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IES Progress Report 2015

AGi32 Version 16 Calculates Photosynthetic Active Radiation (PAR) for Horticultural Applications

Lighting for plants is different from lighting for humans. Light energy for humans is measured in lumens, with light falling onto a surface measured as illuminance with units of lux (lumens per square meter) or footcandles (lumens per square foot). Light energy for plants, on the other hand, is measured as photosynthetic active radiation (PAR), with light falling onto a surface measured as photosynthetic photon flux density (PPFD) with units of Micromoles per second per sq. meter (μmol/s-m2).

	Light for Humans	Light for Plants
Radiant power, 400-700 nm	Lumens	Photosynthetic Active Radiation (PAR)
Light falling onto a surface	Illuminance	Photosynthetic Photon Flux Density (PPFD)
Units	Lux, Footcandles	Micromoles per second per sq.meter (μmol/s-m^2)

The spectrum to which plants are most sensitive varies with the species, but for most plants the spectrum is very similar to the visual spectrum to which humans are sensitive, approximately 400-700 nm. This is the range that stimulates photosynthesis. Any photons within this spectrum that are absorbed by the plant will contribute to photosynthesis. However, not all wavelengths have an equal likelihood of being absorbed, as determined by the various plant pigments that might be present. As with human vision, plants are more likely to respond to (absorb) light in some wavelengths than others.

The mathematical basis for the calculation of PPFD:

If the spectral power distribution (SPD) of a light source is known across the relevant wavelengths (400-700 nm), then the amount of photosynthetic energy available to plants can be determined. Based on its SPD, a light source will have a conversion factor that can be used to translate luminous flux density (illuminance) received by the plant into photosynthetic photon flux density (PPFD), in μmol/s-m^2.

One watt of radiant power at 555 nm is by definition equal to 683 lumens. Given the CIE 1931 luminous efficiency function $V(\lambda)$, we can calculate the spectral radiant flux $\Phi(\lambda)$ for plants in watts per nanometer for each lumen as:

$\Phi(\lambda)$/lumen = $[W_{rel}(\lambda)] / [683 * \Sigma(400\text{-}700) [V(\lambda) W_{rel}(\lambda) \Delta\lambda]]$

where $W_{rel}(\lambda)$ is the relative spectral power distribution and $V(\lambda)$ is the luminous efficiency function at wavelength λ.

With this, the photosynthetic photon flux (PPF) per nanometer in micromoles per second per nanometer can be calculated:

PPF /nm = $(10^{-9}) * [\lambda \Phi(\lambda)] / (N_a hc)$,

where:

N_a = Avogadro's constant, 6.022×10^{23}

h = Planck's constant (6.626×10^{-34} joule-seconds)

c = speed of light, 2.998×10^{8} m/s

λ = wavelength in meters.

Summing over the range of 400-700 nm yields the photosynthetic photon flux (PPF) per lumen for the given light source:

Approximately $8.359 * 10^{-3} * \Sigma(400\text{-}700) [\lambda \Phi(\lambda) \Delta\lambda]$

Given an illuminance value (lux or footcandles), we can similarly calculate the photosynthetic photon flux density (PPFD) in micromoles per second per square meter (μmol/s-m^2) for the given light source.

SPD graphs are relatively easy to come by, but finding the same information in tabular form, needed for the above equations, is more difficult. One source is CIE 15:4, Colorimetry (2004). Adding digitized data from one LED manufacturer's white LED SPD curves, we can arrive at the following table of PPFD Conversion Factors, for converting illuminance in *kilolux* to PPFD in μmol/s-m^2:

Light Source	Conversion Factor
CIE A (incandescent, 2856K)	17.0
CIE 5000K daylight (D50)	28.5
CIE 5500K daylight (D55)	28.0
CIE 6500K daylight (D65)	25.2
CIE 7500K daylight (D75)	22.8
CIE HP1 (standard HPS, 1959K)	3.9
CIE HP2 (color-enhanced HPS, 2506K)	13.0
CIE HP3 (metal halide, 3144K)	9.2
CIE HP4 (metal halide, 4002K)	9.0
CIE HP5 (metal halide, 4039K)	13.9
2700K white light LED (Philips Luxeon Rebel LXW9-PW27)	16.9

3000K white light LED (Philips Luxeon Rebel LXW9-PW30)	18.2
3500K white light LED (Philips Luxeon Rebel LXW7-PW35)	17.4
4000K white light LED (Philips Luxeon Rebel LXW8-PW40)	17.7
5000K white light LED (Philips Luxeon Rebel LXW8-PW50)	14.6

These Conversion Factors are available in the PPFD Factors dialog in AGi32.

The above summary is from the AGi32 software Help System and has been adapted from the complete article *Photometry and Photosynthesis by Ian Ashdown, Chief Scientist, Lighting Analysts, Inc.* The complete article can be found in Lighting Analysts All Things Lighting Blog. This article has also been published in Mar/Apr 2015 issue of *LED Professional Review* (www.led-professional.com).

Calculating Photosynthetic Photon Flux Density (PPFD) in AGi32

As described above, the equivalent to illuminance (fc or lux) for plants is Photosynthetic Photon Flux Density. Specifying PPFD as a calculation metric in AGi32 is performed by selecting a specific calculation type (like illuminance or luminance) for the calculation point grid rather than as a light source characteristic. This assumes that all sources contributing to the calculation grid have the same PPFD Factor.

Calculation points must be placed on a surface or on an imaginary work plane. PPFD is then selected as the calculation type and the appropriate PPFD Factor either selected from the table, or, if known, entered in the field provided. AGi32 will use the PPFD Factor to convert illuminance to PPFD in micromoles per second per square meter (μmol/s-m^2).

To specify PPFD calculations in AGi32:

1. Begin with a Room or Object that will have the calculation points in or on it. Initiate the *Automatic Placement* command.
2. Navigate to the Workplane or Tag the surface(s) where you wish to place the points.
3. Set the Point Spacing.
4. For the Calculation Type, select *5- PPFD* (Figure 2).
5. For the PPFD Factor, click in the field to see the ellipsis (...) button, and then click on that button to open the PPFD Factors dialog.
6. Select one of the listed light sources, or add your own to the table by entering a new source name in the blank field at the bottom (marked with an asterisk) as well as a PPFD Factor (the conversion factor) in the second column (Figure 2).

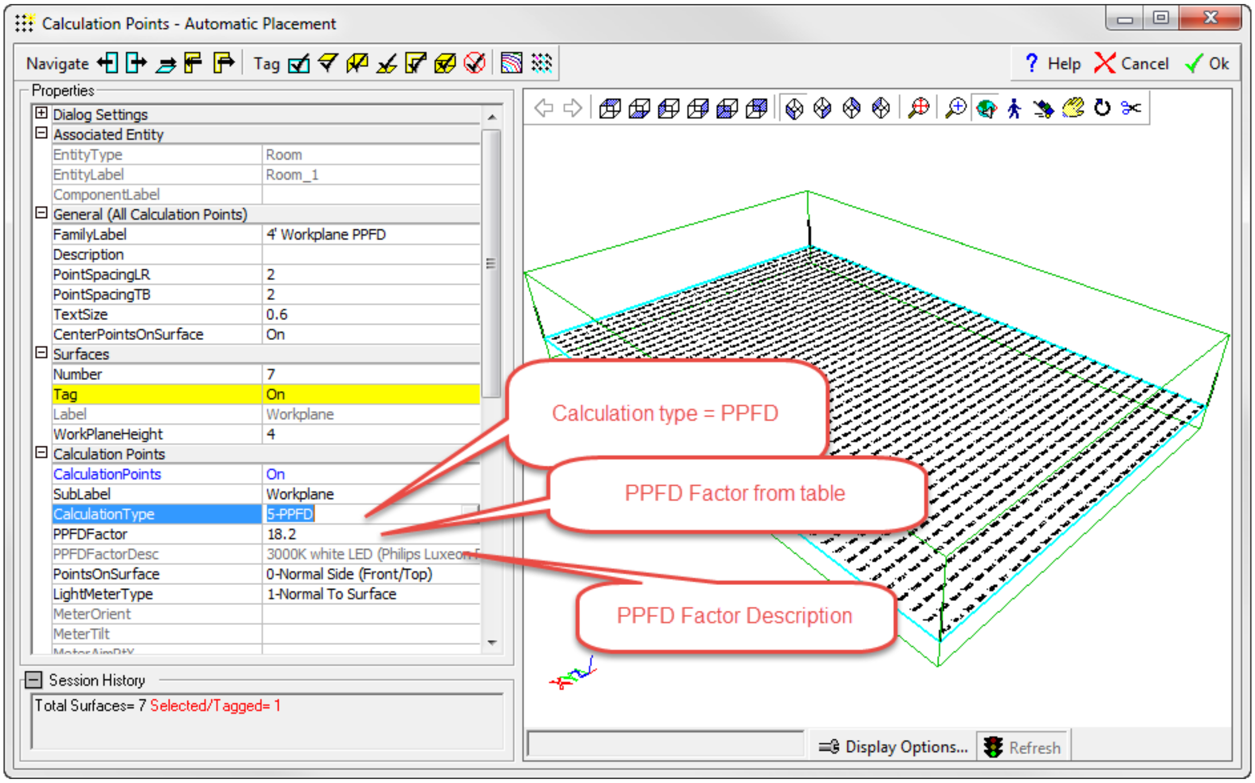

Figure 1 - AGi32 Automatic placement calculation points dialog

7. Click *OK* to return to the Automatic Placement dialog. The PPFD Factor and the source description will appear below the Calculation Type (5- PPFD).

9. Click *OK* to complete the command. The points will be placed as specified.

10. Calculate the results (Figure 2).

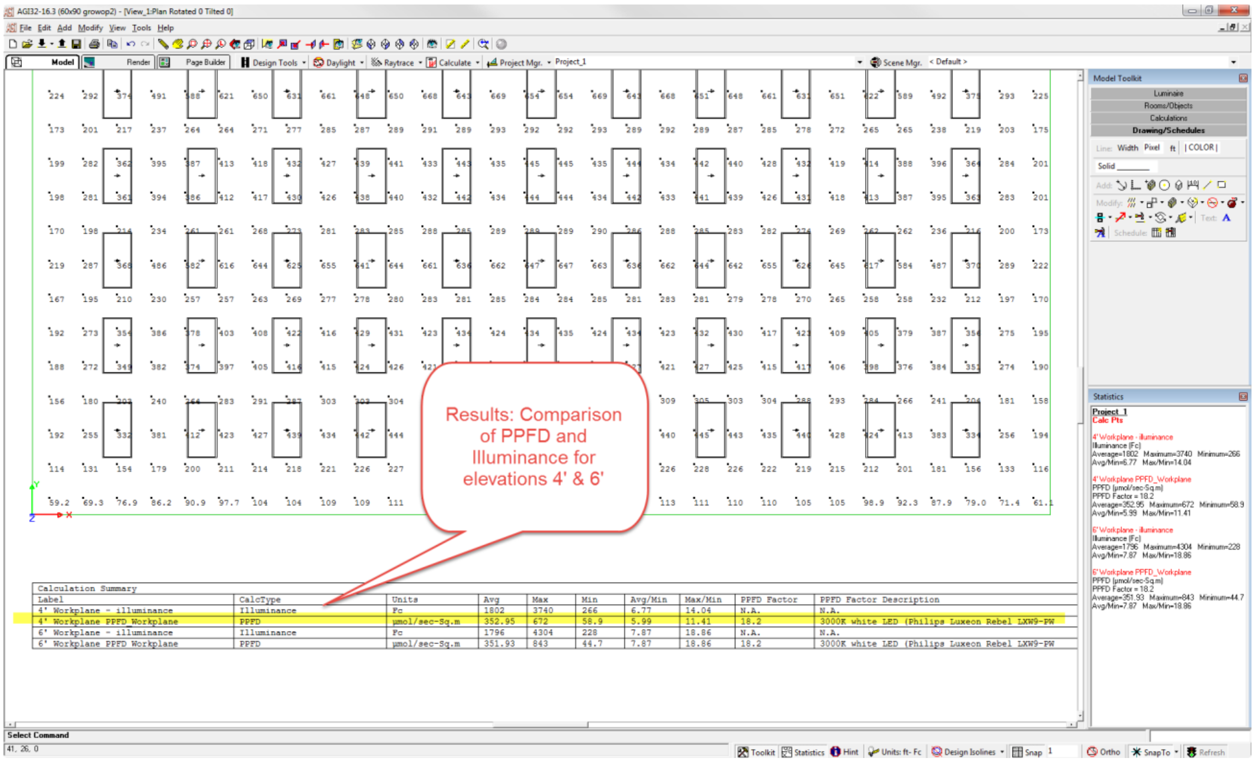

Figure 2 - Calculated results shown in AGi32

About Lighting Analysts and lighting standards

Following Lighting Analysts mandate of being proactively involved in the development of lighting standards worldwide, we contribute our perspective of being one of the companies responsible for implementing the latest calculation standards in lighting design software.

Lighting Analysts senior scientist, Ian Ashdown, is a member of the American Society of Agricultural and Biological Engineers (www.asabe.org) ES-311 Plant Growth LED Lighting Committee. Activities of this committee are documented in the LEDs Magazine article: *Stakeholders make progress on LED lighting horticulture standards*, Published on: June 2, 2015, by Jianzhong Jiao, Director of Regulations and Emerging Technologies, OSRAM Opto Semiconductors

This committee is developing radiation metrics for plant growth that will unify and extend the definitions of solar and electric lighting radiation, including ultraviolet, visible and far-red (700 nm to 800 nm).

Lighting Analysts contribution as an invited member to this project has been to research existing plant lighting metrics, write the formal metric definitions, and ensure that the metrics will be compatible with CIE Lighting Vocabulary and IES RP-16-10 definitions. Ian also wrote the document introduction and researched the ISO standards on solar radiation, along with contributing our knowledge and experience with radiometric and spectroradiometric measurement techniques and technology.