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Contents

Summary

New lighting systems have received significant interest from growers in recent years with many undertaking trials of specific products, often LED lamps. This technology offers new options and also challenges including the need to understand light and how lamps supply this from a new perspective.

This project was designed to provide impartial support to growers by highlighting technical specifications of lamps which will underpin choice of products to install including:-

- Efficiency of electrical input to light output of example lamp units
- Practical installation factors such as
  - arrangement of lamps in the glasshouse in relation to the distribution of light output
  - light output per unit weight of a lamp
- Explanation of key features to consider when choosing new lighting systems including power factor, electrical supply voltage, life/depreciation of units.

The performance of some example systems was measured in a UKAS accredited independent test laboratory to provide some typical information. This publication does not provide a comprehensive overview of all lamps on the market and is not designed to make recommendations on which system a grower should select. However, we hope the understanding provided will enable growers to make more informed choices.

With the new flexibility that LED lights now offer to alter light spectrum growers also need to refresh their understanding of how plants respond to different wavelengths of light. A technical report written by Dr Phillip Davis with the AHDB project CP 085 provides complimentary information to the technology focused information provided within this report by outlining our current understanding of plant light responses to the different wavelengths of light.

Novel Lighting Systems

The rapid development of high intensity supplementary lighting systems, including the availability of LED's, has created new opportunities for the use of artificial light in UK horticulture. In particular, LED lighting systems are viewed as being highly electrically efficient, potentially reducing the energy use of supplementary photosynthetic illumination. They may also offer defined spectral outputs to elicit specific plant responses.

A number of new lighting systems have been made available to the horticultural industry, primarily by Philips and European manufacturers, but also Phytolux in the UK. However, there is no comparative information on new lighting system electrical efficiencies or spectral outputs.

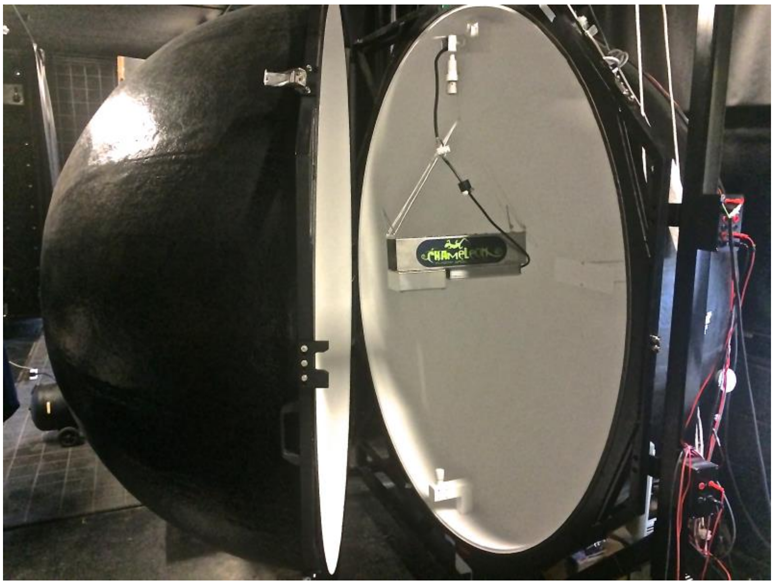
There is also no comparative information on the impact of their luminaires. It is therefore highly problematic to make simple informed decisions on lamp selection for horticultural application.

The global lighting industry is also innovating at a very high rate. A large number of new lighting systems are emerging onto the global market, these include very high light output LED arrays (used for street lights), new luminaires for LEDs (designed as heat sinks), new LED lights (wider colour outputs) and new discharge lamps including induction and plasma lamps. Notably, induction and plasma lamps have spectral outputs closely aligned to the solar spectra.

This report provides a review of the current LED and plasma systems which are emerging onto the horticulture sector market. These novel lighting systems are benchmarked to a 600W high pressure sodium source as an example of a lamp regularly used by growers. It therefore provides the basis for growers to compare different lighting systems. It also provides underpinning insight to help the selection of any type of lighting systems which may be on or about to enter the market.

Measuring Performance of Lighting Systems: Integrating sphere, goniometers

There are two internationally recognized approaches to measure the spectral output and electrical efficiency of a light source; by using either an integrating sphere or goniometer. The integrating sphere typically has a very large diameter and is coated with a highly reflective coating (photograph below). 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 detector. A goniometer, up to 8m in length is a device, which rotates a lamp steadily through space and at all angles relative to a detector. The goniometer can therefore accurately measure the directional light output of any lamp and luminaire. It gives a very accurate mapping of where the light falls from a lamp, and by complex mathematical integrations can also be used to measure total light output and efficiency. In this project, a 1.8m calibrated integrating sphere, held at the LIA laboratories in Telford was used to measure lamp spectral performance and energy efficiency. For luminaire performance, a 7m goniometer at Piseo in France was applied. Both laboratories are audited to international standards and at the LIA the calibrated lamps are NPL (National Physics Laboratory) accredited.



A plasma lamp inside a 1.8m integrating sphere at the LIA laboratory.

Lamp performance measurements

The key operational potential of a light unit is judged from its spectral output. Spectral output of a lamp is typically measured in 1nm waveband steps and provided as $Wm^{-2}nm^{-1}$. Data are then converted to $\mu mol.m^{-2}s^{-1}nm^{-1}$, and the total quantity of photosynthetically active light emitted between 400nm to 700nm determined. Very accurate measurements of lamps electrical performance are also required; this includes data on operating voltage and current, as well as the power factor of the lamp.

Power Factor

Power factor is important when considering the electrical wiring requirements of a lighting installation. Power factor is the ratio of working power (kW) to apparent power (kVa) 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 commercially available equipment. This low power factor impacts on commercial lighting installations in two ways;

- Cables must be sized to allow for the inductive loads that are imposed by the luminaires. If cable sizes are not adequate, the system will be overloaded and light 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 c0.95 are common for LED luminaires. This eliminates the problems that occur with HPS distribution design and simplify the cabling requirements for an installation. Running costs can also be reduced where a site is supplied on an electricity contract that has a kVa maximum demand component.

Electrical Supply Voltage

Electricity supply voltage tolerance in the UK is the same as the rest of Europe and it is 230V/400V; -6%/+10%. Electricity suppliers are legally obliged to ensure that all supplies meet this requirement at the point of supply to a site.

In addition, the voltage on a lighting installation will vary depending on the length and size of the cables running from the electricity company point of supply to the lighting installation. 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 (i.e. a 10% reduction on the nominal supply voltage)

The photon flux output of an HPS lamp is sensitive to supply voltage and a 1% drop in voltage can lead to 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 the rated light output.

LED's are far less affected by variations in supply voltage as the internal electronic drivers used in the luminaires compensate for voltage variations. A typical specification from a leading LED manufacturer is that the luminaire 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 therefore efficiency that are commonly seen on installations with HPS.

Luminaire life and light output depreciation

The manufacturers of LED's claim that a key advantage of their equipment is it has a longer useful life than traditional solutions like HPS.

Depending on how many times they are turned on and off, HPS lamps typically last 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 of operation. After this time the light output of the lamp has normally reduced to 90% of its rated output. HPS luminaires have a longer life than this, and it's normal to expect the luminaire to last 25 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 LED luminaires is compared to HPS there are clear advantages. Most notably LED's 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. Unfortunately the in-service experience with LED's is currently not sufficient to justify these claims. However, the expectation is that LED installations will maintain their design output for longer than HPS.

Measuring the efficiency of a light source

By convention, to measure the electrical efficiency of a lamp the light output is divided by the measured working power only, and this is determined for horticultural uses as μmol / J, where μmol is from 400 to 700nm (see Appendix for an overview of lighting units). In household lighting the typical measure is lumen / J, where the lumen spectrum is weighted to the spectral response of the human eye. Although μmol / J gives a guide on light output of a lamp, it must be cautioned that this may not necessarily be correlated to the performance of a crop or plant. Plants have complex reactions to spectral quality, which are not well known, and these may have positive or negative effects relative to any measured lamp electrical efficiency.

Energy efficiency of light sources

Two aspects of energy efficiency are important to consider: the efficiency of the LED device itself (source efficacy); and how well the device and fixture work together in providing the necessary lighting (luminaire efficacy). How much electricity is used to generate light depends not only on the LED device, but also on the lighting fixture design. The efficiency of a poorly designed fixture that uses even the best LEDs will be only a fraction of what it would be if the luminaire were well designed. Prior work on HPS units suggests that luminaire light output can vary by up to 25% depending upon brand of manufacturer (Both et al., 1997, Acta Hort, 418, 195-202). Variances of efficiency are caused by the design of the reflector, its coating and for HPS whether it redirects light back onto the arc of the lamp per se. High HPS arc temperatures from reflected light will reduce the efficiency of the lamp.

Discharge Lamps, LEDs and Plasma

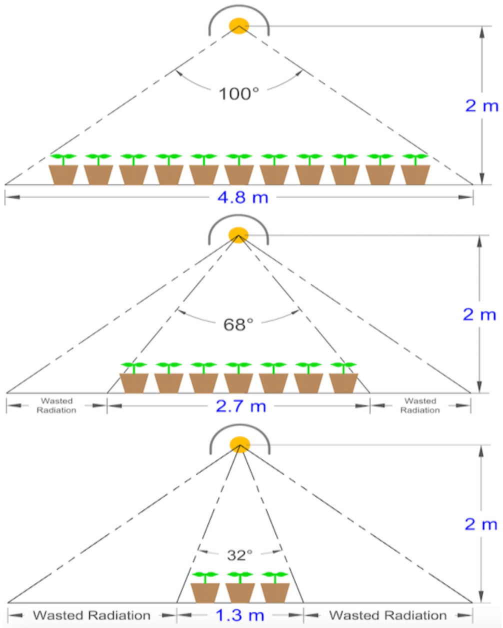
There are now very diverse ranges of lighting technologies, which have been applied to horticultural use. The most common system is the high-pressure sodium (SON/T or HPS lamp). These are typically employed at lamp wattages between 400 and 1000W (often 600W). High intensity discharge lamps such as HPS lamps generate an electrical arc between two electrodes; the colour of the lamp is a function of the metallic compounds within the plasma of the arc. HPS lamps need a ballast to stabilize the current passing into the arc, and these now tend to be electronic. Electronic ballasts are more efficient than older magnetic components. HPS lamps can loose c. 5% of their efficiency after 10,000 hours of illumination (source Philips Lighting Guide).

There are now a considerable number of LED light sources entering the market. They all work by emitting light through the process of electroluminescence, where electrons passing through a semi conductor release energy in the form of photons. LEDs were originally invented in 1927, but have only recently received significant interest in Horticulture. The rate of LED efficiency improvements has been described by Haitz’s law, which states that every decade, the cost per lumen will fall by a factor of 10, and the amount of light generated per LED package increases by a factor of 20, for a given wavelength of light. This is analogous to Moore's law, which states that the number of transistors in a given integrated circuit (computer power) doubles every 18 to 24 months. On this basis, we are likely to see significant efficiency (and cost) improvements in LED technology over the foreseeable future. Technological improvements will be via new developments in semiconductors, power electronics, power distribution systems and luminaire/optic design.

The waveband at which light is emitted is influenced by the chemical composition of the semiconducting material within the LED. Individual semiconductors emit monochromatic light. Different colours are achieved by building arrays of chips which either emit a blend of different monochromatic wavebands (typically red: green: blue, RGB), or they may also use phosphor coatings which absorb blue light and fluoresce it into longer and a wide band of "white wavebands". The use of phosphor coatings to create a more balanced "white" light is at the expense of efficiency; the florescence process will use some energy and a proportion of the photons will be fluoresced backwards into the electrical components of the luminaire. Horticultural LED systems use a range of approaches to generate light, some use a combination of different monochromatic colours (often just two, blue and red) others use phosphors to generate a more balanced spectrum.

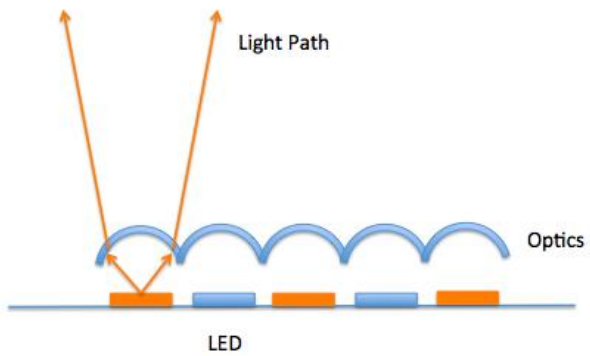
The process of electroluminescence is still relatively inefficient and any wasted energy is converted into heat. This heat energy will warm the semiconductor which reduces the efficiency of the light. LED light output decreases with operating temperature; efficiencies are often stated at a measured temperature of 25ºC but the actual semiconductor temperature can warm to between 60 and 80ºC with an efficiency loss of >10%. Large-scale LED arrays, as used for horticultural purposes, are therefore designed with large heat sinks, to pull energy away from the semiconductors. They may even have fan assisted ventilation systems, although these can also impact on energy consumption. Fans are also a moving part which may require maintenance. Consistent high semiconductor temperature therefore reduces the light output of the LED (by up to 15%). High LED semiconductor temperatures also reduces the life of the LED, a white paper by Lumiled (LED designers) and Philips (http://www.ledjournal.com/main/wp-content/uploads/2012/05/Philips_Understanding-Power-LED-Lifetime-Analysis.pdf) suggests life of an LED can more than double if semiconductor temperature is reduced from 135 to 115ºC. However, LED longevity is considered to be very good, and typical life times of 25,000 hours are reported.

LEDs differ from HPS lamps in that they have a far lower total radiant output; the energy conversion losses from LEDs tend to be via heat generation within the semiconductor components and electronics. HPS lamps operate at very high temperatures and also loose significant amounts of energy at non PAR , near infra red and long wavelengths. Thus when substituting LED's for HPS, care must be taken to understand that the radiation energy balance of the crop is likely to change. For LED's most of the downward radiation load will be in the 400 to 700nm wavebands. LED's do not emit near infra radiation and operate at a lower temperature than HPS thereby reducing the downward thermal energy load onto the crop. This radiation also heats the crop and studies have consistently shown that for equivalent PAR irradiances, HPS lighting maintains a warmer crop leaf temperature than LED lighting. In many Dutch studies to compensate for the reduced output of radiant heat, higher air temperatures have been used to represent the HPS radiation effect. This increased thermal energy input should be considered when examining the overall energy efficiency of an LED compared to HPS system. However, thermal energy generated through boilers tends to be cheaper per kWh than electricity. Lower plant temperatures can reduce the rate of plant development and slow down leaf production, fruiting and flower durations. These impacts have been consistently noted in studies comparing LEDs to HPS lights. For instance, Dueck et al. (2011, Acta Hort 952, pp 335-52) reported an up to 1.5°C reduction in leaf temperature of tomatoes when grown under LED's compared to HPS. These impacts may cause a slight delay in developmental responses, for example Dueck et al (Greensys 2015, in press) noticed a 3 to 5 day delay in response time of chrysanthemums grown under LED's rather than HPS.



All LED lighting systems operate using DC current, but nearly all greenhouse electrical systems operate off 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.

After the light has been generated many LEDs use an optical lens to focus the radiation emitted into specific areas. Multiple internal reflections of light through the optics will reduce the light output 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; some luminaires are designed to have very focused light distribution systems, other broadcast the light over wide planes. If light is broadcast too widely within a greenhouse, it may not be incident on the crop or will pass through the walls of a glasshouse. Light focused too narrowly may lead to uneven growth response issues.



Plasma lamps operate slightly differently to HPS units, 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.

Luminaires

Luminaire efficiency is the second key facet of lighting system design and efficiency. Analogous to the optical arrangement of the LED, the luminaire design is critical to ensure emitted light is fully incident upon the crop, and is also not absorbed by the luminaire. Luminaire efficiency is often measured as the downward light output ratio (DLOR), which quantifies the proportion of light produced by the light source reaches the target plane. For example if the DLOR is 0.7, 70% of the light from the source reaches the target horizontal plane. Whilst this measure is far from perfect for horticulture (especially if you are lighting vine crops), it does give a way to make comparative assessments. Recently, reflector efficiencies of up to 96% are reported by manufacturers. Luminaires vary hugely in their shape and design. Too wide a dispersal of light can reduce unit efficiency, too narrow a dispersal can lead to “hot spot zones” of high light within a crop. Good manufacturers should have an excellent characterization of their luminaire performance and will seek to use mathematical models to develop optimal lighting system layout corresponding to the light distribution patterns required.

Current Systems on the Market

The performance of seven different commercially available LED, plasma and HPS lighting systems were reviewed to provide an indication of the type of variation to expect between units and therefore a better idea of the type of performance data to consider when purchasing lighting equipment. This study **is not** designed as a comprehensive overview of all available equipment, which is being constantly refined by manufacturers. We are therefore very grateful for the participation of the manufacturers for supplying their equipment and allowing the tests to be conducted. A number of manufacturers were, for various reasons, not able to supply equipment for independent testing. A number of other light sources e.g. xeon lamps, metal halide solutions, other forms of induction or plasma lamps may also be available for growers to purchase in future but at the time of this study (May 2015), their manufacturers were not considering them for horticultural applications.

The tests were conducted at the LIA independent testing in Telford (March / 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.

The data produced from these tests are presented as a series of data files at the end of this report. There is no attempt to rank the individual units using these data because actual lamp selection will depend on many grower and lamp manufacturer considerations, including potential benefits compared to the cost, capital costs, electrical requirement etc. and the units provided are one off examples not a comprehensive set of units from all possible suppliers. We reiterate that the aim of the study was to provide growers with some indication of the type of data they should be looking for their lamp manufacturer to provide. Growers who are interested in the application of LEDs should try a number of potential options so that the equipment is matched to their own circumstances. Good manufacturers should be able to provide their own independently verified data (from an accredited test laboratory) on light output efficiency (µmol / J), light spectral output from 400 to 700nm and details of the luminaire distribution patterns. These manufacturers should then be able to specify the wiring installation and luminaire spatial distribution. However, the acid test for a grower will be to understand the reactions of their own crops to the light spectral distribution of a particular lamp.

In terms of the data gathered here, the wide variation between lamps can be seen from the overview data in table 1 below. The inclusion of a SONT unit in these tests provides comparative data for units growers will be more familiar with, including a reference point for energy efficiency (µmol/J).

Light output efficiency varies between 1.16 to 2.71 µmol / J, with the benchmark HPS/SON/T performing at 1.92 µmol / J. The lowest efficiency was reported for the plasma lamp (1.16), however, this has a distinct spectral output closely matched to the solar spectrum. There have been few if any studies comparing the growth of plants under plasma lamps compared to HPS or LED's and so to date it is not clear whether spectral benefits outweigh the efficiency reduction in the lamp in µmol / J. Similarly, there were LED's with efficiency outputs lower than the HPS control, though again these have been designed to deliver specific spectral outputs.

Data are also provided on unit weight, this will be a key criteria in terms of the glasshouse structural implications of the lamp weight loading. These structural implications need to be carefully considered prior to any installation. In terms of the devices tested here unit mass varied between 3.5 (Unit 4 and 5) to 12.3kg (unit 3), units 4 and 5 had radiant powers / kg (a measure of light output per unit of luminaire mass) of 26.3 to 27.7 W per kg, this compares well with SON/T lamps which still have the highest radiant power kg of 31.3 W per kg.

The lamp voltages vary between 200 and 423V, reflecting whether a unit has been designed for 3 phase (typically 410 to 420V) or single phase power (typically 240V). The lamps' power represents the total load of the lamp (both inductive and working). The power factor represents the proportion of the load which is actually working to drive the lamp. The data confirms that LED's have high power factors (0.92 to 0.99) compared to a SONT/T at 0.81. The plasma lamp also has a high power factor of 0.98.

Table 1. Overview data from LIA testing of some example lamp units (More detail is given in Appendix 1)

	LED Units					Plasma	SONT
Test Condition	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Voltage	200.4	240.3	220.4	411.4	422.7	240.0	400
Current mA	3262.0	946.0	1885.7	452.0	476.7	2119.6	1988.0
Power (W)	628.4	208	403.2	184.3	198.4	497.9	646.8
Power factor	0.96	0.92	0.97	0.99	0.98	0.98	0.81
Radiant power (380 to 780nm W)	177.2	51.6	177.4	92.2	97.1	124.2	203.4
Efficiency (µmol / J)	1.44	1.27	2.43	2.71	2.56	1.16	1.92
Unit weight (kg)	8.8	9.6	12.3	3.5	3.5	11.3	6.5
Radiant power per unit weight (W/kg)	20.1	5.3	14.4	26.3	27.7	5.5	31.3

The appendices also show the spectral output of each of the 7 units tested. Of the 5 LED's tested (units 1 to 5) all systems show peaks in the blue and red spectral regions at c. 450 and 660nm. Unit 1 has a degree of output between 500 and 600nm suggesting a phosphor coating has been applied to produce a wider range of spectral outputs. Unit 2 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 (unit 6) 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 currently being investigated within the AHDB Horticulture funded project CP 125. This will be key knowledge required to underpin the development of LED's for the horticultural industry.

Goniophotometer data is useful for checking light distribution of a luminaire. The data show there were striking differences in light distribution pattern between the three units tested. Unit 4 had a wide dispersal in both the vertical and horizontal axis. The horizontal cone is near circular. For unit 6, the plasma lamp, the unit has a square shape, producing a near square horizontal distribution cone with a relatively uniform surface light distribution. For unit 7, the HPS lamp, the vertical distribution has a bat wing cone, resulting in a highly directional light output within the horizontal cone. The unit is designed for high density installations of adjacent lights with focused output cones.

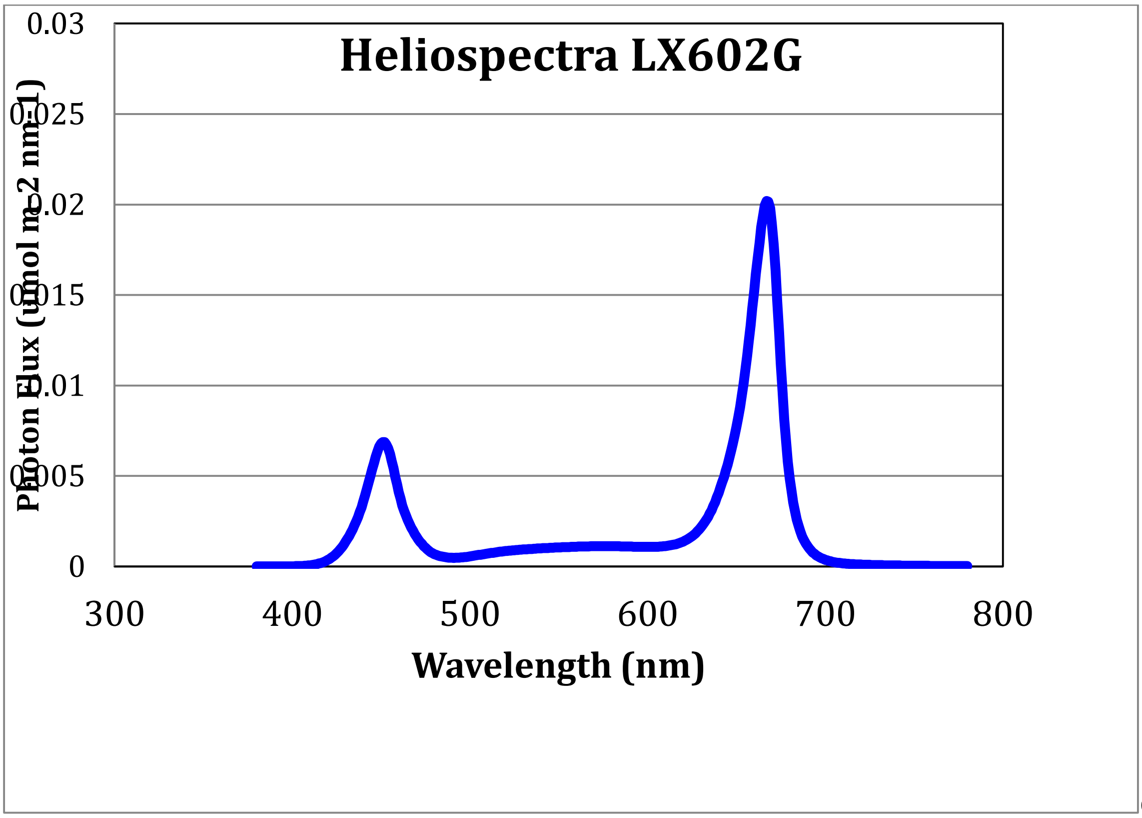
Each of the lighting systems will have been designed with a consideration as to how they can be laid out in a full greenhouse array. The plasma shows a peak direction output at c. 40 degrees, and a square spatial distribution on the horizontal floor. This suggests the units will be laid on a square grid within the greenhouse. The HPS unit has a bat wing distribution suggesting 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 will located in quite high density to gain an even light distribution.

Appendix 1. Reports on example lamp units tested

Unit 1 Heliospectra LX602G

Model HLB607-G2-B-L2-RC

LED 600W. 100-200V 50/60Hz



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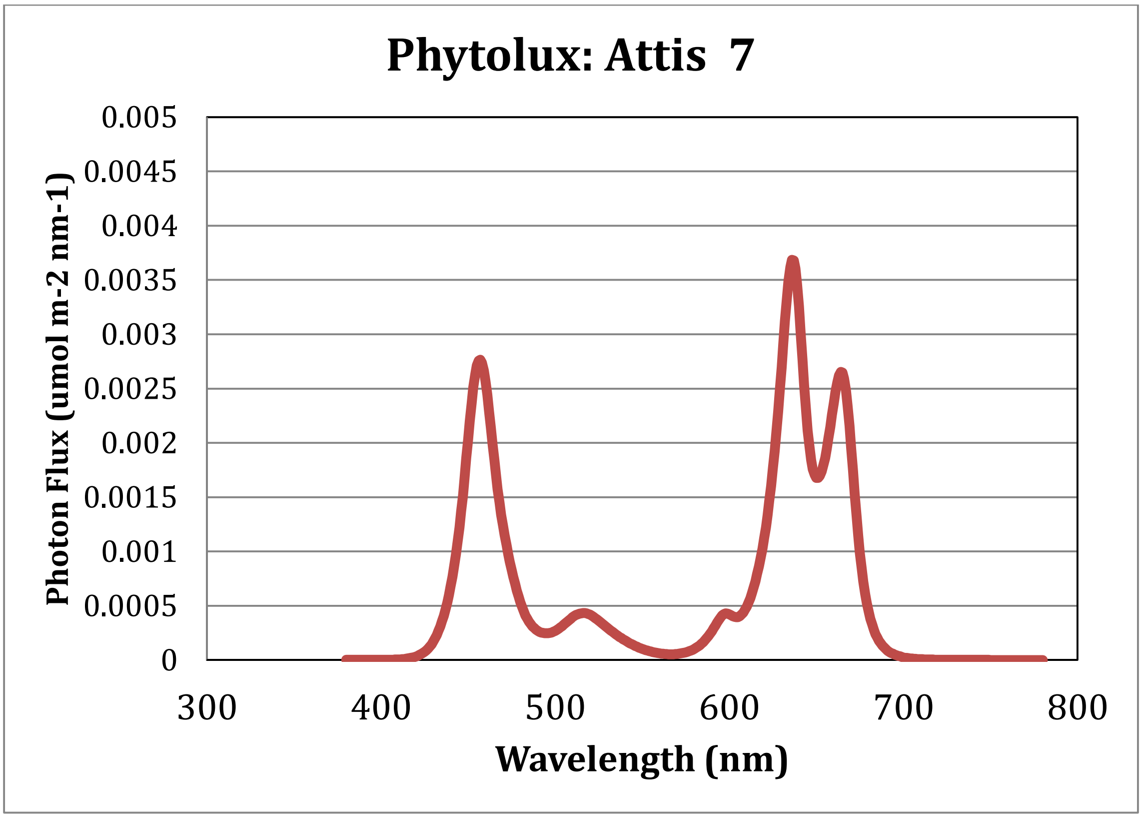
Test Condition	
Voltage	200.4
Current mA	3262.0
Power (W)	628.4
Power factor	0.96
Radiant power (380 to 780nm W)	177.2
Efficiency (µmol / J)	1.44
Mass (kg)	8.8
Radiant power per kg	20.1

Unit 2. **Phytolux Attis-7**

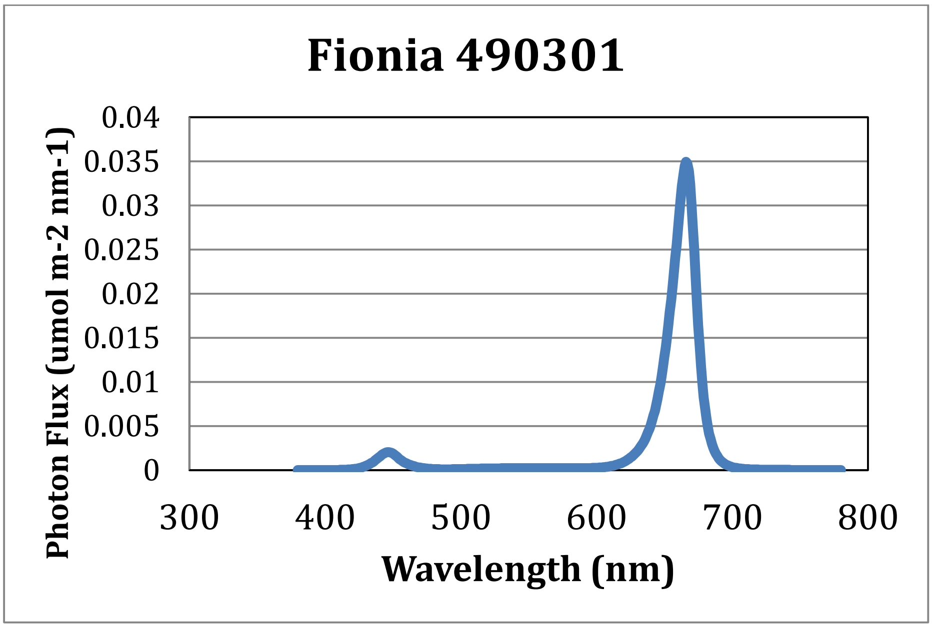
LED 184W. 100-240V 50



Test Condition	
Voltage	240.3
Current mA	946.0
Power (W)	208
Power factor	0.92
Radiant power (380 to 780nm W)	51.6
Efficiency (µmol / J)	1.27
Mass (kg)	9.6
Radiant power per kg	5.3

Unit 3. Fionia 490301

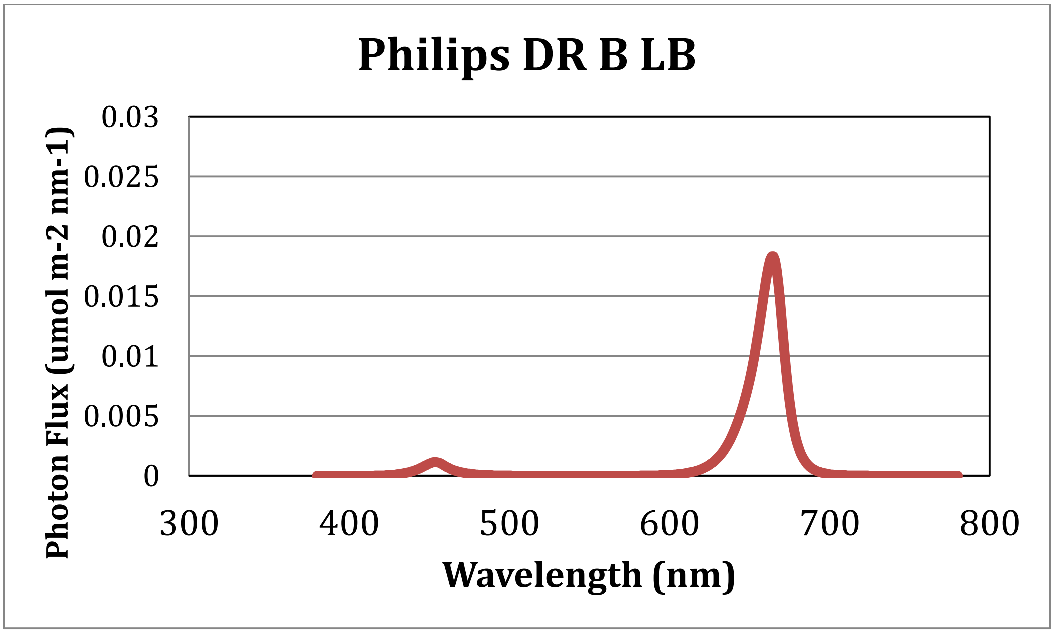
LED 400W. 220V 50Hz



Test Condition	
Voltage	220.4
Current mA	1885.7
Power (W)	403.2
Power factor	0.97
Radiant power (380 to 780nm W)	177.4
Efficiency (µmol / J)	2.43
Mass (kg)	12.3
Radiant power per kg	14.4

Unit 4. Philips GreenPower DR/B LB 400V

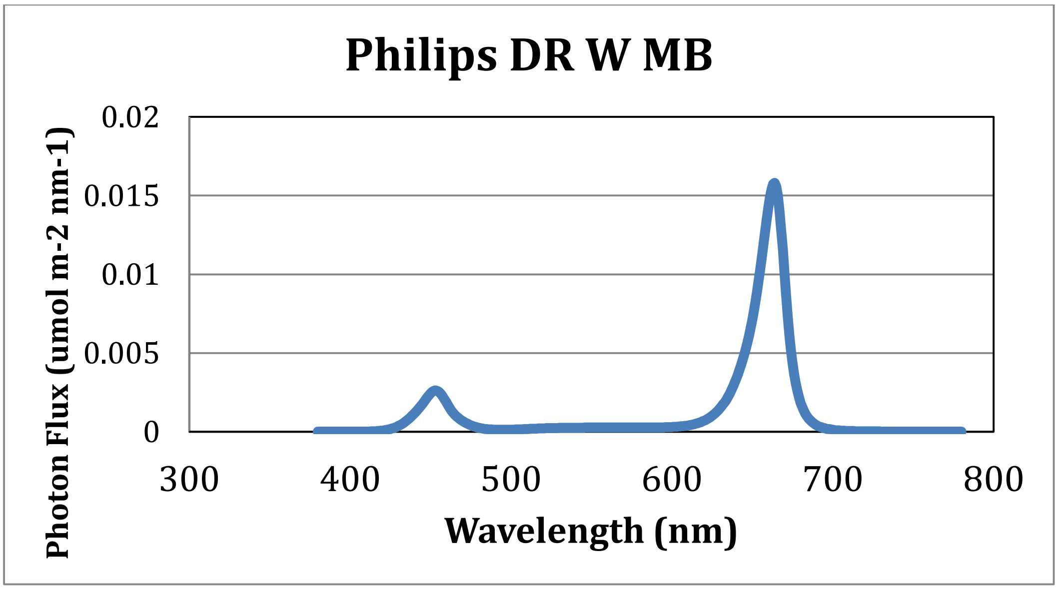
LED 190W 400V 50Hz AC



Test Condition	
Voltage	411.4
Current mA	452.0
Power (W)	184.3
Power factor	0.99
Radiant power (380 to 780nm W)	92.2
Efficiency (µmol / J)	2.71
Mass (kg)	3.5
Radiant power per kg	26.3

Unit 5. Philips GreenPower DR/W MB 400V

LED 200W 400V 50Hz AC

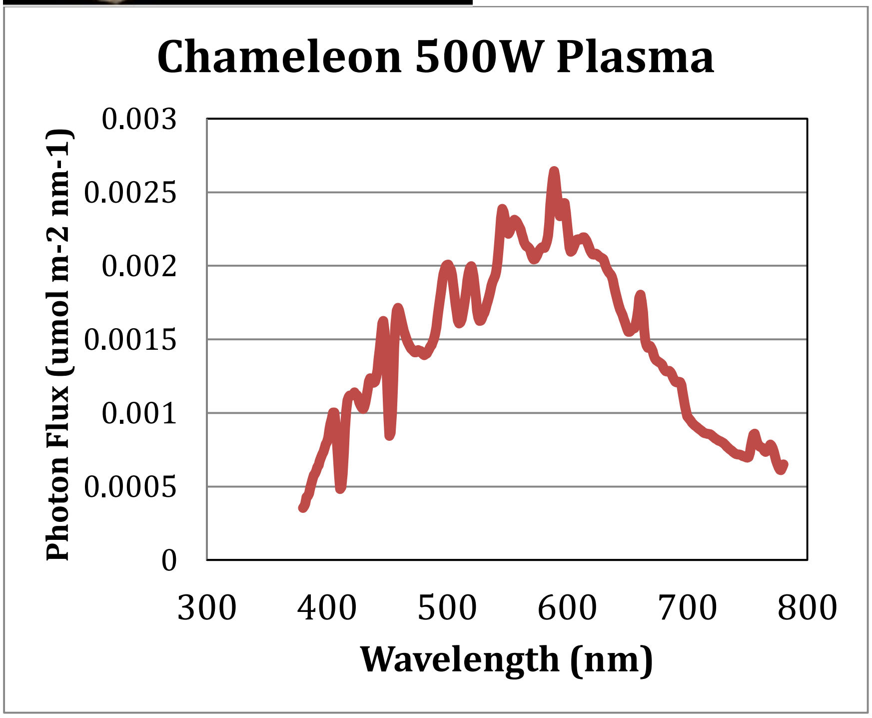


Test Condition	
Voltage	422.7
Current mA	476.7
Power (W)	198.4
Power factor	0.98
Radiant power (380 to 780nm W)	97.1
Efficiency (µmol / J)	2.56
Mass (kg)	3.5
Radiant power per kg	27.7

Unit 6. Chameleon Plasma Growth Light

Model 407.704.3000

Plasma 500W 200-277V 50/60 Hz AC

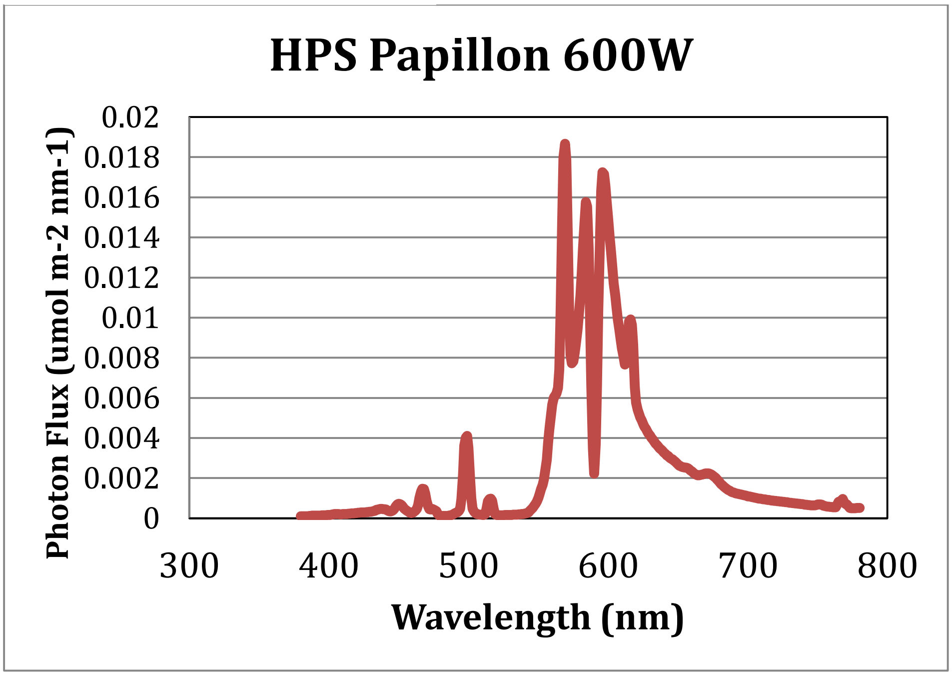


Test Condition	
Voltage	240.0
Current mA	2119.6
Power (W)	497.9
Power factor	0.98
Radiant power (380 to 780nm W)	124.2
Efficiency (µmol / J)	1.16
Mass (kg)	11.3
Radiant power per kg	5.5

Unit 7. Papillon Green House Light 400V 600W

Papillon 270 P-270460

HPS 600W 400V AC

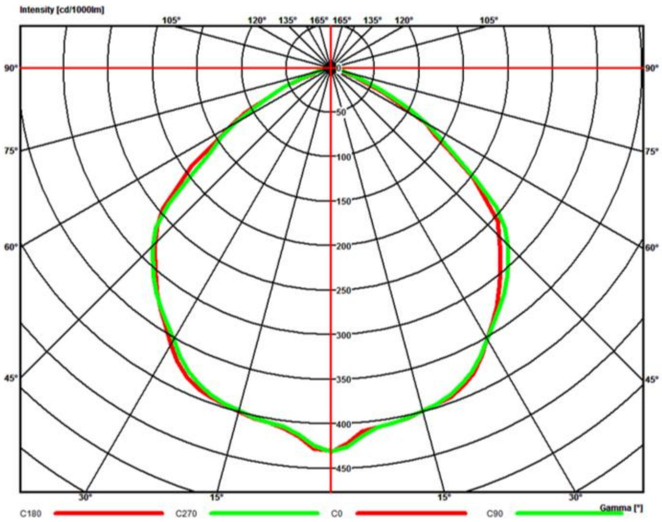


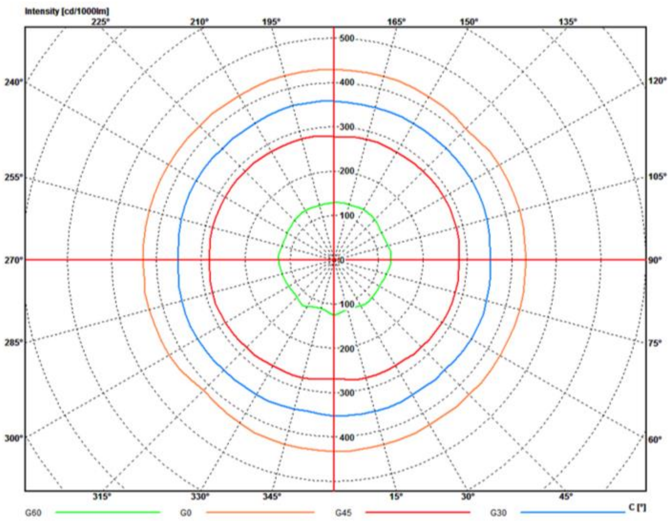
Test Condition	
Voltage	400
Current mA	1988.0
Power (W)	646.8
Power factor	0.81
Radiant power (380 to 780nm W)	203.4
Efficiency (µmol / J)	1.92
Mass (kg)	6.5
Radiant power per kg	31.3

Goniophotometer Data

Unit 4. Philips GreenPower DR/B LB 400V

Polar plot

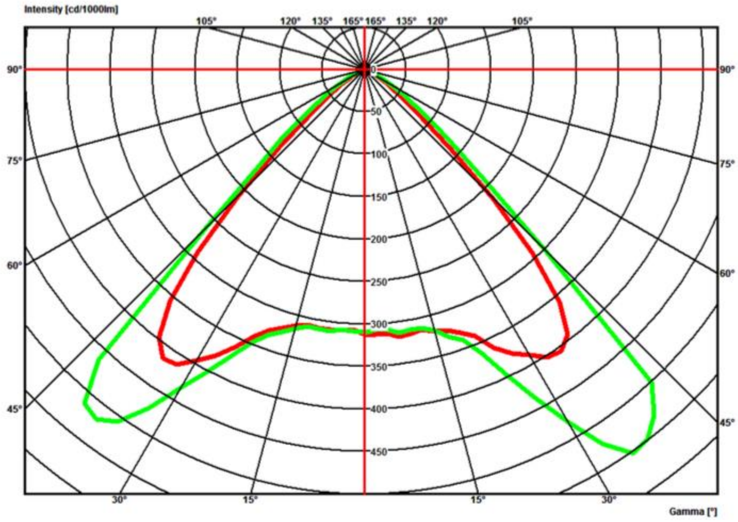


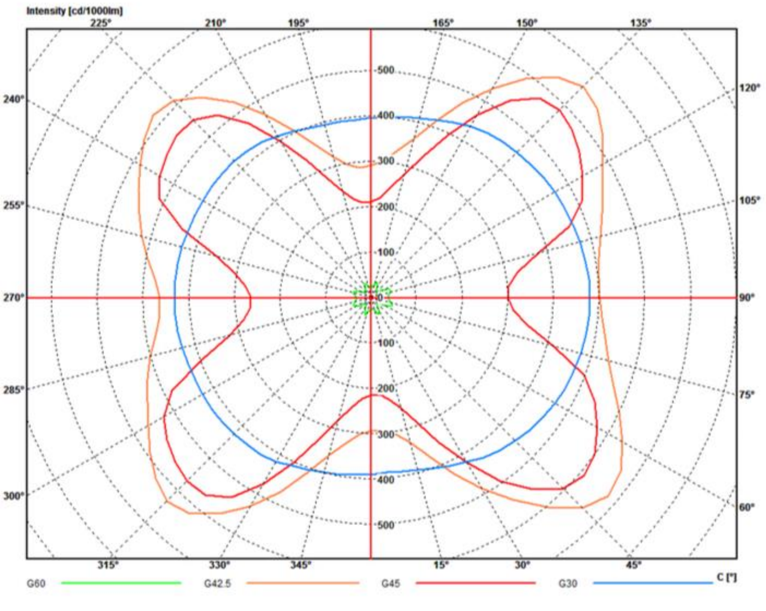


Cone diagram. Light distribution on a horizontal plane

The light is dispersed wide from the luminaire in both the vertical and horizontal axis. The horizontal cone is near circular.

Unit 6. Chameleon Plasma Growth Light



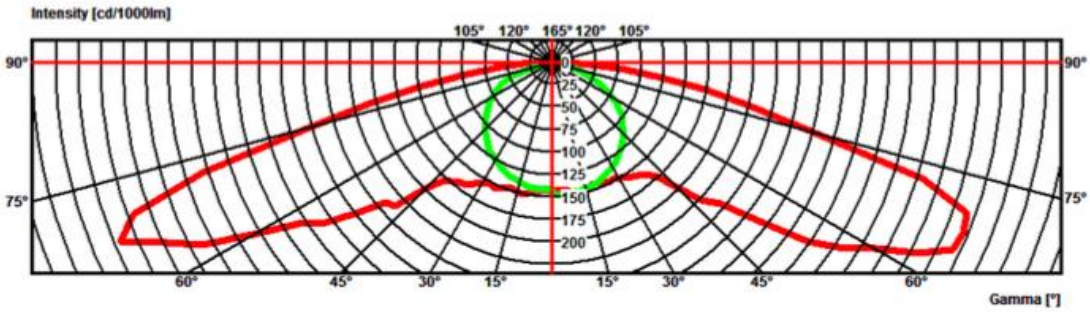


Polar plot

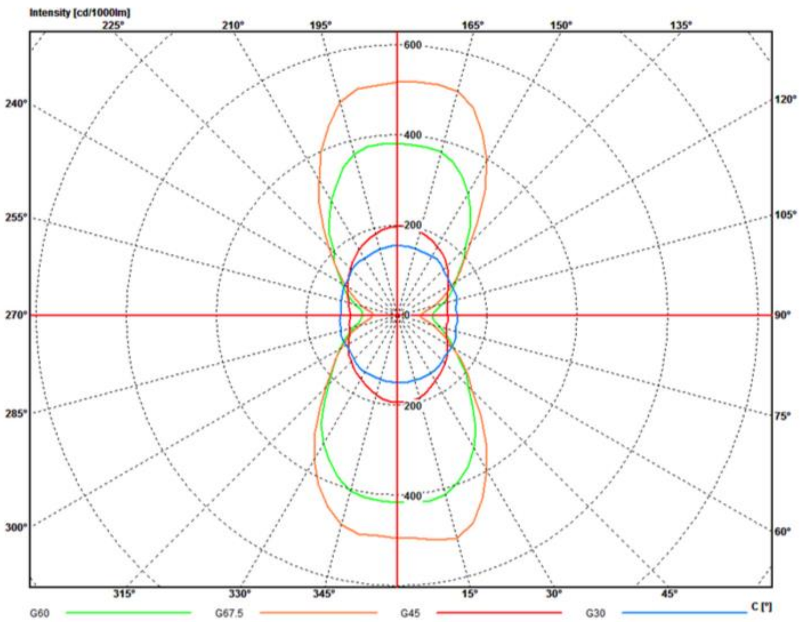
Cone diagram. Light distribution on a horizontal plane

The unit has a square shape, producing a near square horizontal distribution cone with a relatively uniform surface light distribution.

Unit 7. Papillon Green House Light 400V 600W



Polar plot



Cone diagram. Light distribution on a horizontal plane

The vertical distribution has a bat wing cone, resulting in a highly directional light output within the horizontal cone. The unit is designed for high density installations of adjacent lights with focused output cones.

Appendix 2. 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 electro magnetic energy.

Photon is a pack of electro magnetic 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 photons in light is extremely large, they are usually counted in mol (6×10^{23}).

Irradiation is the noun used to describe light as a form of electro magnetic energy

Radiant energy is the energy emitted, transferred or received in the form of electromagnetic radiation. The unit of radiant energy if the joule (J). For plants the photosynthetically active radiation is considered to be between 400 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 1 m^2), so the unit is W/m^2.

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

Photosynthetic efficiency is the efficiency of a lamp in converting input electrical energy to photosynthetically active radiation (400 to 700nm) and its units are µmol / J.