Horticulture lighting – seeded by LEDs

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Abstract

Today more than half of the world's population lives in cities; in 2050 two thirds of all people on earth will live in urbanized metropolitan areas. Traditional agriculture will not be able to provide such megacities with enough healthy nourishment. One possible solution: Urban farming. Growing tomatoes, melons and the like in the midst of the big city, and these plants will need to be fed as well, primarily with water and light. Compared to conventional agricultural lighting solutions, LEDs achieve significant increases in energy efficiency and can, thus, help vegetable and fruit cultivation in the metropolises of the world to finally become truly viable.

Arranged meticulously in long rows running down the large building, a sea of lettuce heads bathes in a pinkish light. What at first glance looks like a science fiction scenario already exists today in many metropolitan areas around the world. In so-called urban farms, people in Asia, the USA and Europe are cultivating vegetables, herbs and fruits in the middle of the cityscape. In modern versions of the urban garden plot agriculture has been relocated, for example, to old industrial buildings and warehouses.

For that new indoor horticulture farming you need special light: LEDs (Light Emitting Diodes) can supply light with a distinct red or blue component based on wavelength; exactly the light that plants such as iceberg lettuce, tomatoes and basil need for photosynthesis and for optimal growth. The light colors emitted by the diodes combine and produces the pink aura. Another advantage: by using LED light, the modern farmer is no longer dependent on natural light sources. With the supplemental LED lighting grow light levels can be raised in order to enhance photosynthesis and thereby improve growth and quality of the plants. With artificial LED light the light period can be controlled by extending the natural day length to get more plant growth in a shorter time. There is also the possibility of cultivation without daylight: regardless of rain or the lack of sunlight, the constant light produced by the LEDs ensures consistent growth of healthy, fertile plants.

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1 Introduction

Horticulture is a specialized term for agriculture that deals with art, science, technology, and the business of growing plants. In general, urban farming based on horticulture is implemented in commercial greenhouses, corporate indoor urban farms and vertically stacked farming configurations, as well as via home and do-it-yourself commercial and recreational farming. Urban farming seeks to provide an answer to the exciting challenges of agriculture and its role in an urban environment. The continuous expansion of modern metropolises in the presence of technology demands appropriate solutions for the improvement of the traditional farm-to-table process (harvesting, storage, processing, packaging, sales, and consumption).

The farm-to-table movement raises issues regarding the latest changes in the approach to food safety, freshness, seasonality, and economics for small farms. Believers of the farm-to-table ideal often point their motivation to the lack of fresh, locally grown produce, resulting in poor flavor and reduced nutritional integrity. The invasion of genetically modified foods contrasts the vanishing small family farms of heirloom and open-pollinated fruits and vegetables, with the dangers of a highly centralized food growing and distribution system. These trends are expected to boost the popularity and assimilation of urban farming regardless of the farming scale, as the process of locally incorporating indoor or outdoor gardening is both educational for enthusiasts and green-friendly for the environment.

Light affects the plant growth in many ways: The most important fact is the light quantity. The amount of light affects the photosynthesis process in the plant. But the light has to contain the right spectral composition. The composition of the different wavelength regions is important for the growth, shape, development and flowering of the plant. How the different regions of the wavelength in the illumination spectrum effect the plants is shown in table 1. The photoperiod, (i.e. the timing and duration of light) is crucial and mainly affects and controls the flowering of the plants. With the right horticulture lighting farmers are able to control the growth of the plants in different stages of the life cycle, independent from weather conditions and time of the year.

Wavelength range [nm]	Photosynthesis	Further Effects	Further Effects	Further effects
200 – 280		Harmful		
280 – 315		Harmful		
315 – 380				
380 – 400	Yes			
400 – 520	Yes	Vegetative growth		
520 – 610	Some	Vegetative growth		
610 – 720	Yes	Vegetative growth	Flowering	Budding
720 – 1000		Germination	Leaf building and growth	Flowering
> 1000		Converted to heat		

Table 1 Effects of different wavelength regions

Over the past millennia, agricultural farming has had to be entirely outdoors in order to obtain the sunlight necessary for growing plants. However, some countries with harsh, arid terrains struggled to support traditional outdoor farming. Breakthroughs in light-emitting diode (LED) technology are enabling opportunities to grow plants in ways that were previously not plausible. All plants use photosynthesis to convert carbon dioxide (CO_2), water (H_2O), and light energy, most often sunlight, into chemical energy for the plant (carbohydrates, $C_xH_xO_x$) and oxygen (O_2). For photosynthesis, the blue and red wavelength regions of the spectrum are most important as these wavelengths react with chlorophyll a and b.

As shown in Figure 1 chlorophyll a and b are mainly responsible for photosynthesis and for the definition of the photosynthetically active area, which represents the area of radiation that contains the photobiological important wavelengths (from 400 nm to 700 nm). Carotenoid represents further photosynthetic pigments also known as antenna pigments. The phytochromes pr (red) and pfr (far-red) are responsible for phytomorphogenic effects such as germination, plant growth, leaf building and flowering. These effects can be controlled by applying a spectrum that contains light in the sensitivity area of the phytochromes - which means with a certain mix of 660 nm and 730 nm. The red and far-red light mediates the conversion of phytochromes, which can control the triggers for flowering. LEDs are able to deliver all the important wavelengths and provide the energy for the plant to live and grow (Figure 1). The growing and harvesting of plants indoors and in greenhouses is set to greatly increase over the next several decades as a logical response to mankind's ability to guide the best type of lights efficiently and effectively upon plants. Plant growth will greatly benefit by the controls that can be realized through urban farming methods.

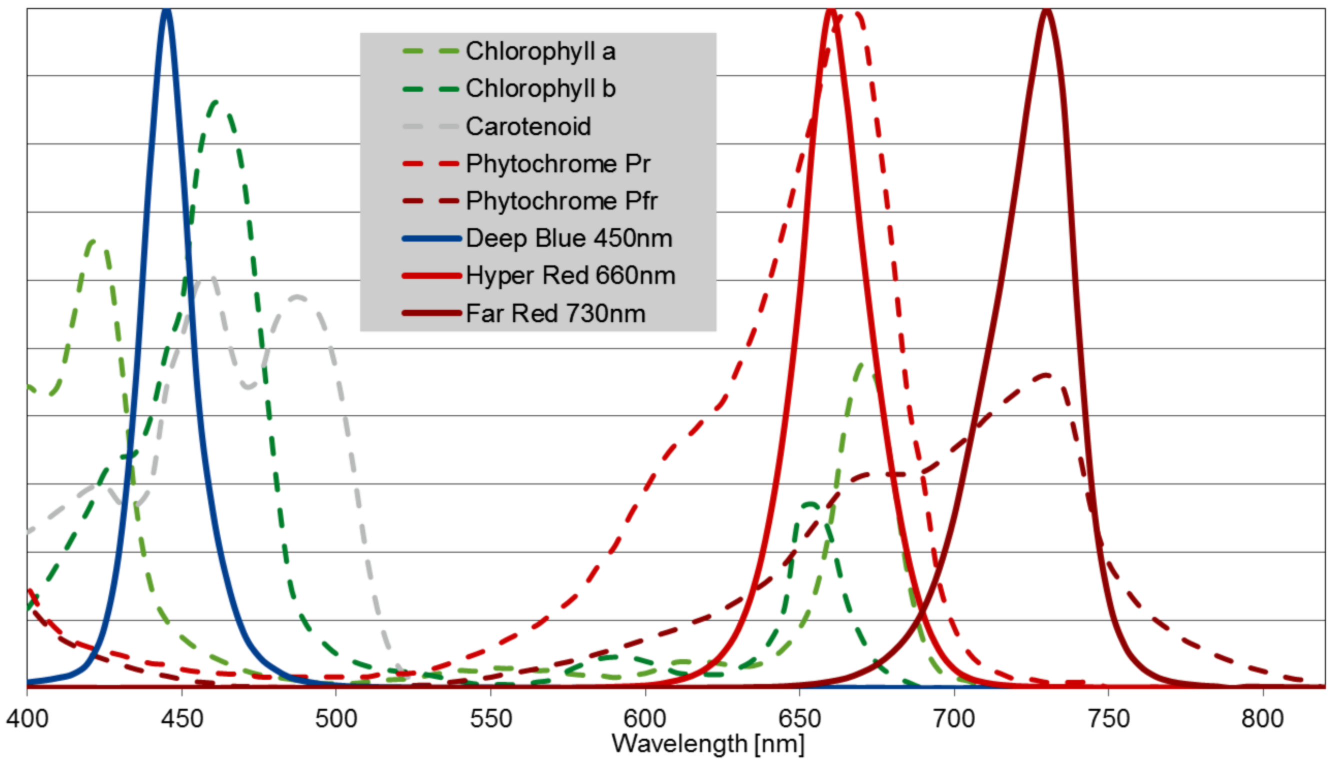

Figure 1 Photobiological sensitivities and LED spectra

In horticulture lighting the amount of light is not measured in lumen but in the number of photons. The perfect light for growing plants is not the same as for human vision because what a plant 'sees' is very different from what we as humans see. In our eyes the light is reacting with the photoreceptors, in the plant it is reacting with the chlorophyll, the carotenoids and the phytochromes. The common unit in horticulture lighting is µmol/s in the photosynthetically active region from 400 nm to 700 nm (Figure 2).

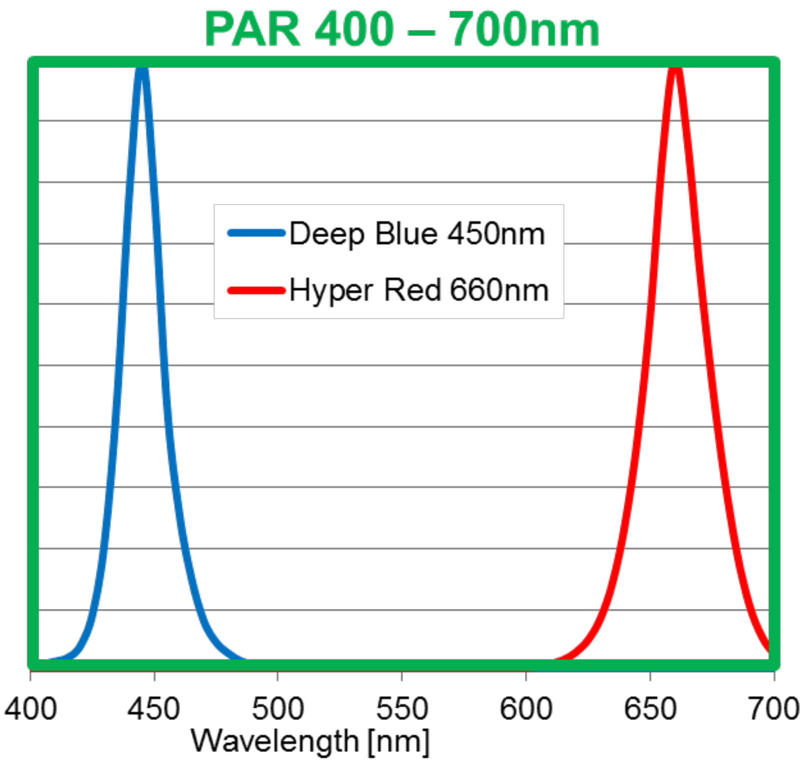

Figure 2 Photosynthetically active region

According to the Food and Agriculture Organization of the United Nations (FAO), urban farming will become increasingly popular all over the world, with 800 M of the 7.4 B people (11 percent) practicing it. The annual growth rate prognoses for urban farming projects exceed 25 percent. Europe is the present leader in this field. However, the Asia-Pacific region is expected to undergo the world's fastest rate of rural to urban development, meaning it will ultimately be the global leader within the time span of the next generation.

Urban farming eliminates the need for long-haul transportation and distribution of food, and reduces the distance from inception to the consumer. As issues related to lighting, power, and runoff are effectively dealt with, the adoption of urban farming methods will speed up.
In general, vegetables, with short production cycles - from planting to final harvest - are ideal candidates for consideration. With the continued inflow of humanity from rural to urban centers, city buildings, out of necessity, are becoming more crowded and are being built higher. Urban farming may take advantage of multiple floor buildings by developing farms at various floor levels throughout the building, to derive maximum utility from scarce urban space. Plants that do not need a lot of light, such as peppers and spinach, are logical crops for such urban farms.

2 Growing opportunities by enabling indoor photosynthesis via color LEDs

With the exception of roof-based gardens, urban farming in multi-level buildings is likely to require artificial light. The development of a wide variety of color LEDs means that urban farmers are no longer dependent on natural light sources. Today's widely used high-pressure sodium lamps (HPS) produce over 100 lm/W across a wide spread spectrum (Figure 3). But a high efficacy in Lumen per Watt is misleading since plants don't perceive light in this way. In addition, such lamps have a typical lifetime of only 8000 hours and need minutes to reach full power. Compared to HPS lamps, LEDs offer the benefits of delivering efficient light at the right wavelengths and over a long operating lifetime.

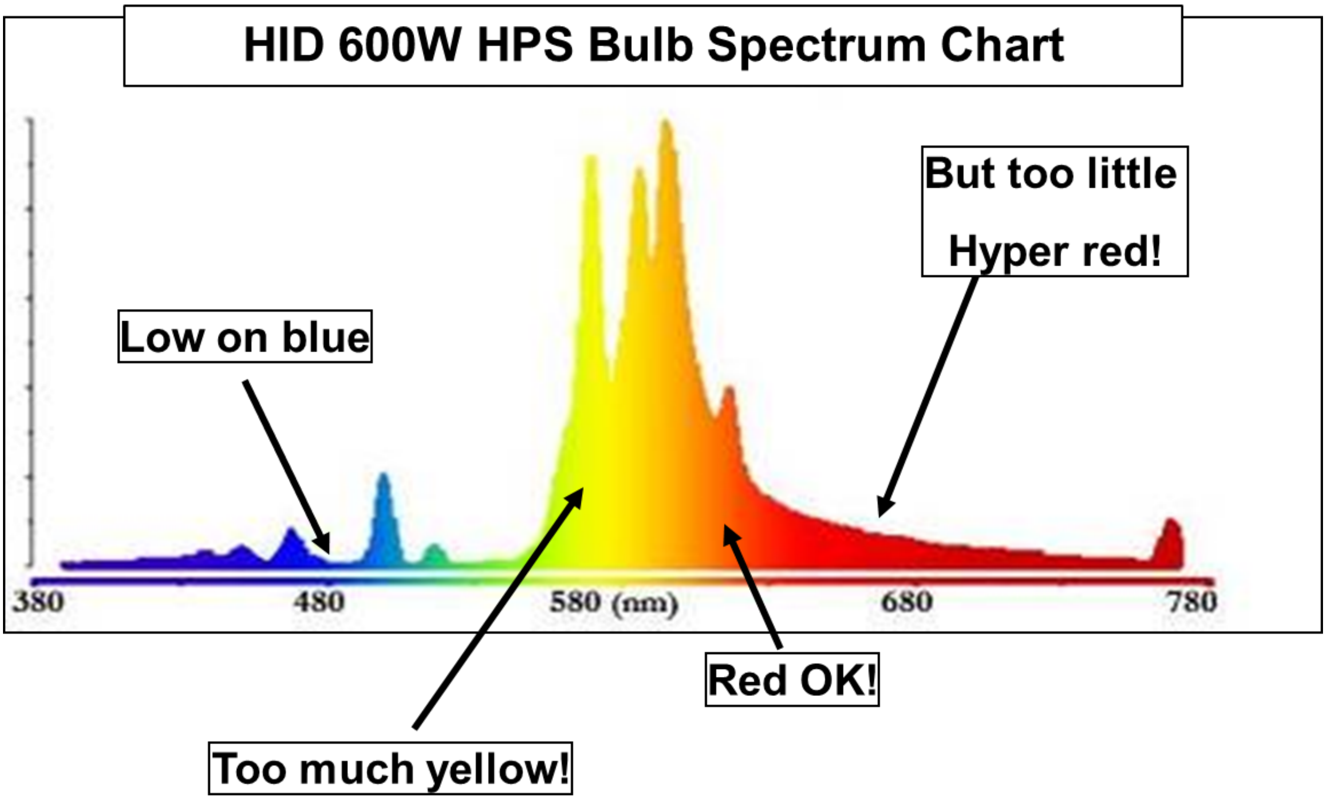

Figure 3 Spectrum of an HPS lamp

Solutions that bring together LEDs with the appropriate electronic controls can deliver tailor-made lighting solutions to make the most of plant growth irrespective of prevailing weather conditions or availability of natural light. Urban farmers have, due to the ability of modern LEDs, the opportunity to tune the wavelength spectrum of light and the timing of the exposure for different plants. Exposing the plants to larger components of red or blue wavelengths can foster maximum growth, while maximum energy saving options can be reached through properly selected solid-state lighting (SSL) and power controls.

It is clear, therefore, that a comprehensive lighting solution for successful urban farming needs a combination of the highest quality color LEDs and advanced power management and control semiconductor technologies. This is where Infineon Technologies in conjunction with LED suppliers such as OSRAM Opto Semiconductors - a well-known, well-established long-term supplier of color LEDs – can offer distinct advantages.

The OSRAM Opto Semiconductors product portfolio comprises high-performance LEDs for a wide range of applications including automotive and general lighting designs as well as miniature LEDs for indicators, infrared diodes (IRED), semiconductor lasers and detectors. Of particular interest to the urban farmer is the company's OSLON SSL family of wavelength-specific LEDs for horticulture applications. Integrating these LEDs into designs built using Infineon's comprehensive portfolio of integrated circuits (ICs) for lighting applications – including low-voltage and high-voltage power semiconductors, microcontrollers, controller ICs, driver devices and advanced color control solutions – delivers high-efficiency, flexible, controllable and reliable lighting designs optimized for horticulture applications.

OSRAM OSLON SSL product family

The OSRAM OSLON SSL product family is a continuation of a well-established platform that delivers the high efficacy necessary for professional indoor and outdoor lighting. Featuring a ceramic package for superior corrosion robustness, the devices address the need for long lifetime applications. The product family combines high performance with low thermal resistance that enables operation across a range of driving conditions. Key parameters are binned at 85°C, which is closer to the real customer application conditions.

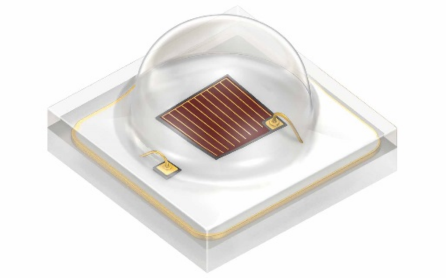

Figure 4 OSLON SSL

The OSLON SSL color line provides a unique portfolio of saturated colors, with the broad range of encompassing eight colors in wavelengths from 451 nm up to 730 nm.

Figure 5 OSLON SSL color

As mentioned previously, the most common colors for horticulture applications are deep blue (450 nm), hyper red (660 nm) and the outstanding far-red (730 nm), which contain the most important wavelengths for the photobiological processes of plant growth. All OSLON SSL LEDs are available with viewing angles of 80° and 150°, while the deep blue, true green, amber, hyper red and far-red can also be supplied with a 120° viewing angle. This variability ensures that there is an OSLON SSL device for the widest possible range of optical systems and designs.

color	type	$\lambda_{dom/\ peak}$	Typ Output (350 mA / 25°C)	radiation angle
deep blue	GD CSxPM1.14	450 nm	650 mW	80 ° /120°/ 150°
blue	GB CSxPM1.13	465 nm	33 lm	80 ° / 150°
true green	GT CSxPM1.13	528 nm	130 lm	80 ° /120°/ 150°
yellow	GY CSxPM1.23	590 nm	76 lm	80 ° / 150°
amber-red	GA CSxPM1.23	617 nm	105 lm	80 ° /120°/ 150°
red	GR CSxPM1.23	623 nm	72 lm	80 ° / 150°
hyper red	GH CSxPM1.24	660 nm	425 mW	80 ° /120°/ 150°
far red	GF CSxPM1.24	730nm	270 mW	80 ° /120°/ 150°

Table 2 Product portfolio of OSLON SSL color

With an ultra-compact 3 mm x 3 mm footprint and a maximum driving current of up to 1 A the OSLON SSL color is the perfect solution for high-performance solutions in urban farming. By providing a very low thermal resistance, the LEDs can help engineers lower heatsink costs while delivering greater light output – especially when used in conjunction with the appropriate power management and control semiconductors. Alongside deep blue (450 nm), hyper red (660 nm) and far-red (730 nm), the family incorporates white LEDs to complete a comprehensive CRI and CCT range that matches the full gamut of possible horticulture lighting requirements.

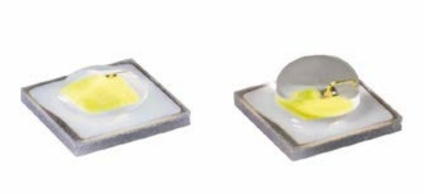

Figure 6 OSLON SSL white

Type	Radiation angle	CCT [K]	CRI (typ.)	Typ. Output
GW CSxPM1.PM	80°/150°	3000 – 6500	72	144 lm @ 5000 K, 85°C
GW CSxPM1.EM	80°/150°	2500 – 5000	82	117 lm @ 3000 K, 85°C
GW CSxPM1.CM	80°/150°	2700 – 4000	92	103 lm @ 3000 K, 85°C

Table 3 Product portfolio of OSLON SSL white

3 Managing LEDs in horticulural lighting designs

Solid-state lighting devices such as LEDs must be powered, managed and controlled. OSRAM Opto Semiconductors color LEDs are best controlled using technology from a company that understands well how to power and drive them. Infineon Technologies, through a combination of innovation and technology leadership, has achieved a number one ranking in semiconductor power products and offers many other solutions essential to horticulture lighting designs. Infineon is focused on making life easier, safer, and greener—with technology that achieves more, consumes less power, and is accessible to everyone.

To successfully design horticulture urban lighting with color LEDs, system efficacy (Luminous FluxOUT/PowerTOTAL), power conversion efficiency (POUT/PIN) and design flexibility are among the most critical points. Often these interrelationships result in design compromises for engineers. Electronic power consumption is an issue, as is the desire to implement proper thermal management in order to ensure long lifetime for the colored LEDs and the associated

SSL system electronics. However, adding external sensors with positive temperature coefficient (PTC) or negative temperature coefficient (NTC) thermistors to the SSL system raises system cost and complexity.

Infineon's technologies, when used in combination with OSRAM Opto Semiconductors' OSLON SSL color LEDs, address many of these issues.
The key to making the best use of advanced LED technologies such as those from OSRAM Opto Semiconductors is selection of the most appropriate technologies for driving, controlling and managing the lighting system. Depending on the particular application, this is likely to include LED drivers and controllers, microcontrollers, AC-DC and DC-DC power conversion technologies and power transistors.

Consideration will need to be given to design issues such as system power requirements, whether the LEDs are configured in a single- or multi-string arrangement, and what type of diming functionality may be needed. Device selection criteria will range from topology considerations in the case of LED drivers to, efficiency, size, ease-of-use and price issues when it comes to MOSFETs.
Figure 7 illustrates the range of components that Infineon offers for LED-based lighting applications.

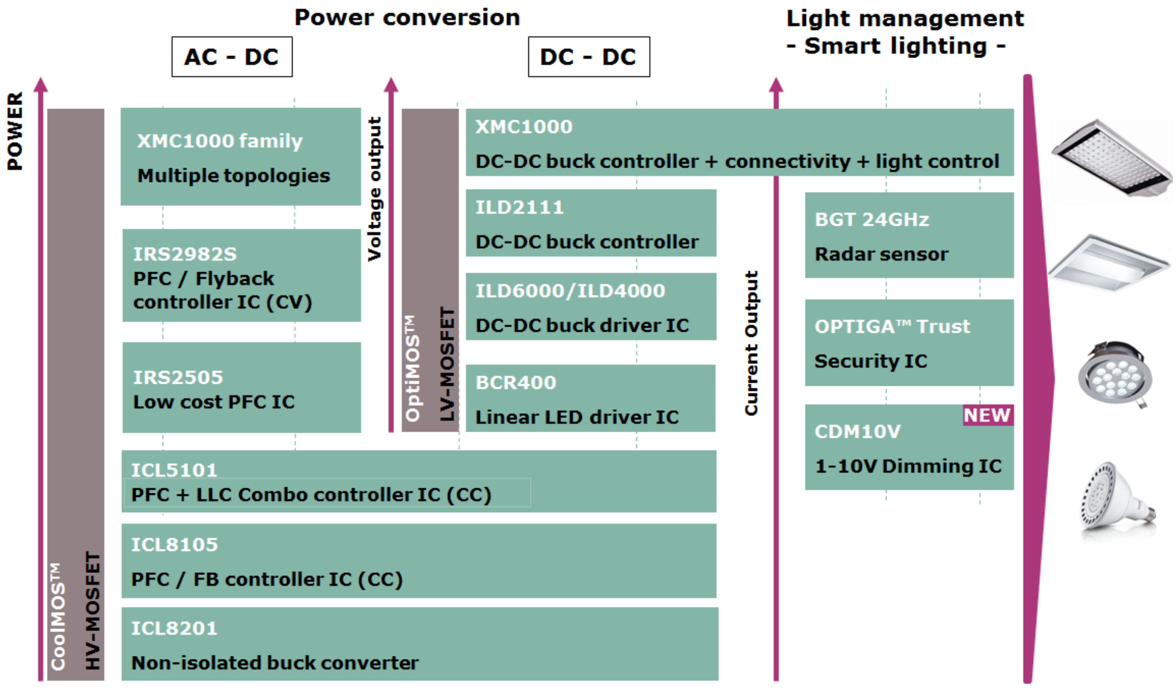

Figure 7 Expanded lighting portfolio

4 Single-color string topologies

4.1 < 100 watts

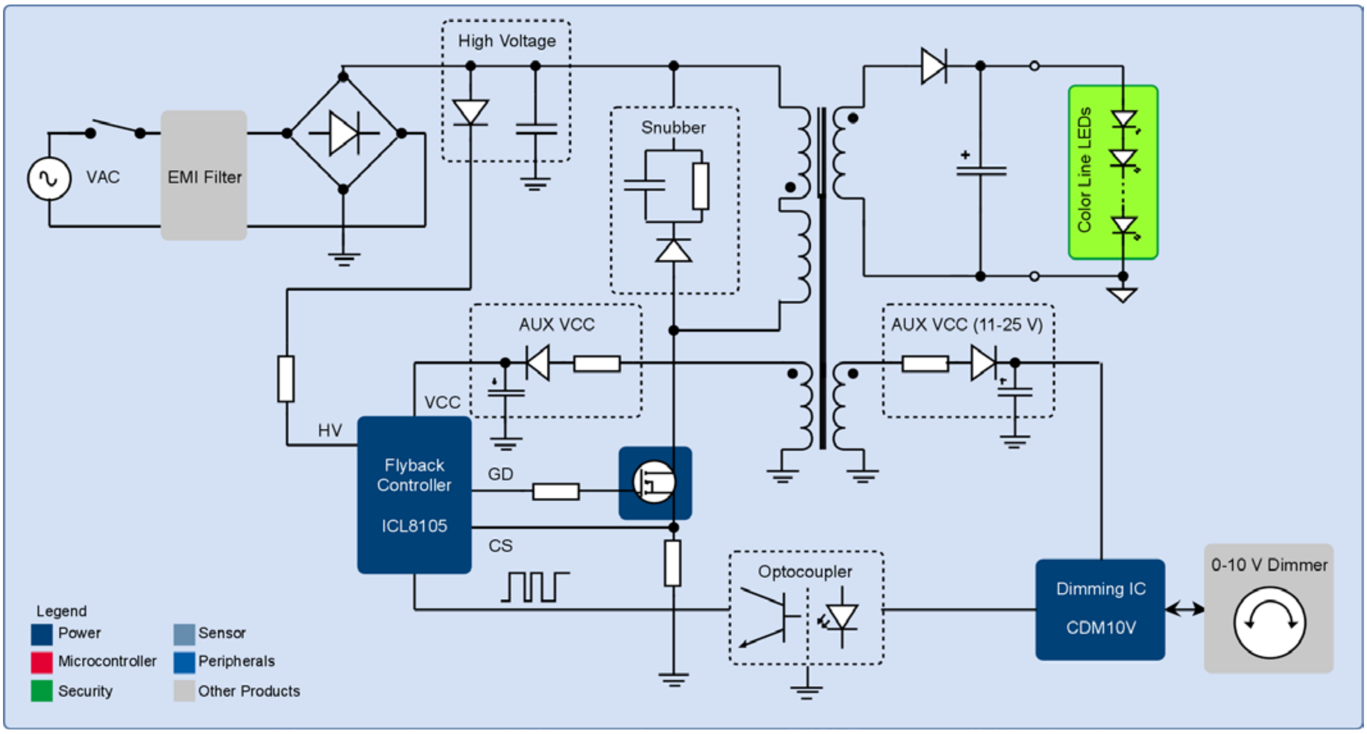

Figure 8 Single-color string topology less than 100 W

For single-color topologies operating below 100 W, the Infineon ICL8105 flyback controller is a great fit, especially when incorporated with the innovative CDM10V dimming IC. This high-performance configurable single stage flyback controller, with Power Factor Correction (PFC) builds a constant current output LED driver. The ICL8105 is fully compatible with universal AC input voltages and provides advanced control algorithms for multi-operation modes such as quasi-resonant, discontinuous conduction or active burst mode. The controller delivers high efficiency (91%), high power factor (0.90) and low harmonic distortion (<10%) through the entire load range with full functionality and guaranteed smooth transitions between operating modes. The optional active burst mode control scheme significantly extends the dimming range and is aligned to the line frequency, avoiding effects like flicker or shimmer while also reducing audible noise. The chip offers many digitally configurable parameters giving the flexibility to easily adapt solutions for LED currents, ripple reduction, latch or restart mode and much more. As a result, one device can be used to address several different requirements.

Infineon's IRS2982 incorporates a single stage LED converter suitable for many topologies, e.g. PFC/Flyback or boost, buck, SEPIC. It runs CrCM and DCM for a wide load range. With supporting primary side control the BOM cost is reduced. Applying an external MCU is easily possible to support dimming or controlling interfaces and sensors.

4.2 > 100 watts

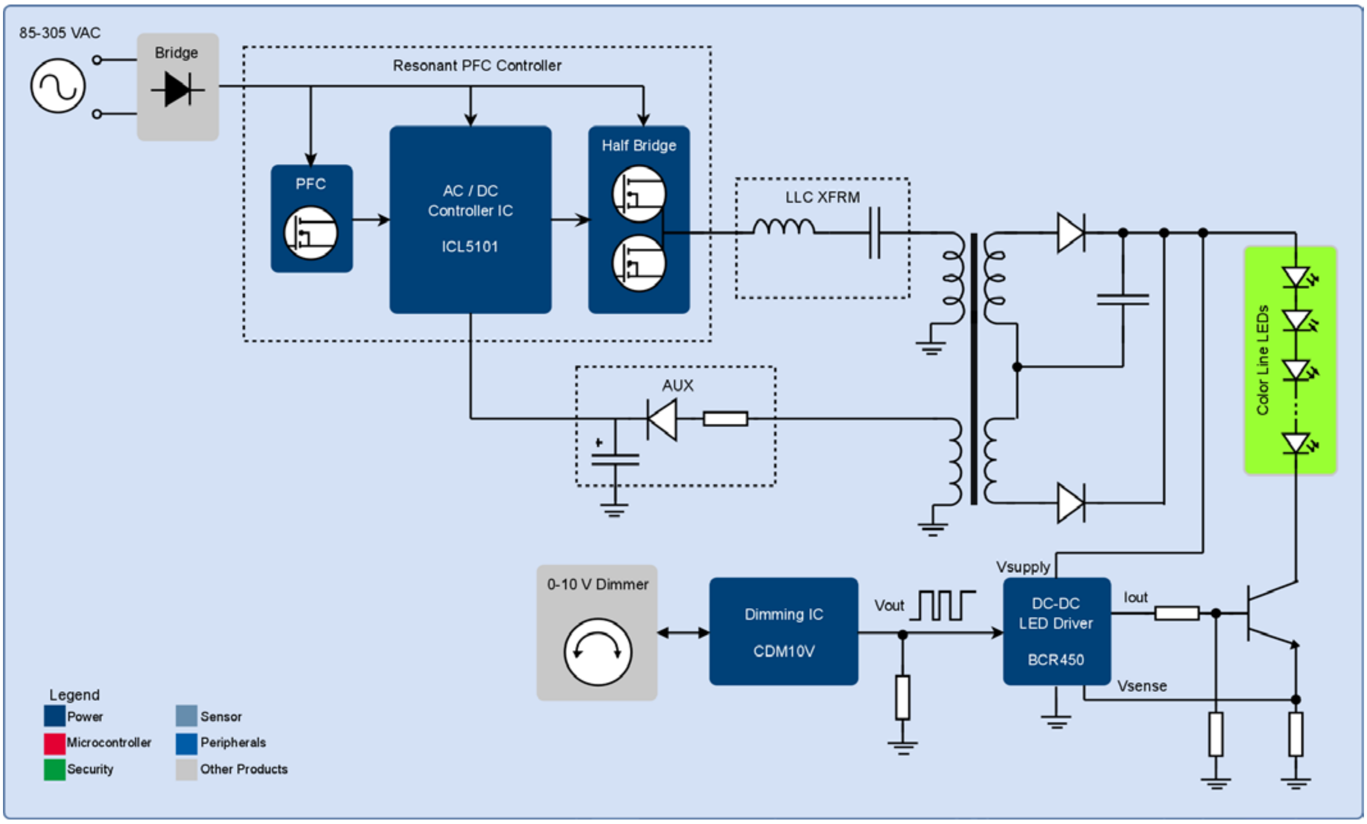

Figure 9 Single-color string topology greater than 100 W, with BCR450

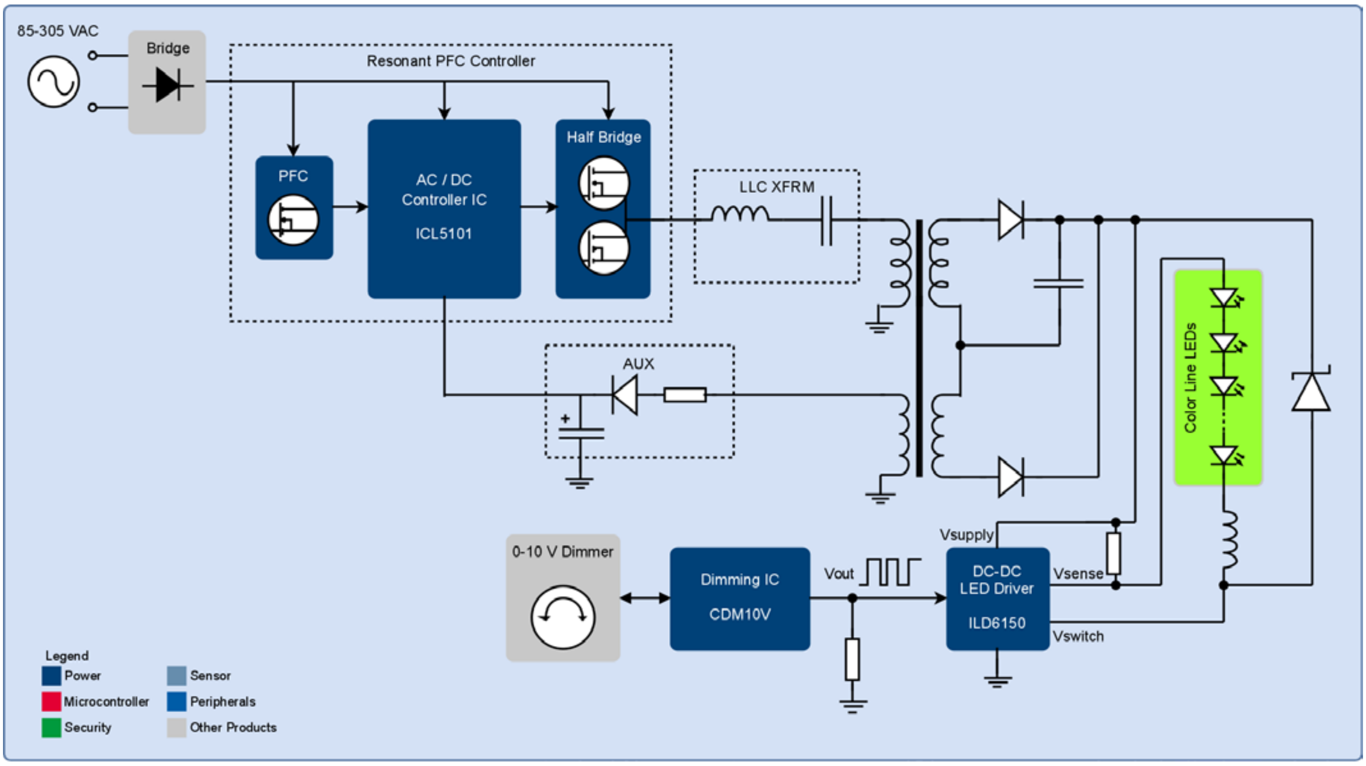

Figure 10 Single-color string topology greater than 100 W, with ILD6150

The ILD6000 DC-DC LED driver series is a unique step-down (BUCK) converter family that allows input operation up to 60 V_{DC}, the maximum Safety Electrical Low Voltage (SELV). The ILD (Infineon Laser Driver) family is able to handle a wide range of current up to 1.5 A and works well for one to 18 colored LEDs with little to no change in the number of external components. Efficiencies to 98 percent ensure little power is wasted, while a fast 1 MHZ switching speed minimizes required inductor size. With the integrated MOSFET, this beneficial combination allows easy and simple designs for small form-factor solutions. The ILD6000 series with the ILD6070 (60 V_{DC}, 0.7 A) and the ILD6150 (60 V_{DC}, 1.5 A) deliver excellent solutions for color LED applications - solutions that provide designers with their own internal thermal sensor for full integration. As a result, there is no need for an external NTC/PTC device, which saves extra costs. Optionally, engineers can disable the internal sensor and incorporate an external thermal NTC/PTC device for maximum design flexibility.

The BCR450 Power LED driver IC from Infineon can also be used in place of the ILD6000 series for DC-DC topologies that are greater than one hundred watts (>100 W). This works well with both single- and multi-color topologies. The device can be triggered by an external signal, which is also suitable for regulating the brightness of the LEDs through PWM dimming.

5 Multi-string topologies

5.1 Tuning in full color

Full color tuning (FCT) and multicolor LED strings require accurate control to ensure the correct power output for providing a specific mixture of wavelengths for the plants. This is best achieved through the use of a microcontroller (MCU). Infineon is a leader in providing microcontrollers for color LED applications such as those used in urban farming. The company's XMC™ series, for example, comprises 32-bit ARM® Cortex™-M industrial microcontrollers that feature an application-specific capability for lighting, motor control, and power conversion.

5.2 Brightness and color control unit

One of the XMC™ application-specific features for lighting is a Brightness and Control Unit (BCCU) that simplifies digital LED dimming and eases color control applications. It is specifically designed to automatically control the dimming level and color of multichannel LED lamps, requires little user code, and supports completely flicker-free operation due to its 12-bit pulse density modulation (PDM) dimming signals. The exponential dimming engine provides automatic gradual brightness change and invisible dimming steps.

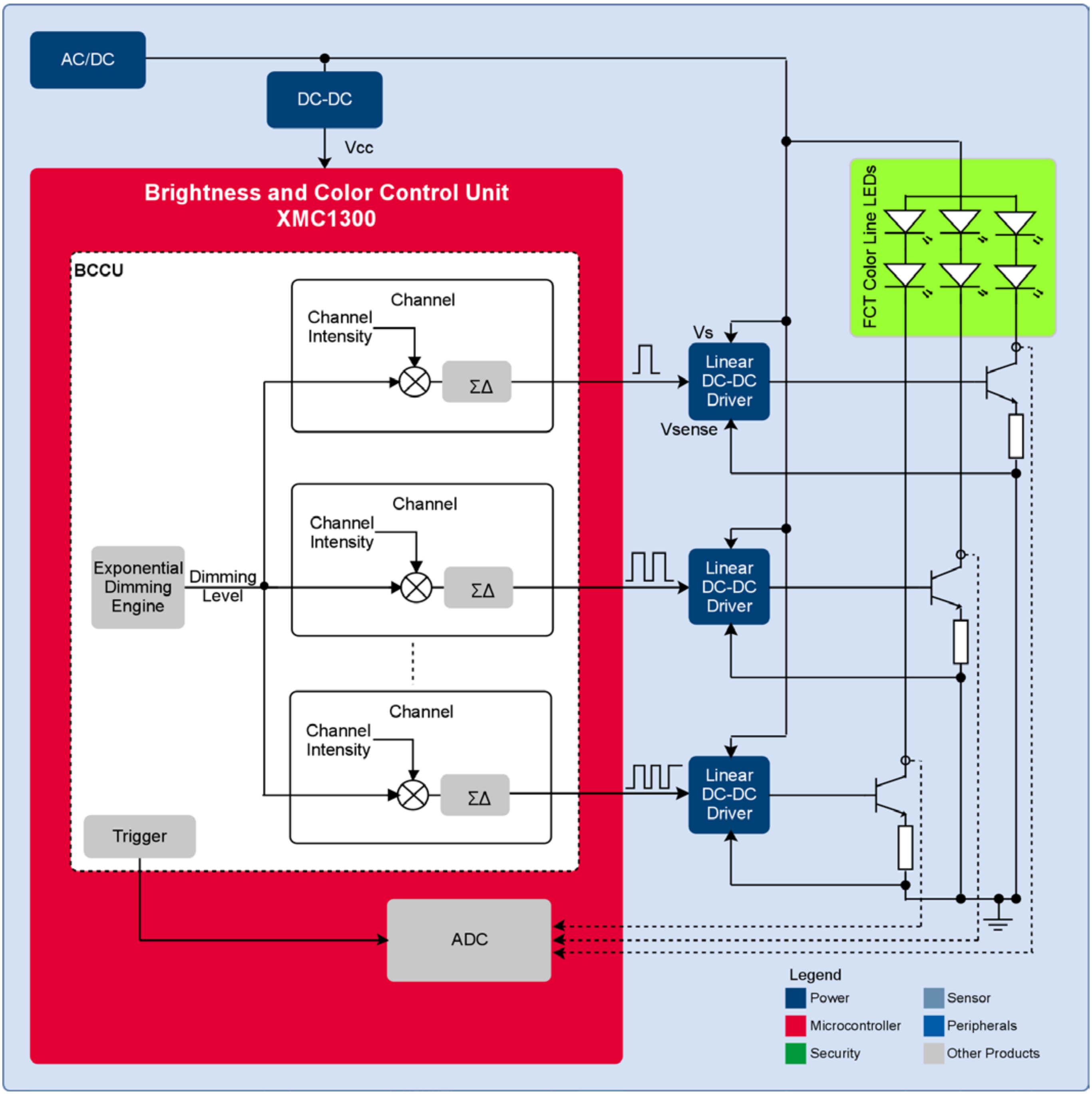

Figure 11 Multi-string topology with FCT and BCCU

6 Reference design – horticulture module

Together with partners LEDiL and Fischer electronic, a reference module for horticulture lighting applications has been developed (Figure 12). The PCB was implemented with 20 OSLON SSL 150 hyper red and 5 OSLON SSL 150 deep blue LEDs. All OSLON SSL products have the same footprint. The different colors can easily be changed to address the need of

Figure 12 Reference design – horticulture module

different plants. By addition of a diffractive lens, it is possible to get the right amount of light and energy precisely where it is needed – for example, on a field of green seedlings or dozens of tulips in full bloom.

There are different ways to illuminate a greenhouse. The conventional method is the toplighting (Figure 13). The high power consumption and the heat of conventional HPS luminaires demand that there be a distance between the light source and the plants. By using LEDs it is possible to minimize that distance or change the illumination system to interlighting (Figure 14). In this case the lighting is in-between the plants and leaves. This should reduce the shadowing of the leaves which may occur by top lighting, thus increasing the amount of light - even on the lower leaves. Unlike the hot HPS luminaires, the comparatively low temperatures on the LED luminaire won’t damage the plants.

Figure 13 Toplighting

Figure 14 Interlighting

Different LED light ratios can be used to serve different purposes. Luminaires can be optimized for efficiency, vegetative growth or seedlings by changing the amount of light in different regions of wavelengths. In Figure15 there are some example LED light ratios for different implementations.

General purpose – high efficiency		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	23%
GH Cxxx	660nm	77%

The highest efficacy of µmol/J from the spectrum can be achieved by using the 660nm Red LEDs combined with some 450nm Blue LEDs to maintain a reasonable ratio between the wavelengths

Vegetative Growth		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	50%
GH Cxxx	660nm	50%

Especially for growth of the leafy green vegetable plants the vegetative growth ratio is used to achieve fastest growth where visible assessment of plant health is not important

Best for seedlings		
Type	Wavelength	mW Ratio
GD Cxxx	450nm	75%
GH Cxxx	660nm	25%

A high blue content in the spectrum is recommended for growth of the seedlings.

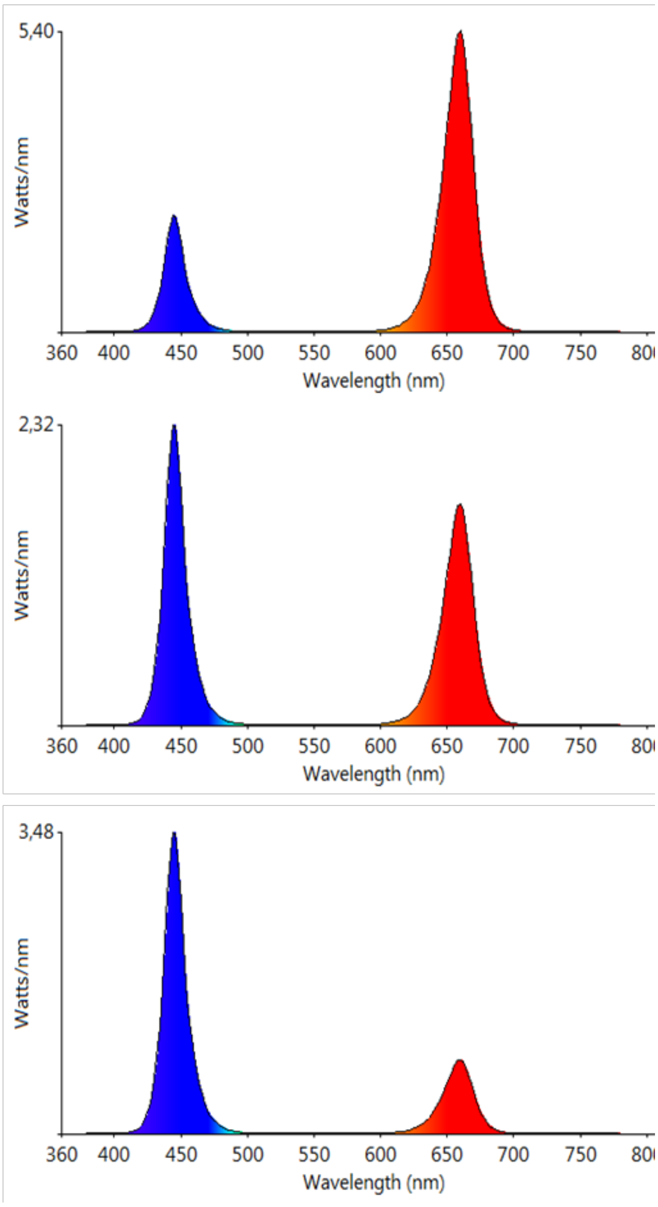

Figure 15 Example LED light ratios

7 Conclusion

Urban farming growth in the world is now seeded by LEDs. High-quality colored LEDs perfectly target and stimulate the available opportunities to support plant growth, while power conversion and intelligent lighting LED driver solutions ensure that horticulture lighting is green in every sense of the word. Artificial illumination with accurately controlled and managed LEDs enables effective plant growth. Combined, OSRAM Opto Semiconductors and Infineon provide the technologies that is perfect for sowing the seeds of this growth.

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