OSRAM
Opto Semiconductors

LEDs for horticultural lighting applications

Application Note

Valid for:
OSCONIQ® P 2226
OSLON® SSL
OSLON® Square

Abstract

LED light can be used for the illumination of plants in horticultural lighting applications. The different types of lighting required for the various plants can be addressed by matching LEDs, fulfilling the requirements of the systems in the best possible way. As greenhouses and plant factories are areas with tough environmental conditions, the luminaire which protects the LED must be designed with care so that the LED can fulfill its entire lifetime potential.

This application note provides an introduction to horticultural lighting, focusing on typical lighting recipes and applications based on the LED product portfolio of OSRAM Opto Semiconductors. Furthermore, we present the design considerations and the Horticulture Tool.

Further information:
OSRAM Opto Semiconductors supports its customers in designing system solutions for horticultural lighting concepts by an application service: https://apps.osram-os.com/Horticulture/

Author: Retsch Stefanie / Wilm Alexander

Table of contents

A. Horticultural lighting

The illumination of plants varies significantly from illumination for humans. Since plants have different receptors and cells to sense and process light, the unit for the light quantity is photon-based in contrast to other general lighting applications. For example, where humans see various colors, plants react to the different intensity ratios of the spectrum and respond accordingly. These different ratios enable the grower to influence various parameters of the plant such as biomass, form, nutrition content, taste and the point in time of the flowering. The various types of lighting for plants can be addressed with matching LEDs to fulfill the requirements of the systems in the best possible way. As greenhouses and plant factories are areas with tough environmental conditions, the luminaire which protects the LED must be designed with care so that the LED can fulfill its entire lifetime potential.

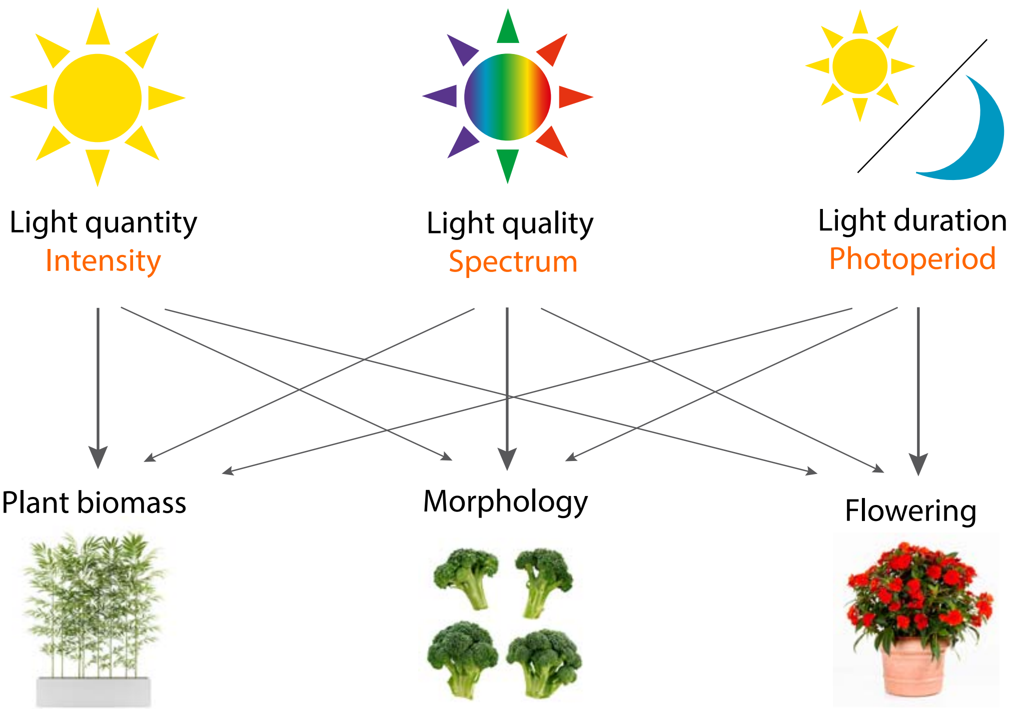
What type of light do plants need?

It is well known that factors such as temperature, humidity, root-zone temperature, wind, water, nutrients, and oxygen/carbon dioxide levels play an important role in regulating the growth of plants. In addition to these factors, light plays a major role in the growth cycle of a plant. In fact, the various properties of the light interact to control the growth and development of plants.

Since farming began, all varieties of crops, flowers, and herbs have been cultivated under sunlight. Thereby, the intensity, the spectrum and the duration of the sunlight influences the morphology, growth and flowering in a natural way (see Figure 1).

The quantity or intensity of the light, which can be quantified by the photon flux density (PFD), has a great influence on the plant biomass and its rate of growth. The light quality, or the distribution of spectral power density, has been shown to be effective in regulating the morphology and even the color of certain genotypes of plants. Finally, the photoperiod or light duration can effectively control the flowering times of certain short-day and long-day plants. These divisions are not exclusive, but all these lighting factors work together to regulate the overall growth of plants.

Figure 1: Plant biomass, morphology and flowering times can be controlled by regulating light quantity, quality and duration



Light metrics in comparison

Light is a form of energy that consists of photons behaving like a wave. Since light is energy, it can neither be created nor destroyed. It merely transforms from one form to another and generates photochemical reactions in living beings. For humans, light reacts with the short, medium and long photoreceptors in the eye to allow us to see in color. In contrast, for plants light reacts with chlorophyll, phytochromes, etc. to regulate growth (Figure 2). Here, different absorption curves of plants can be distinguished. For example the chlorophyll absorption curves are mainly responsible for photosynthesis and therefore for the growth of plants. The phytochromes are sensors of the plant which react to the environment and adjust the morphology. This fundamental difference is the reason why the metrics we use for human vision today cannot be applied to horticultural lighting (see Table 1).

Figure 2: The absorption curves of plants are not the same as for the human eye. Different spectrum and metrics are necessary to quantify horticultural lighting

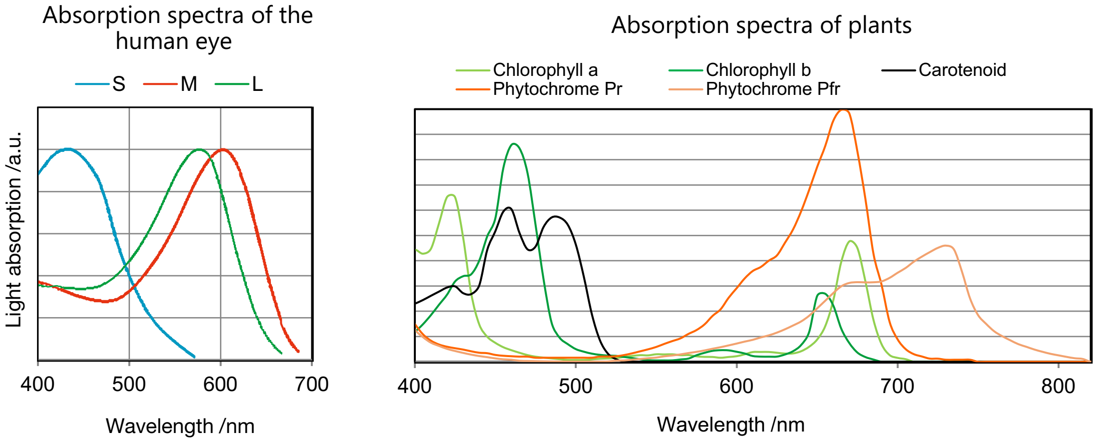


Table 1: Lighting metrics for humans versus horticulture

	Humans	Plants Photosynthesis	Plants Sensitivity
Sensitivity	Eye sensitivity curves *360 - 830 nm*	Photosynthetic active radiation (PAR) *400 - 700 nm*	All plant sensitivity curves *280 - 800 nm*
Intensity	Luminous flux *lm*	Photosynthetic photon flux (PPF) *µmol/s*	Photon flux (PF) *µmol/s*
Density	Illuminance, lux $lx = lm/m^2$	Photosynthetic photon flux density (PPFD) $\mu mol/s/m^2$	Photon flux density (PFD) $\mu mol/s/m^2$
Efficacy	Luminous efficacy *lm/W*	Photosynthetic photon efficacy *µmol/J*	Photon efficacy *µmol/J*

Table 1: Lighting metrics for humans versus horticulture

	Humans	Plants Photosynthesis	Plants Sensitivity
Color properties	CRI, CCT, *xy, u'v'*		
Daily amount of light		Daily light integral (DLI) $\mu mol/m^2 day$	Daily light integral (DLI) $\mu mol/m^2 day$

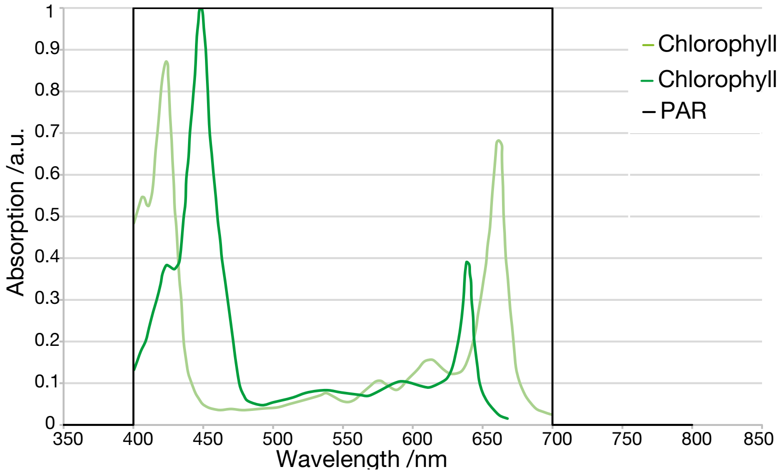
Lighting metrics for plants are essentially photon-based. For example, the photon flux (PF) measures the number of photons in µmol/s that is emitted from a light source while the photon flux density (PFD) measures the number of photons that reach the plant. While the photosysthetic photon flux (PPF) is a value used mainly to describe the spectral region of the photosynthesis in the range of 400 nm - 700 nm, the PF covers the whole spectral range the plants are sensitive to and can also be used for further evaluations. The same applies to the photosynthetic photon flux density (PPFD) and the photon flux density (PFD) as well as their respective efficacies. Color properties such as the color rendering index (CRI) and the correlated color temperature (CCT) are no longer relevant for horticultural lighting, unless the light source also serves as a lighting source for humans. One metric is the daily light integral (DLI), which quantifies the total number of photons that a plant receives in a day.

It has been well researched that plants have evolved to respond to variations in light frequency, intensity and wavelengths. This means that artificial lighting can be used to influence plant growth and development, including the photosynthesis rate, plant form (photomorphogenesis), growth direction (phototropism) and flowering times (photonasty). LEDs are particularly suited for horticultural lighting due to their narrow peak bandwidths, which allow for the creation of specialized lighting recipes which are optimized for various applications, growing conditions and plant species.

Photosynthesis

Plants convert light energy into chemical energy through photosynthesis. Photosynthesis begins when light energy is absorbed by green chlorophyll pigments inside chloroplasts, which are heavily concentrated in leaf cells. Chlorophyll a and b have the highest absorption rate in the blue and red wavelength region. Therefore, the absorption rate in the green wavelength region is lower due to a certain amount of reflection. The resulting chemical energy is stored in carbohydrate molecules which are synthesized from carbon dioxide and water, releasing oxygen as a waste product. The absorption spectra of chlorophyll a and b as well as the PAR (photosynthetic active radiation) are illustrated in Figure 3.

Figure 3: PAR and absorption curves of chlorophyll a and b



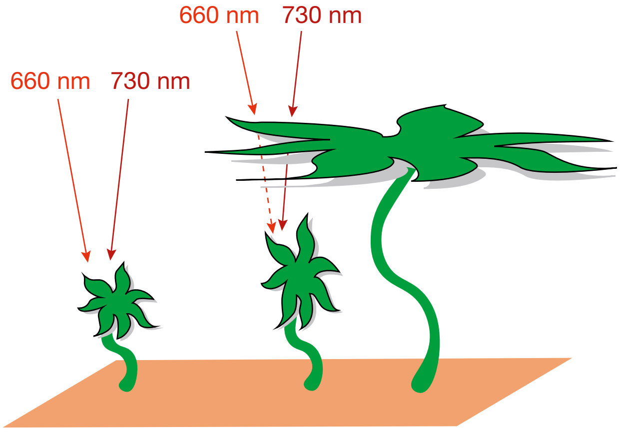
Photomorphology

Light can also regulate the photomorphology of plants, where plant growth reacts to the light spectrum received. This is not related to photosynthesis, where light is used as an energy source. In plants, the phytochromes, phototropins and cryptochromes are responsible for regulating plant growth based on the photomorphogenic effects of light in the short blue wavelength, the hyper red range and the far red range of the electromagnetic spectrum.

One of the most noticeable influences of the photomorphogenic effects of light is a phenomenon known as the shade escape reaction (see Figure 4). The illumination of a plant with a wavelength of 660 nm is signaling the plant direct sunlight. Thus, the plant grows normally. In contrast, illuminating the same plant with a higher ratio of the 730 nm wavelength results in the accelerated stem growth of the plants. The illumination signals the plant that it is growing in the shade of a taller plant. Thus, the plant tries to escape the shade through accelerated stem growth, which leads to taller plants but not necessarily to increased biomass.

Photomorphology provides an interesting solution for growers to control the form and size of their crops. For example, by selecting an optimized light spectrum mix, growers can decrease the stem length while maintaining the fresh weight to save on shipping space. OSRAM Opto Semiconductors offers LEDs which are well suited producing these particular wavelengths (e.g. hyper red at 660 nm and far red at 730 nm).

Figure 4: Shade escape reaction leads to longer stem length



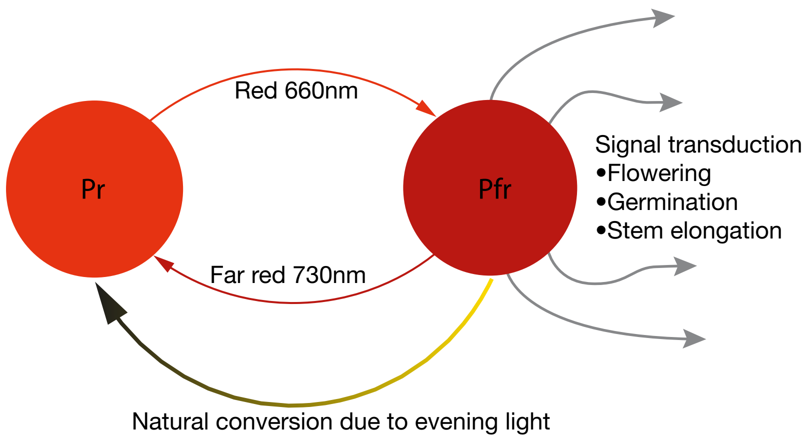
Photoperiod control

Certain desirable plant responses can be triggered by controlling the timing and the duration of the light given to the plant. This is known as photoperiod control and is particularly useful for ornamental plants. Hyper red (660 nm) and far red (730 nm) light has been shown to mediate the conversion of phytochromes, allowing the grower to control the triggers for flowering.

Phytochromes are photoreceptors which are sensitive to red (Pr) and far red (Pfr) light. They mainly influence the germination, plant growth, leaf building and flowering.

The phytomorphogenic effects are controlled by applying a spectrum with a certain mix of 660 nm and 730 nm in order to stimulate the Pr and Pfr phytochromes. The conversion of Pr to its active form Pfr is initiated by red light of 660 nm which represents daylight. During the night, the Pfr is converted back to Pr. This process, also known as dark reversion, can also be actively influenced by 730 nm far red light. This enables the perfect control of the flowering timing independent of the seasons. Figure 5 schematically shows the photoperiodic control process.

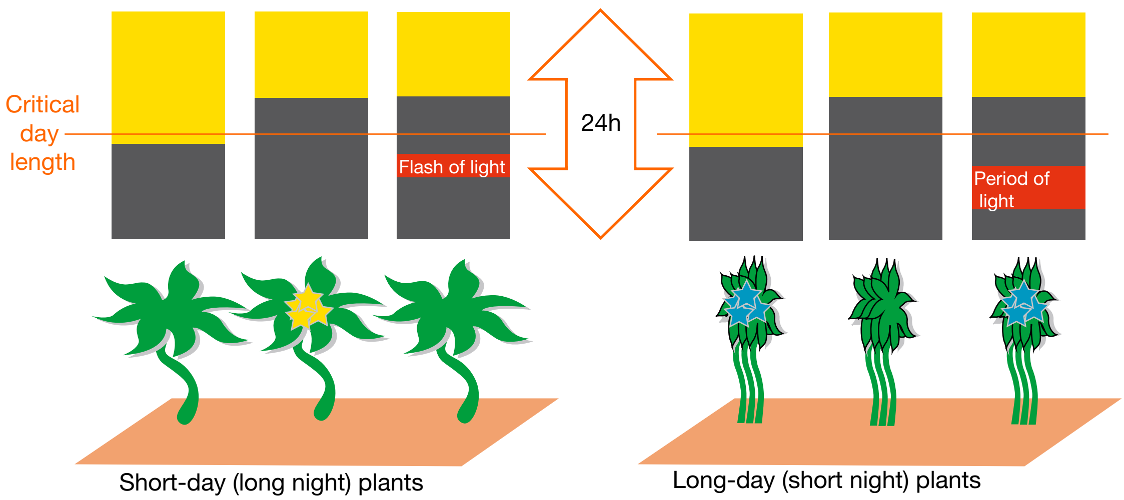
Figure 5: Photoperiodic control



The length of uninterrupted darkness determines the formation of flowers for most types of plants. Plants that require a long period of darkness are known as short-day (long-night) plants. They only bloom when they receive less than 12 hours of light. Most spring and fall blooming flowers come under this category. Some notable examples of short-day plants include chrysanthemum, kalanchoe, ipomoea and euphorbia.

On the other hand, there are also certain types of plants that require a short period of darkness to flower, also known as long-day (short-night) plants. These plants only bloom when they receive light more than 12 hours of light. Some examples of long-day plants include summer blooming flowers and garden vegetables such as lettuce, potatoes and spinach. Certain plants, such as cucumbers and tomatoes, are day-neutral plants which are not affected by photoperiodism. Instead, their flowering times are controlled by their natural development stages or other environmental conditions such as a period of low temperature (vernalization). Figure 6 shows the different types of plants and the photoperiodic controls required to trigger flowering and growth.

Figure 6: Short-day and long-day plants require different photoperiodic controls to trigger flowering and growth



B. Typical lighting recipes

The ability to customize the light of the illumination gives great freedom and versatile options with regard to the spectral composition. The correct spectral power distribution for various purposes and plants is often called "lighting recipes". There are numerous possible combinations so that the perfect recipe is very difficult to determine. Even a general recipe may not work in all combinations.

The following lighting recipes can be used as a good starting point for further evaluations. However, different plants may not react to the given lighting conditions in the same way. Even variants of the same species can behave differently under the same illumination. Therefore, we strongly recommend that you evaluate the recipes in trial runs and adjust and optimize them according to the crop type, the application and the purpose of the horticultural lighting. The recipes are based on general scientific knowledge and publications. Further studies to optimize the spectral composition and to evaluate the effects on the plant more in detail are currently being conducted in numerous universities.

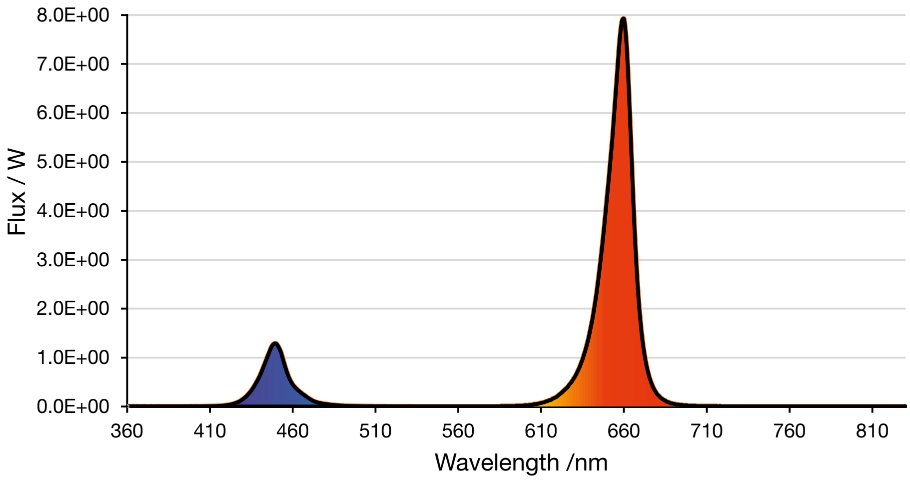
There are various objectives which can be supported by adjusting the spectra of the horticultural lighting. The spectra also depend on the application.

Focus on plant growth

To support plant growth by horticultural lighting the spectra focus on the efficient creation of photons in the photosynthetic relevant region from 400 - 700 nm and especially in the high absorption area around 450 nm and 660 nm. The most efficient way to create photons for photosynthesis is a direct emitting hyper red LED at 660 nm.

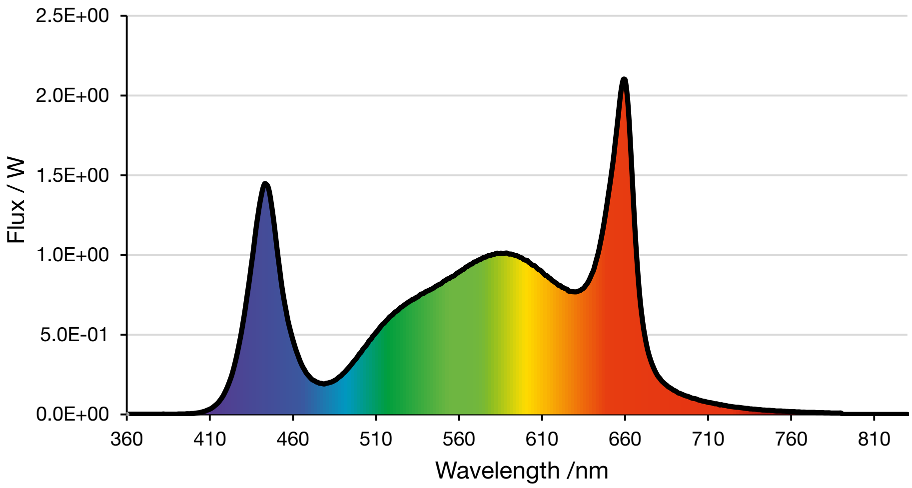
Plant growth by supplemental lighting. For supplemental lighting e.g. in greenhouses the artificial light is added to existing natural daylight. Therefore, the additional light must be generated in the most efficient way and with a clear focus on providing the photons in the absorption maximum of the chlorophyll a and b which are mainly responsible for photosynthesis and enable plant growth. OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 10 % of deep blue LEDs (450 nm) and 90 % of hyper red LEDs (660 nm).

Figure 7: LED emission spectrum recommended for plant growth by supplemental lighting



Plant growth by sole-source lighting. In vertical farms, for example, all the light is produced by artificial light sources. This is also referred to as sole-source lighting. For these kinds of applications and with the main target of plant growth, a combination of the high efficient hyper red 660 nm LED with an efficient white CRI 70 4000 K LED provides energy for the plants to perform photosynthesis. In addition, the mixture will lead to a white light appearance with a high color rendering index to assess the quality of the plants and perform other work tasks. In this case, OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 80 % of white LEDs (CRI70, 4000 K) and 20 % of hyper red LEDs (660 nm).

Figure 8: LED emission spectrum recommended for plant growth by sole-source lighting

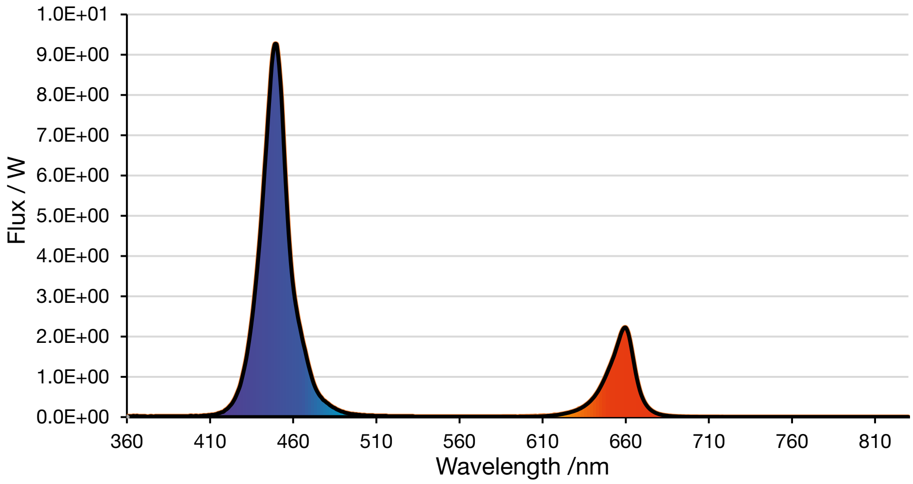


Focus on propagation

Seedlings need a high blue light content to start germinating and sprouting. Therefore, a high deep blue content at 450 nm is important in this application. This can be also supported by far red light at 730 nm.

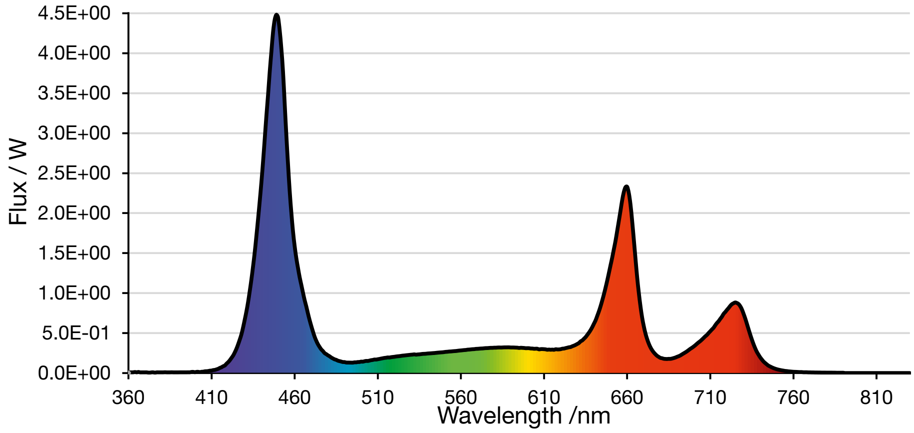
Propagation by supplemental lighting. If natural light is present, the focus of the horticultural illumination should again be on high efficient light creation in the regions required. In this application the emphasis should be clearly on the 450 nm wavelength. Here, OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 75 % of deep blue LEDs (450 nm) and 25 % of hyper red LEDs (660 nm).

Figure 9: LED emission spectrum recommended for propagation by supplemental lighting



Propagation by sole-source lighting. In sole-source lighting conditions such as multi-layer cultivation and vertical farms the spectral composition should be supported by white light and a good amount of far red illumination at 730 nm. In this case, OSRAM Opto Semiconductors recommends the use of a photon flux ratio created by 35 % of deep blue LEDs (450 nm), 25 % of hyper red LEDs (660 nm), 25 % of white LEDs (CRI70, 4000 K) and 15 % of far red LEDs (730 nm).

Figure 10: LED emission spectrum recommended for propagation by sole-source lighting

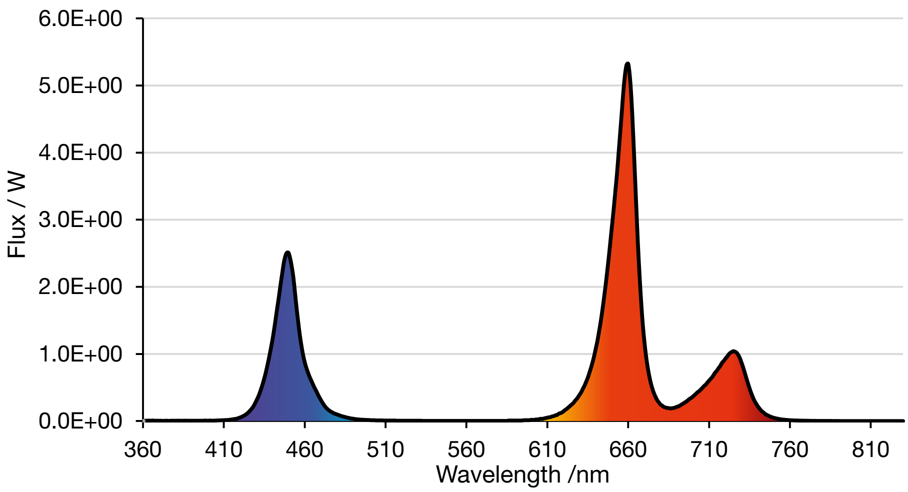


Focus on flowering

A far red content at 730 nm is required in order to induce the flowering of the plant. This can be used especially to adjust the perceived day length of the plant. Some plants only flower if the day is shorter than 12 hours. Some are just the other way round and only flower if the day is longer than 12 hours. In regions with seasons horticultural lighting could be used to induce flowering even if the natural length of the day would not lead to a flowering of the plants.

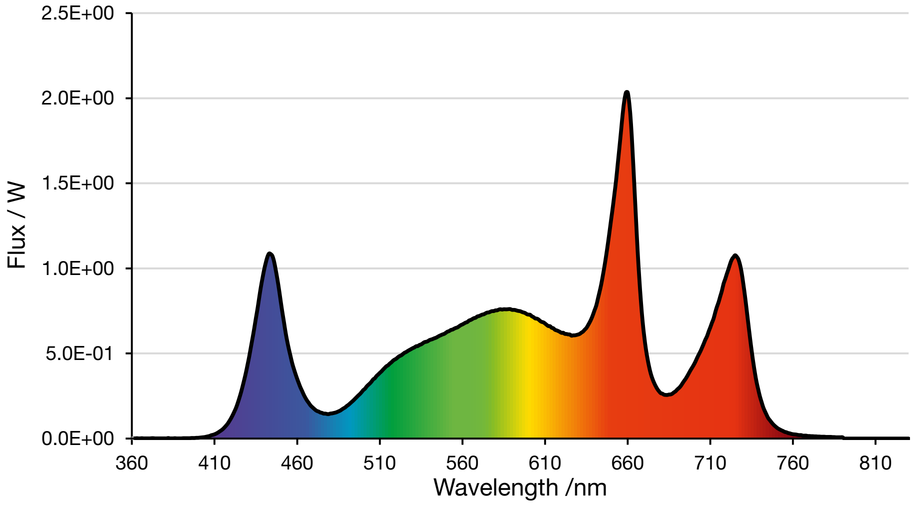
Flowering by supplemental lighting. An additional channel for far red is beneficial to supporting the flowering of the plant in a greenhouse. OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 20 % of deep blue LEDs (450 nm), 60 % of hyper red LEDs (660 nm) and 20 % of far red LEDs (730 nm).

Figure 11: LED emission spectrum recommended for flowering by supplemental lighting



Flowering by sole-source lighting. Since the complete spectrum is generated by artificial light under sole-source lighting condition, it is easier to control parameters e.g. the length of the day. Again a high content of far red helps to induce flowering if the plant is ready. Here, OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 60 % of white LEDs (CRI70, 4000 K), 20 % of hyper red LEDs (660 nm) and 20 % of far red LEDs (730 nm).

Figure 12: LED emission spectrum recommended for flowering by sole-source lighting

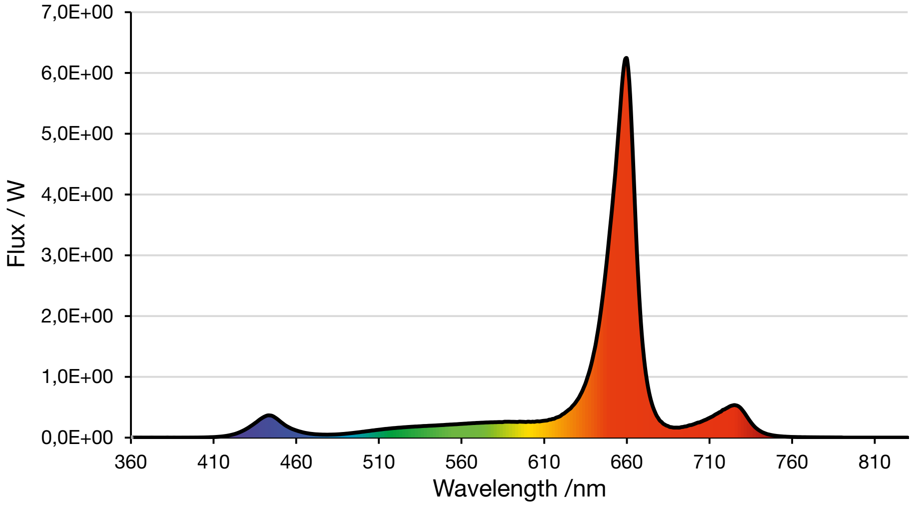


Focus on fruiting

During the fruiting phase the plant needs a high amount of energy to create the fruit body. Therefore, a high amount of light for photosynthesis should be provided.

Fruiting by supplemental lighting. In the fruiting phase a high amount of 660 nm light is necessary to support photosynthesis. In addition, a small amount of far red light at 730 nm helps to support the creation of the fruit body. For this scenario OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 20 % of white LEDs (CRI70, 4000 K), 70 % of hyper red LEDs (660 nm) and 10 % of far red LEDs (730 nm).

Figure 13: LED emission spectrum recommended for fruiting by supplemental lighting



Fruiting by sole-source lighting. Similar to the supplemental lighting the spectrum to support fruiting under sole-source lighting conditions focuses on the creation of highly efficient hyper red light at 660 nm in combination with far red at 730 nm and white light to again enable the assessment of the plants and fruit bodies under pleasant and high CRI lighting conditions. OSRAM Opto Semiconductors recommends the use of a photon flux ratio of 60 % of white LEDs (CRI70, 4000 K), 30 % of hyper red LEDs (660 nm) and 10 % of far red LEDs (730 nm).

Figure 14: LED emission spectrum recommended for fruiting by sole-source lighting

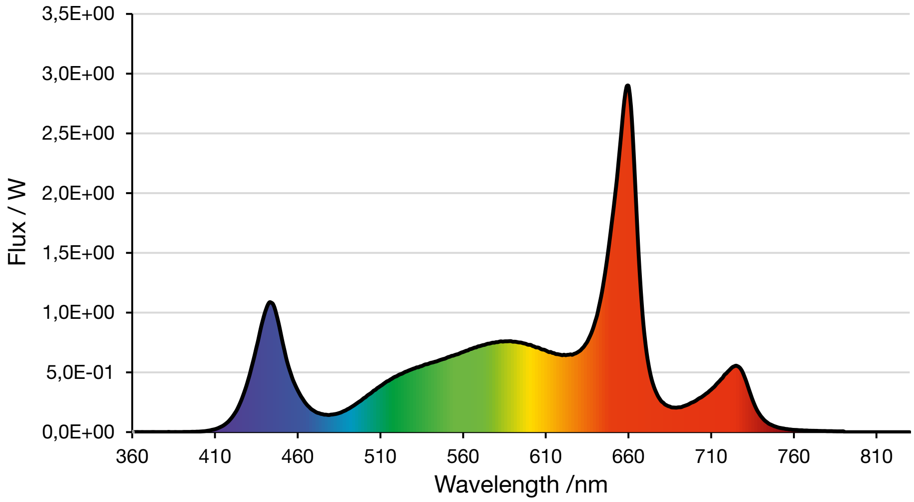


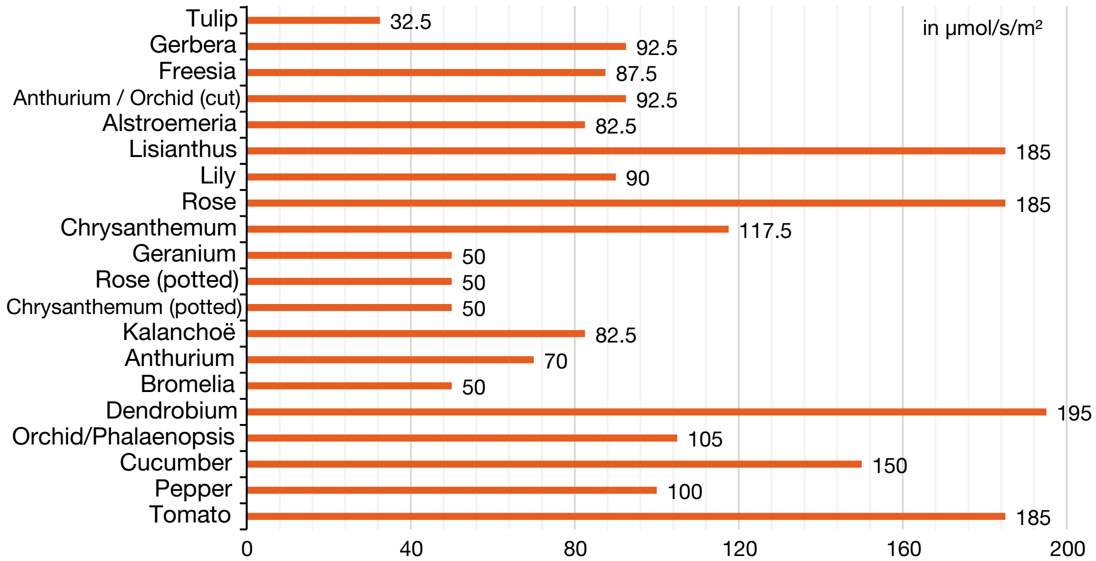
Table 2 provides a summary of the typical lighting recipes previously mentioned.

Table 2: Summary of typical light recipes

Target	Lighting condition	Deep blue 450 nm	Hyper red 660 nm	Far red 730 nm	White CRI 70 4000 K
Plant growth	Supplemental lighting	10 %	90 %		
	Sole-source lighting		20 %		80 %
Propagation	Supplemental lighting	75 %	25 %		
	Sole-source lighting	35 %	25 %	15 %	25 %
Flowering	Supplemental lighting	20 %	60 %	20 %	
	Sole-source lighting		20 %	20 %	60 %
Fruiting	Supplemental lighting		70 %	10 %	20 %
	Sole-source lighting		30 %	10 %	60 %

The lighting recipes mentioned above focus on the relative ratios of the photon flux in the various wavelength regions, describing the spectral composition of the light. The amount of light and therefore the required photon flux density (PFD) on the plant level varies strongly according to the type of plant and the intended purpose. Figure 15 gives an indication of the typical PFD levels required for the growth and flowering of various crops. Again, the amount of light should be carefully evaluated depending on the plant used and the intended purpose.

Figure 15: Typical PFD levels required



C. Typical horticultural lighting applications

There are various kinds of setups of horticultural lighting applications. The main ones are addressed below:

- Top lighting
- Inter lighting
- Vertical farming or multilayer cultivation
- Consumer products

Top lighting

The plants are illuminated from above similar to sunlight. The aim is to supplement natural daylight and raise growth light levels in order to enhance photosynthesis and thereby improve the growth and quality of plants in greenhouses. Additional top lighting is already common with conventional light sources such as high-pressure sodium (HPS). The heavy power consumption and the heat of the HPS luminaires make a large distance between the light source and the plants necessary. The photon flux of conventional luminaires can be up to 2000 µmol/s. LED luminaires do not usually provide a similar high photon flux from one luminaire but from several, more distributed luminaires with lower photon flux. The photon flux per luminaire may change significantly depending on the luminaire setup.

For top lighting OLSON® Square LEDs are recommended to achieve the highest efficacy. The typical values for a photon flux (PF) of 700 µmol/s are shown in Table 3.

Table 3: Top light (typical photon flux 700 µmol/s)

Typical values	Toplight Growth	Toplight Propagation	Toplight Flowering	Toplight Fruiting
PF	703 µmol/s	704 µmol/s	708 µmol/s	708 µmol/s
Efficacy	2.83 µmol/J	2.31 µmol/J	2.55 µmol/J	2.56 µmol/J
PPF	701 µmol/s	702 µmol/s	584 µmol/s	642 µmol/s
P_{el}	248 W	304 W	277 W	276 W

Inter lighting

Using LEDs as a light source is a perfect solution to enable inter lighting. In this case the light sources are placed in between the plants and the leaves. This reduces the shade of the leaves which may result from top lighting and thus increase the amount of light even on the lower leaves. Unlike with hot HPS luminaires, the low temperatures of the LED luminaire do not cause any damage to the plants. Inter lighting is considered as supplemental lighting since the LED lighting is typically used in greenhouses in addition to natural daylight.

For inter lighting OSLON® SSL LEDs are recommended as a compromise between efficacy and uniformity. Other combinations are also possible (e.g. the OSLON® Square at lower currents for high efficacy or the OSCONIC® P 2226 for high uniformity). Table 4 shows the typical values of a photon flux of 100 µmol/s for a luminaire length of 1 m.

Table 4: Inter lighting (typical photon flux 100 µmol/s from 1 m luminaire)

Typical values	Interlight Growth	Interlight Propagation	Interlight Flowering	Interlight Fruiting
PF	102 µmol/s	102 µmol/s	102 µmol/s	101 µmol/s
Efficacy	2.73 µmol/J	2.26 µmol/J	2.50 µmol/J	2.46 µmol/J
PPF	101 µmol/s	101 µmol/s	84 µmol/s	91 µmol/s
P_{el}	37 W	45 W	41 W	41 W

Vertical farming

In vertical farms, plant factories or multi-layer cultivation applications the crop is grown in layer one on top of each other. The light is placed directly above and in close proximity of the crop. This only allows “cold” light sources such as LED luminaires to ensure that the plants are not burned by the high temperature of the light source. Uniform illumination is necessary in order to achieve the even growth of the crop over the complete plant area.

Due to the stacking of plant layers the plants grow completely under artificial light without any daylight at all. This is also referred to as sole-source lighting. This gives complete control over the timing, amount and spectral composition but also requires a complete light content. If people work under these lighting conditions a white light impression is necessary to enable the workers to assess the quality of the plants.

For vertical farming OSCONIQ® P 2226 LEDs are recommended for high uniformity especially in blue. Combinations with other LEDs are also possible to achieve a good compromise between uniformity and efficiency. Therefore the use of OSLON® SSL or OSLON® Square LEDs is also possible. Table 5 indicates the typical values for a single module with 50 µmol/s and a length of 1 m.

Table 5: Vertical farming (typical photon flux 50 µmol/s from 1 m luminaire)

Typical values	Multi-layer Growth	Multi-layer Propagation	Multi-layer Flowering	Multi-layer Fruiting
PF	50 µmol/s	51 µmol/s	50 µmol/s	50 µmol/s
Efficacy	1.80 µmol/J	1.91 µmol/J	1.79 µmol/J	1.85 µmol/J
PPF	49 µmol/s	44 µmol/s	40 µmol/s	45 µmol/s
P_{el}	28 W	27 W	28 W	27 W

Consumer products

Consumer horticultural lighting – Grow Bulbs: The grow bulbs can be used in various non-professional applications. The target is not primarily the rapid growth of the bio mass but mainly to maintain and grow the plant under low light indoor conditions. In addition a pleasant impression is preferred. Various white LEDs in different converter mixes are used for this purpose.

Consumer horticultural lighting – Grow Boxes: Grow Boxes address the life style trend of home growing. Here the plants are grown completely under artificial light and under controlled conditions. The flexibility to adjust the spectrum and the lighting conditions to the different products is the key for this application. A broad range of various LEDs with different wavelength is used to provide exactly the right lighting recipe for the illuminated product. Due to the new application and the significantly different setups and shapes, a typical value or setup cannot yet be determined.

For additional information and reference scenarios please also refer to the Horticulture Tool.

D. LED product portfolio

The LEDs from OSRAM Opto Semiconductors primarily developed for horticultural lighting belong to the OSLON® family (SSL and Square) and the OSCONIQ® P 2226 family. The components are available from mid-power to high-power and cover a broad range of colors including white. Table 6, to Table 9 provide an overview of the product portfolio from OSRAM Opto Semiconductors.

Table 6: LED product portfolio (OSCONIQ® P 2226)

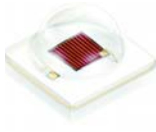
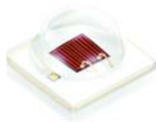
OSCONIQ® P 2226 — professional mid-power components (0.3 W)

LED Type	GD DASPA2.14	GH DASPA2.24	GF DASPA2.24	GW DASPA2.UC
Size	2.2 mm * 2.6 mm			
Color	Deep blue	Hyper red	Far red	White
Wavelength	450 nm	660 nm	730 nm	6500 K, CRI 67
Performance	166 mW 0.62 µmol/s 2.15 µmol/J	110 mW 0.60 µmol/s 2.80 µmol/J	66 mW 0.40 µmol/s 2.21 µmol/J	42 lm 0.60 µmol/s 2.06 µmol/J

OSCONIQ® P 2226 is also available in additional colors (Blue, True green, Yellow, Red) and White (CRI 70, CRI 80)

Table 7: LED product portfolio (OSLON® SSL)

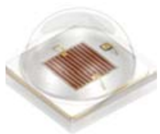
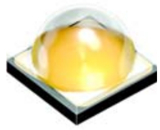
OSLON® SSL — professional high-power components (1.0 W)

				
LED Type	GD CSSPM1.14	GH CSSPM1.24	GF CSSPM1.24	GW CSHPM1.PM
Size	3.0 mm * 3.0 mm			
Color	Deep blue	Hyper red	Far red	White
Wavelength	450 nm	660 nm	730 nm	5000 K, CRI 70
Performance	690 mW 2.61 µmol/s 2.61 µmol/J	425 mW 2.32 µmol/s 3.24 µmol/J	270 mW 1.77 µmol/s 2.41 µmol/J	144 lm 2.04 µmol/s 1.98 µmol/J

OSLON® SSL is also available in additional colors (blue, true green, yellow, red) and white (CRI 70, CRI 80, CRI 90 from 2500 K to 6500 K)

Table 8: LED product portfolio (OSLON® Square)

OSLON® Square — professional high-power components (2.0 W)

			
LED Type	GD CSSRM2.14	GH CSSRM2.24	GW CSSRM2.PM
Size	3.0 mm * 3.0 mm		
Color	Deep blue	Hyper red	White
Wavelength	450 nm	660 nm	5000 K, CRI 70
Performance	1392 mW 5.23 µmol/s 2.57 µmol/J	905 mW 4.96 µmol/s 3.30 µmol/J	314 lm 4.44 µmol/s 2.20 µmol/J

OSLON® Square is also available in additional white (CRI 70, CRI 80, CRI 90, CRI 95 from 2400 K to 6500 K)

Table 9: LED product portfolio (Duris® S5)

Duris® S5 — consumer mid- / high-power components (0.3 W and 1.0 W)

LED Type	GP PSLR31.14	GP PSLM31.14	GW PSLM31.FM	GW PSLM31.FM
Size	3.0 mm * 3.0 mm	3.0 mm * 3.0 mm	3.0 mm * 3.0 mm	3.0 mm * 3.0 mm
Color	Purple	Purple	Full spectrum white	Full spectrum white
Wavelength	450 nm + 660 nm	450 nm + 660 nm	4000K, CRI 90	4000K, CRI 90
Performance	332mW 1.51umol/s 1.6 umol/J	124mW 0.57umol/s 2 umol/J	25.6lm 0.41 umol/s 2.27 umol/J	110.7lm 1.77 umol/s 1.84 umol/J

The typical blue PPF contribution (400-500 nm) is 12.5% for Purple
Duris® S5 full spectrum white is also available in 5000K

E. Horticulture Tool

OSRAM Opto Semiconductors provides an additional application service which supports its customers in finding system solutions for horticultural lighting concepts.

https://apps.osram-os.com/Horticulture/

F. Fixture design considerations

OSRAM Opto Semiconductors performs extensive qualification tests to ensure stability and to improve the products. However, the detailed design of the application system is crucial to ensure that the LEDs are not affected by any harmful substances. Sulfur contamination should be especially avoided as this can lead to corrosion or deterioration.

For further information on this topic please refer to the application notes "Chemical compatibility of LEDs" and "Preventing LED failures caused by corrosive materials".

To ensure the proper function of the LEDs, the application system must be tested regularly in relation to the harmful substances from and around the application in conjunction with the LED materials.

As always OSRAM Opto Semiconductors supports its customers in finding the best solution for their specific application during their development and design process. For further information and support please contact your local OSRAM Opto Semiconductors sales office.

Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

www.ledlightforyou.com

ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM, Munich, Germany is one of the two leading light manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany), Penang (Malaysia) and Wuxi (China). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

DISCLAIMER

OSRAM Opto Semiconductors GmbH

Head office:

Leibnizstr. 4
93055 Regensburg
Germany
www.osram-os.com

OSRAM Opto Semiconductors