectrum is fundamental and must be considered when choosing options to install.

The parallel publication to this guide (Lighting: The principles) provides guidance on how you can expect crops to respond to different light spectrums. A highly energy efficient lamp may not give you the plant shape needed for marketing, for example, which may be achieved with a different balance of light spectrum.

Measuring the output of a light and its energy use is relatively straightforward. Standard measurement methods can be used that allow different designs and models to be compared on an equivalent basis. The following section describes the measurements made in the AHDB Horticulture funded project CP 139.

Light output and spectral distribution

For horticulture, the total quantity of Photosynthetically Active Radiation (PAR) emitted between 400nm to 700nm is considered the most suitable measure of light output. This is determined by measuring the light output in 1nm waveband

steps. The unit of measurement is $Wm^{-2}nm^{-1}$. However, radiant energy is transmitted in discrete packets called photons.

The rate of photosynthesis is driven by photon receipt (between 400nm to 700nm) and not necessarily their energy level. The number of photons received is counted in μmol , 1 mol has 6×10^{23} photons. On this basis for horticultural lighting, it is now convention that W (total energy) is converted into the number of photons received and this is expressed in units of $\mu mol.m^{-2}s^{-1}nm^{-1}$.

There are two internationally recognised ways that spectral output is measured. These use either an integrating sphere or goniometer.

An integrating sphere (typically of around 1.75m to 2m diameter) is a spherical housing with a highly reflective internal coating (Figure 1). The lamp is placed inside the sphere and the light bounces in all directions creating a uniform irradiance at all points in the sphere and on a light sensor.

A goniometer is a device that measures the directional light output of a lamp and luminaire assembly and it provides a 'map' of where the light falls. To do this, it rotates the test lamp through all angles relative to a detector. By using complex data summations, the total light output can also be determined.



Figure 1. Integrating sphere

In project CP 139 a 1.8m integrating sphere at the Lighting Industry Association (LIA) laboratories in Telford was used to measure the spectral performance of a range of lights. Also a 7m goniometer at Piseo in France was used to measure the performance of the accompanying luminaires.

Energy efficiency

When measuring the performance of a light it is essential that the operating conditions of the lamp comply with the specifications of the manufacturer. Operating voltage is particularly critical, and when independent tests are done, whether it is in an integrating sphere or a goniometer, this is accurately adjusted to match those specified by the manufacturer. Sensors are also used to measure the electricity consumption of the light.

When both the amounts of light produced and the power used are known they can be used to calculate the energy efficiency of the light. Total PAR produced is used along with the lamp power input as follows:

- Light out (PAR) is measured in $\mu\text{mol s}^{-1}$.
- Power input is measured in W.
- Light efficiency = light out/electrical power input = $\mu\text{mol s}^{-1} \text{ W}^{-1}$.

As $1 \text{ W} = 1 \text{ J s}^{-1}$ the units of lamp efficiency can be stated as $\mu\text{mol/J}$. This is the universally used unit of expressing the efficiency of a horticultural light.

Example: A manufacturer states that a lamp has:

1. A photon flux output of $520 \mu\text{mol s}^{-1}$.
2. A power consumption of 200W.

Lamp efficiency is calculated as 1. divided by 2. or $520 / 200 = 2.6 \mu\text{mol/J}$ in this case.

Summary

- Based on our current understanding of plant responses to different light spectra it is not possible to measure the true efficiency of a plant lighting system.
- Using light unit efficiency in $\mu\text{mol/J}$ is the current best compromise. However, this only measures the efficiency of a light to convert electricity into PAR. It takes no account of the response of the crop.





SECTION TWO

Equipment selection – lamps and luminaires

Lamps – HPS v LEDs and plasma

HPS

The most commonly used light in horticulture is the HPS lamp. Commercial installations usually use 400W, 600W or 1,000W lamps. Detailed information about HPS lamps, their characteristics and how to maximise their operating efficiency is given in the AHDB Horticulture grower guide 'Supplementary lighting: Equipment selection, installation, operation and maintenance', 2001. An electronic version of this guide is available on the AHDB Horticulture website.

HPS works by generating an electrical arc between two electrodes that are mounted inside the glass envelope of the lamp. The colour of the light produced, and therefore, its spectral distribution, is a function of the metallic compounds within the plasma of the arc.

In order to operate, HPS lamps need to be used in a fitting (known as a luminaire) that houses a number of electrical or electronic components. These components stabilise the electrical current passing into the arc. Collectively, these components are commonly called the ballast.

Older HPS luminaires use electromagnetic ballasts whereas the latest designs use fully electronic ballasts. Electronic ballasts are more efficient.

LED

LED lamps work by passing electricity through a semiconductor, which releases energy in the form of photons. Originally invented in 1927, LEDs have only recently received significant commercial interest. Like many electronic and semiconductor technologies, the recent rate of development of LEDs has been rapid. Efficiency and cost improvements in the last few years have accelerated the commercial uptake of LED lighting.

The waveband at which light is emitted is dependent on the chemical composition of the semiconducting material within the LED. Individual semiconductors emit monochromatic light and arrays of chips are used to achieve different colours. These emit a blend of different monochromatic wavebands that are typically red, green and blue (known as RGB). Alternatively, phosphor coatings are used to absorb blue light and fluoresce it into 'white wavebands'. However, whilst using phosphor coatings creates a more balanced spectral output, it is at the expense of efficiency.

Commercially available horticultural LEDs use a range of approaches to generate light, some use a combination of different monochromatic colours (often, just blue and red) whilst others use phosphors to generate a more balanced spectrum.

The process of electroluminescence is still relatively inefficient and wasted energy is converted into heat. This heat energy warms the semiconductor and reduces the efficiency of the light production. LED light output decreases with operating temperature. Manufacturers typically quote efficiencies at 25°C, but the actual semiconductor temperature can warm to between 60°C and 80°C. These higher temperatures can give losses of >10%. Large-scale LED arrays, as used for horticultural purposes, are therefore designed with large heat sinks to remove heat away from the semiconductors. They may even have fan assisted ventilation systems, but the energy used to power the fan can reduce the overall efficiency of the light.

All LED lighting systems operate using direct current (DC), but nearly all greenhouse electrical systems operate off alternating current (AC) driven power systems. Within the luminaire the electronics will therefore include an AC to DC rectifier. The power conversion process from AC to DC can lead to some energy losses of up to 7%, depending upon the system applied.

Plasma

Plasma lamps operate differently again and they generate light by exciting plasma inside a closed transparent burner (or bulb) using radio frequency (RF) power. The plasma can heat up to very high temperatures and produce a near solar spectral output. The photograph of the integrating sphere shown (Figure 1) demonstrates a plasma lamp under test conditions at the Lighting Industry Association (LIA), this shows a very 'white light'. The colour is similar to sunlight as the plasma bulb operates at an extremely high temperature (c. 5,000K), which is close to the temperature of the surface of the Sun (5,778K).

Summary

- New lamp designs are now commercially available and can be used as an alternative to HPS for horticultural lighting applications.
- Because of the way they operate, designs like LED and Plasma can produce spectral outputs that are not available from HPS.
- More R&D is needed to give a better and complete understanding of how different crops respond to the different parts of the light spectrum.

Luminaires

The luminaire is the 'light fitting' which holds the components that make an electrical light operate. It also holds the reflector or lens that directs the light generated by the 'light bulb' towards the area that needs to be lit.

With traditional designs like HPS, the luminaire holds a bulb mounting device (such as a screw fitting) to allow the bulb to be removed and replaced. With new lighting technology like LED, the luminaire and the light source are usually designed as one integrated unit.

Work on HPS units suggests that luminaire light output can vary by up to 25% and the design of the reflector, its coating and how light is reflected back onto the arc of the lamp all affect performance. Light reflected back into the lamp will also reduce the efficiency and life of an HPS lamp.

Good luminaire design is therefore critical to ensure that the light emitted by the light source is fully targeted upon the crop. Luminaires vary hugely in their shape and design, and with traditional light sources like HPS, the shape of the reflector has to be chosen with the application in mind. Too wide a dispersal of light can reduce efficiency whereas too narrow a dispersal will give 'hot spots' of high light intensity within a crop. Good manufacturers have a range of luminaire designs to suit a wide range of applications.

A commonly used measure of luminaire efficiency is the downward light output ratio (DLOR). This quantifies the proportion of light produced by the light source reaching the target plane. For example, if the DLOR is 0.7, 70% of the light from the bulb reaches the target horizontal plane. This measure is far from perfect for horticulture (especially when lighting vine crops like tomatoes), but it does give a way to make comparative assessments. Some manufacturers of HPS luminaires quote DLOR figures of up to 0.96, indicating that very little light is wasted by the best designs.

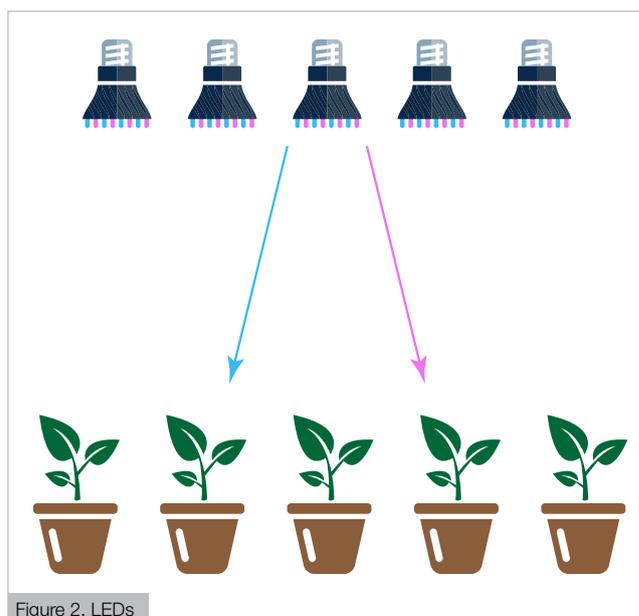
Some LEDs use an optical lens after the light has been generated. This focuses the light into specific areas. However, multiple internal reflections of light through the optics can reduce the efficiency of the unit, and the optics can have a significant impact on the performance of the luminaire. The directional light output cone is a key luminaire selection criterion.

LEDs – the efficiency of light and luminaire assembly

As previously highlighted, LEDs are normally designed as an integral light and luminaire assembly. This means that two aspects are important with this design of lamp:

1. The efficiency of the LED itself.
2. How well the LED and its fixture work together.

A poorly designed fixture that uses the best LEDs will suffer from poor performance, so it is vital that the performance of the lamp and luminaire assembly is considered when comparing the various options for an installation.



Summary

- Traditional light designs like HPS use luminaires that allow lamp removal for replacement, cleaning etc. Here the luminaire houses all of the components needed for lamp operation. The shape of the luminaire's reflector is matched to how it is used in the greenhouse.
- LEDs and plasma have an integrated light and luminaire assembly. This means that lamps are not normally interchangeable or replaceable.
- Some designs of LEDs use a lens to direct and concentrate the light produced to a specific area. This helps to stop stray light but it can affect the overall light production efficiency of the unit.
- With LEDs and plasma, it is important to assess the overall efficiency of the lamp and luminaire as a single unit. This is different to HPS where the lamp and luminaire can be assessed separately.



SECTION THREE

Installation requirements

As highlighted in the previous section, to get the rated output from a light, it is important that the electricity used to power it is supplied within operating tolerances that are specified by the manufacturer. If these conditions are not met, the consequences are that the light output will be reduced and the efficiency will suffer. In the extreme, the installation may even be dangerous.

The most important factors are as follows:

Electrical supply voltage

Electricity supply voltage in the UK is the same as the rest of Europe and it is 230V single phase or 400V three phase. The electricity supply regulations allow for a tolerance on this nominal voltage of -6%/+10% and electricity suppliers are legally obliged to ensure that all supplies meet this requirement at the point of supply to a site.

In addition to this variation in voltage at the point of supply, the length and size of the cables running from the electricity company point of supply to the lighting installation can also affect the voltage. Conventional electrical wiring design allows for a voltage drop between the site main switch and the farthest electrical connection point. This means that, when taken in combination with the statutory electrical supply tolerance, a nominal 400V supply may be as low as 361V at the farthest point on a lighting system (ie a 10% reduction on the nominal supply voltage). This reduced voltage has implications on system output and efficiency.

The output of an HPS lamp is particularly sensitive to supply voltage, and a 1% drop in voltage gives a 3% reduction in light output. This means that a luminaire at the farthest point on a lighting system may be delivering as much as 30% below its rated output.

On the other hand, LEDs are far less affected by variations in supply voltage. This is because the internal electronics used in LED fittings compensate for voltage variations. A typical specification from a leading LED manufacturer is that the fitting will operate safely within +/-15% of the nominal voltage (230/400V). This means that, so long as conventional wiring design principles are correctly applied, LED lighting installations are less likely to suffer from the variations in light output and efficiency that are commonly seen in installations with HPS.

Power factor

Power factor is important when considering the electrical wiring requirements of a lighting installation. Power factor is the ratio of working power (W) to apparent power (Va) and it ranges from 0 to 1. The energy actually used and consumed by a lamp is the working power; the apparent power is the

sum of the working power plus any reactive power, typically generated by inductive loads. Inductive loads require electrical current to generate a magnetic field, enabling some types of lamp such as HPS to operate. However, the only energy consumed is the working power.

An inherent characteristic of HPS lamps is that they have a significant inductive load and therefore a low power factor. Even though some HPS luminaires include internal components to correct the power factor, values of around 0.8 are typical for commercial installations. This low power factor impacts in two ways:

- Cables must be sized to allow for the inductive loads that are imposed by the lights. If cable sizes are not adequate, the system will be overloaded and output reduced. An overloaded electrical system can also be dangerous.
- Some electricity contracts have a pricing structure that includes costs for the apparent power (kVa) demand on the supply. In these circumstances, the running costs of systems with a low power factor can be higher than necessary. The solution is to ensure that power factor correction equipment is installed so that the operational power factor on the electricity supply is as close to 1 as possible.

One of the advantages of novel lighting equipment is that many have high power factors. Values of around 0.95 are common for LED luminaires. This eliminates the problems that occur with designing cabling requirements for an installation of HPS lights.

Useful life and light output depreciation

Manufacturers of LEDs claim that an advantage of their equipment is it has a longer life than traditional solutions like HPS.

Depending on how many times the lamp is turned on and off, HPS typically lasts around 15,000 hours. However, because of depreciation in the light output and the need to maintain a uniform light distribution, the normal recommendation is to replace lamps after 10,000 hours. After this time the light output of the lamp has usually reduced to 90% of its rated output. HPS luminaires have a longer life than this, and it is normal to expect the luminaire to last 25,000 to 30,000 hours. However, care must be taken to ensure that the internal components (particularly the capacitor) do not suffer catastrophic failure.

When the specification of an LED luminaire is compared to HPS there are clear advantages. Most notably LEDs claim to have a life of 25,000 hours after which the light output has only degraded to 95% of the rated 'as new' output. The in-service experience with LEDs is currently not sufficient to justify these claims, however, the expectation is that LED installations will maintain their design output for longer than HPS.

A word about heating

LEDs produce far less radiant heat than HPS, so care must be taken when using them as an HPS replacement.

The radiant heat from HPS heats the crop and studies have shown HPS lighting maintains a warmer crop leaf temperature than LED lighting with the same light output. In some Dutch studies, higher air temperatures have been used to compensate for the reduced radiant heating. This additional heating must be considered when examining the overall energy efficiency of an LED system compared to HPS, including the suitability of increased air temperature to substitute for the direct radiant heating effect of HPS lamps on plant tissues.

Also, consideration must be given to the heating arrangement used in the greenhouse to ensure that any additional heat can be effectively supplied to the crop. From a cost perspective, heating energy generated by boilers tends to be cheaper per kWh than electricity.

Summary

- The light output of LEDs drops less than HPS when the supply voltage is reduced.
- LEDs have a higher power factor than uncorrected HPS lamps. This makes the installation of an LED system potentially less problematic than one based on HPS lamps.
- Manufacturers' data indicates that the useful life of LEDs is longer than HPS. However, because commercial LED installations on nurseries are still relatively new, there is currently no practical data to confirm the manufacturers' claims.
- The light output of an LED over its working life will depreciate less than HPS. Again, this can only be assessed from the manufacturers' data as there is sufficient in-service information from growers to confirm the claims.
- Because LEDs produce less radiant heat than HPS, plant temperature under LED lighting will usually be less than under HPS lighting. Additional heating may therefore be needed to redress this.





SECTION FOUR

Performance – currently available commercial systems

Seven different commercially available LED, plasma and HPS lighting systems were tested in project CP 139. The objective of these tests was to indicate to growers how performance might vary between some examples of current commercial horticultural lighting hardware in order for them to undertake their own informed comparisons of lamp technical data provided by suppliers¹.

The study **was not** designed to be a comprehensive side-by-side test of different equipment from different manufacturers. The lights tested were simply a selection of units kindly loaned to the project for tests to be undertaken. These lights also had very different spectral outputs and it is therefore misleading to take this information as a valid simple side-by-side comparison. The inclusion of a HPS light in the tests provides comparative data for units that growers will be more familiar with, including a reference point for energy efficiency ($\mu\text{mol}/\text{J}$).

The tests were conducted at the LIA independent testing in Telford in March and April 2015, UK using a 1.8m integrating sphere. Three lamps were also sent to the Piseo lab in France, where the performance of their luminaires were measured using a 7m goniophotometer.

Light output and efficiency

The results of the tests are summarised in Appendix One.

The results show the performance range and how new technologies like LED and plasma compare to HPS. For example, three of the tested LEDs are more efficient at producing PAR than the benchmark HPS, whereas two LEDs and the plasma are less efficient. However, and particularly in the case of the plasma, the spectral output of the lights must be taken into consideration. For example, the plasma has a whole spectrum output closely matched to the solar spectrum rather than a more limited output from the HPS. This also applies to the LEDs with lower $\mu\text{mol}/\text{J}$ values than HPS.

Appendix One also provides information on luminaire weight. This is an important consideration as heavy lighting units can potentially cause problems with the overloading of the greenhouse structure. Low weight units with a high efficiency are therefore desirable.

Lamp selection for a commercial installation will depend on many considerations including capital costs, running cost, electrical requirement etc. Growers who are interested in the application of LEDs should therefore investigate a number of potential options so that the equipment matches to their own circumstances. Good manufacturers can provide their own independently verified data on light output performance. This will enable growers to compare actual performance to example figures.

Spectral distribution

Appendix One shows the spectral distribution of the lights in the test. All five LEDs show peaks in the blue and red spectral regions at circa 450nm and 660nm. One LED has some output between 500nm and 600nm suggesting a phosphor coating has been applied to produce a wider range of spectral outputs. Another unit has a large peak of blue (450nm) plus two red peaks including one of 634nm. There is also a green peak at 511nm. The plasma lamp has a spectral output well matched to a solar spectrum.

There is clearly a need to test the impact of different lamp spectral outputs on crops grown under glasshouse conditions and this is being investigated within the AHDB Horticulture funded project CP 125. A considerable amount of work is also going on around the world including grower trials that are being done in partnership with lighting suppliers. This will be key knowledge required to underpin the development of LEDs for the horticultural industry.

Light distribution

Goniophotometer data is useful for checking light distribution of a luminaire. Each of the lighting units is designed with a consideration as to how they can be laid out in a full greenhouse array. The plasma shows a peak direction output at around 40 degrees, and a square spatial distribution on the horizontal floor. This suggests the units will be laid on a square grid within the greenhouse. The HPS unit has a batwing distribution indicating they are designed to have a wide spread across a greenhouse bay, but will be mounted in close proximity along the bay. The LED unit 4 has an almost circular distribution; this suggests they need to be located close together to achieve an even light distribution (Appendix Two).

¹ AHDB Horticulture is grateful for the contribution of the manufacturers that provide the lights tested in project CP 139.

APPENDIX ONE

Summary results from Project CP 139

	Spectral distribution diagram	PAR efficiency ($\mu\text{mol/J}$)	Power factor	Radiant power/unit weight (W/kg)
LED 1		1.44	0.96	20.1
LED 2		1.27	0.92	5.3
LED 3		2.43	0.97	14.4
LED 4		2.71	0.99	26.3

Figure 3.

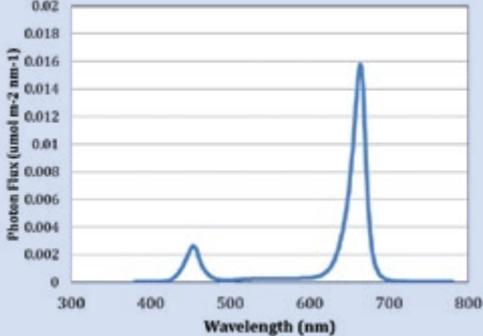
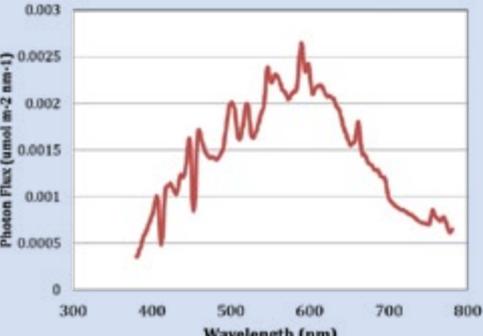
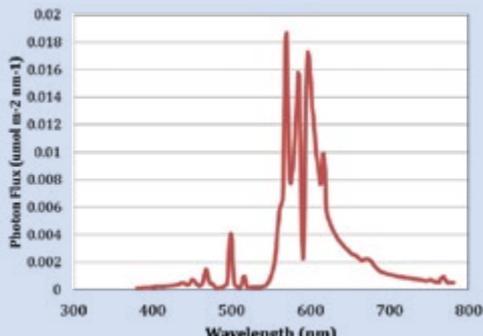
	Spectral distribution diagram	PAR efficiency (μmol/J)	Power factor	Radiant power/unit weight (W/kg)
LED 5		2.56	0.98	27.7
Plasma		1.16	0.98	5.5
HPS		1.92	0.81	31.3

Figure 3. continued

APPENDIX TWO

Example light distribution plots

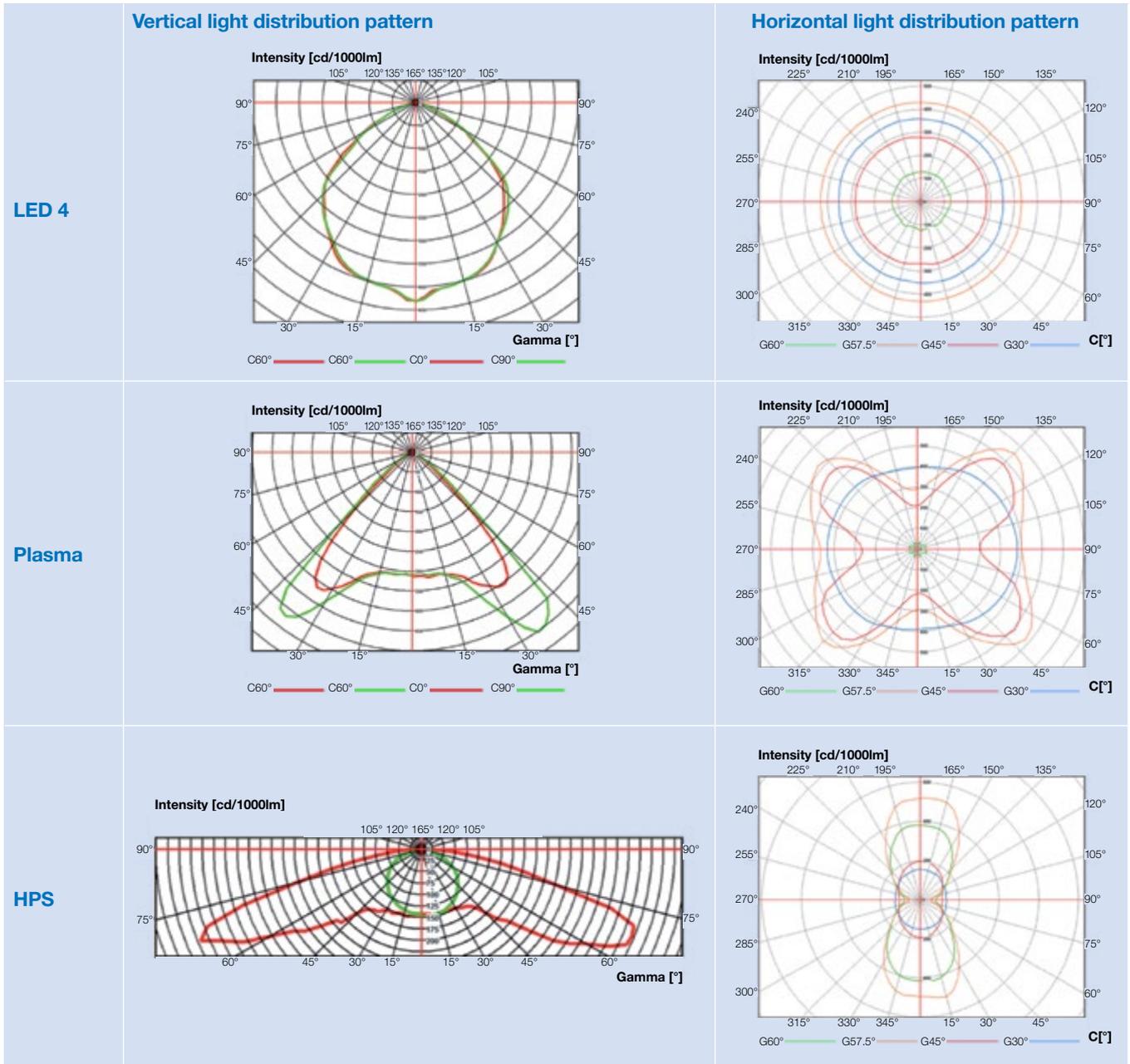


Figure 4.

APPENDIX THREE

Terms and units

When considering horticultural lighting systems it is important to understand the differences between the concepts of radiant energy, luminous energy and photosynthetically active energy. The principle terms are described below:

Nanometer (nm) is the unit to describe the wavelength of electromagnetic energy.

Photon is a packet of electromagnetic energy. The energy contained within a photon is a function of the wavelength of the photon, blue light is more energy intensive per photon than red light for example. The rate of photosynthesis is considered to be dependent upon the number of incident photons, not the energy contained within them. As the number of photons in light is extremely large they are usually counted in mol (6×10^{23} photons).

Irradiation is the noun used to describe light as a form of electromagnetic energy.

Radiant energy is the energy emitted, transferred or received in the form of electromagnetic radiation. The unit of radiant energy is the joule (J). For plants the photosynthetically active radiation is considered to be between 400nm to 700nm.

Radiant flux is the rate of flow of energy, this is usually described in Watts (W) which is one joule per second.

Irradiance is the flux received per unit of area (usually 1m^2), so the unit is W/m^2 .

Photosynthetically active radiation (PAR) is the number of photons between 400nm to 700nm, which fall upon a unit of surface area over a fixed amount of time, and units are $\mu\text{mol m}^{-2}\text{s}^{-1}$.

Photosynthetic efficiency is the efficiency of a lamp in converting input electrical energy to photosynthetically active radiation (400nm to 700nm) and its units are $\mu\text{mol}/\text{J}$.



Want to know more?

If you want more information about AHDB Horticulture, or are interested in joining our associate scheme, you can contact us in the following ways...

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