MAKING SENSE OF Light Sensors

Learn to convert radiation data from your environmental computer into daily light integral.

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During the winter, greenhouse growers in Northern regions often become concerned that their plants are not receiving enough light to produce good quality crops. However, many do not know what light levels their crops are receiving because they do not understand the radiometric units their environmental computers display each day. In this article, we discuss light sensors, light units, and how to convert the units your environmental computer displays into more meaningful values.

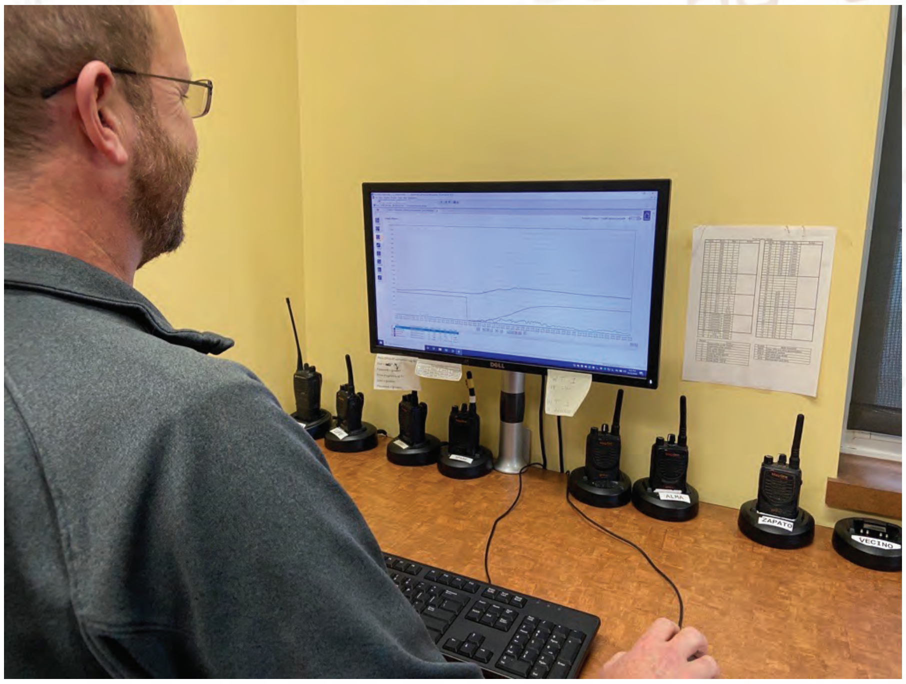
Plants use and respond to wavelengths of solar radiation ranging from UV-B (as low as 280 nm) to far-red (FR) light (as high as 750 nm or so). However, photosynthesis is mainly stimulated by wavelengths of light between 400 and 700 nm, which is known as photosynthetically active radiation (PAR). Outside of the PAR range, energy can contribute less or not at all to photosynthesis but may influence the concentration of pigments (UV radiation), regulate photoperiodic and elongation responses (FR radiation), and increase plant temperature (infra-red; IR). These wavebands as well as other light terms and units are defined in the sidebar.

There are several units used by scientists and growers to measure light both inside and outside the greenhouse. For plant applications, we should use light units that represent the number of photons within PAR since they are what drive photosynthesis and thus plant growth. Therefore, we need to use quantum units. Since the number of photons is so large, we measure them in moles (mol) of photons, and 1 mol = 6.022×10^{23}. One micromole (µmol) equals 1×10^{-6} mol so therefore, 1 µmol = 6.022×10^{17}.

Most environmental control computers are connected to a pyranometer mounted to a weather station outside the greenhouse (Figure 1). This sensor measures total short-wave energy from 300 to 2,800 nm from the sun and sky. This includes UV radiation, photosynthetic (and visible) light, near infra-red (NIR), and IR. These measurements can be used to assist in an array of climatic and irrigation decisions and environmental control settings such as heating, cooling, shading, irrigation, and supplemental lighting. Figures 2 and 3 show screenshots as examples of radiation sums reported by environmental control computers.

Pyranometers measure total short-wave energy, but we are interested in photons within PAR. A pyranometer provides radiometric units, which are typically expressed in watts per square meter ($W \cdot m^{-2}$) or joules per square meter and second ($J \cdot m^{-2} \cdot s^{-1}$). (Note that 1 W = 1 $J \cdot s^{-1}$.) Since we are most interested in PAR, we need quantum units in $\mu mol \cdot m^{-2} \cdot s^{-1}$. Therefore, we need to do some math to convert from radiometric to quantum units.

As noted above, 1 $J \cdot m^{-2} \cdot s^{-1}$ equals 1 $W \cdot m^{-2}$. The approximation that 1 $W \cdot m^{-2}$ or $J \cdot m^{-2} \cdot s^{-1} \approx 4.57\ \mu mol \cdot m^{-2} \cdot s^{-1}$ for sunlight (conversely, 1 $\mu mol \cdot m^{-2} \cdot s^{-1}$ = 0.22 $W \cdot m^{-2}$) can be used IF the $W \cdot m^{-2}$ or $J \cdot m^{-2} \cdot s^{-1}$ that your environmental



Chuck Jagger, director of production at Henry Mast Greenhouse in Byron Center, Michigan is downloading accumulated radiation data from their environmental computer to calculate the daily light integral (DLI) for the previous day.

Figure 1. A pyranometer mounted on a weather station atop a greenhouse. *(Photo: Jonah Brown)*

	Radiometric	QUANTUM Instantaneous average (per second)	Cumulative (daily light integral)
	$J \cdot cm^{-2} \cdot d^{-1}$	$\mu mol \cdot m^{-2} \cdot s^{-1}$	$mol \cdot m^{-2} \cdot d^{-1}$
Yearly Minimum	49	11	1.0
Yearly Maximum	2,951	669	57.8
Yearly Average	1,230	279	24.1

Table 1. Example showing the yearly minimum, maximum, and average solar radiation conversion from joules per square centimeter per day ($J \cdot cm^{-2} \cdot d^{-1}$) to micromoles per square meter per second ($\mu mol \cdot m^{-2} \cdot s^{-1}$) to the daily light integral in moles per square meter per day ($mol \cdot m^{-2} \cdot d^{-1}$) for a greenhouse in a northern latitude.

TERM	DEFINITION
Daily light integral (DLI) ($mol \cdot m^{-2} \cdot d^{-1}$)	Cumulative amount of PAR that is delivered each day. It is expressed as moles of light (mol) per square meter (m^{-2}; 10.8 square feet) per day (d^{-1}) or ($mol \cdot m^{-2} \cdot d^{-1}$).
Electromagnetic radiation	Light is a form of energy called electromagnetic radiation, which varies in duration (energy over time), quality (wavelength or color), and intensity (the amount of light at each wavelength or color).
Foot-candle (fc)	Illuminous photometric unit based on the amount of visible light detected by the human eye (primarily green light) and therefore, not appropriate for plants.
Joule (J)	Scientific unit for energy that measures the capacity to do work or generate heat.
Mole (mol) or micromole (µmol)	Very large constant number used in chemistry (6.02×10^{23}) and a micromole is one millionth of a mole.
Nanometer (nm)	A unit of wavelength [billionths of a meter (10^{-9} m)]
Photon or quantum	Individual packets or particles of light energy. The amount of energy in each photon depends on its wavelength (color).
Photosynthetically active radiation (PAR)	Photons with wavelengths between 400 to 700 nm, which are capable of stimulating photosynthesis.
Photosynthetic photon flux density (PPFD)	The amount of PAR reaching a unit area (usually m^2) per unit of time (usually second; s).
Photometric unit (fc or lux)	Measurement of light based on its perceived brightness and thus, is biased toward people. 1 fc = 10.8 lux.
Quantum unit ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Measurement of the number of micromoles (µmol) in the PAR range that reaches one square meter (m^2) every second (s), or $\mu mol \cdot m^{-2} \cdot s^{-1}$. Quantum meters are the most appropriate instrument to measure light intensity for photosynthesis and plant growth because it is not biased toward the human eye.
Radiometric unit ($W \cdot m^{-2}$)	Measurement of radiant energy.
Short-wave radiation	Wavelengths from 100 to 2,800 nm
Ultraviolet (UV) radiation	Wavelengths from 100 to 400 nm, although most radiation with wavelengths less than 300 nm is blocked by the ozone layer.
Watt (W)	A unit for the rate of energy use or irradiance. 1 Watt = 1 $J \cdot s^{-1}$
Wavelength (nm)	The distance between two crests of a wave.

Sidebar. Terms, units, and definitions related to plant lighting applications.

computer displays is only for PAR radiation (from 400 to 700 nm). However, almost all pyranometers measure total short-wave radiation and not just the energy in PAR. Therefore, we need to use a different conversion factor.

Approximately 43% of the energy from the sun is within the PAR range, so we need to use the conversion factor of ≈1.96 (rather than 4.57) $\mu mol \cdot m^{-2} \cdot s^{-1}$ per watt of energy. Check with your environmental control computer company to find out what units their system reports. Some provide instantaneous units in $J \cdot cm^{-2} \cdot s^{-1}$ or $J \cdot m^{-2} \cdot s^{-1}$ while others provide cumulative units (the radiation sum per day) of $J \cdot cm^{-2} \cdot d^{-1}$ or $J \cdot m^{-2} \cdot d^{-1}$. Table 1 provides an example of light data measured outside a greenhouse located in the Midwest.

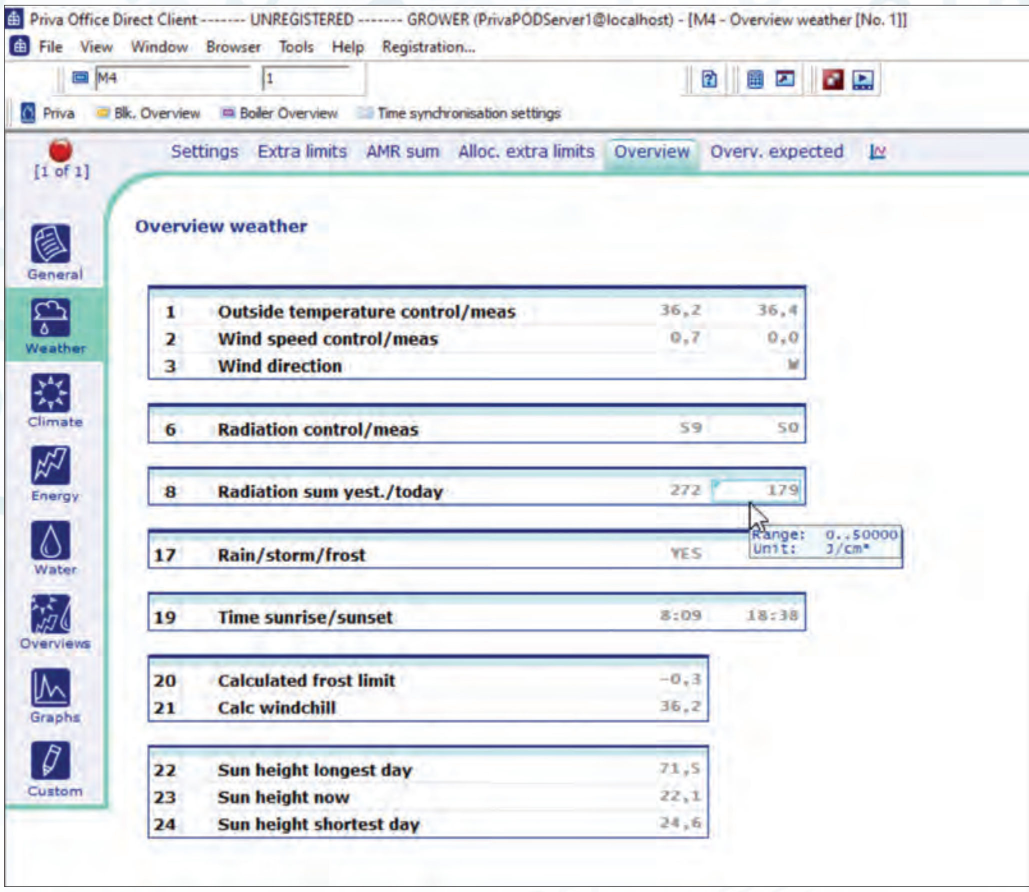


Figure 2. A screen shot of a Priva environmental computer weather station. Note how the radiation sum the previous day was 272 joules per square centimeter per day.

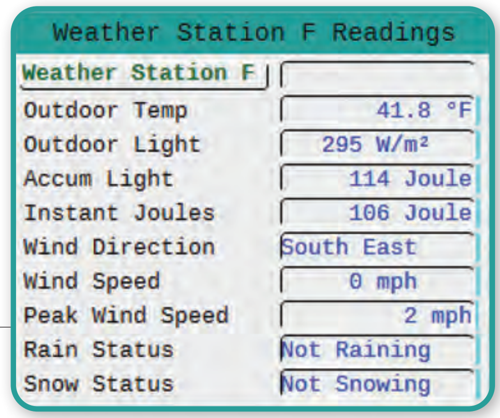


Figure 3. A screen shot of an Argus environmental computer weather station. Note how accumulated radiation sum ("Accum Light") was 114 joules per square centimeter per day.

CONVERSIONS IN ACTION

Let's say you want to calculate the daily light integral (DLI) that is reaching your greenhouse (outside) each day, and your environmental computer provides a radiation sum in $J \cdot cm^{-2} \cdot d^{-1}$. Let's use an example of 1,230 $J \cdot cm^{-2} \cdot d^{-1}$. First, let's convert cm^2 to m^2:

$$1{,}230\ J \cdot cm^{-2} \cdot d^{-1} \times 10{,}000\ cm^2 \text{ per } m^2 = 12{,}300{,}000\ J \cdot m^{-2} \cdot d^{-1}$$

Next, let's convert days into hours and then into seconds:

$$12{,}300{,}000\ J \cdot m^{-2} \cdot d^{-1} / 24\ h \text{ per } d / 3{,}600\ s \text{ per } h = 142.4\ J \cdot m^{-2} \cdot s^{-1}$$

Since 1 W = 1 $J \cdot s^{-1}$, we can convert this to $W \cdot m^{-2}$ so it has a value of 142.4 $W \cdot m^{-2}$. As discussed earlier, there is 1.96 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of PAR for every 1 $W \cdot m^{-2}$ of short-wave radiation, so we can then convert this into quantum units:

$$142.4\ W \cdot m^{-2} \times 1.96\ \mu mol \cdot W^{-1} = 279.0\ \mu mol \cdot m^{-2} \cdot s^{-1}$$

This is the average value received during a 24-hour period. We can convert this from an instantaneous quantum unit of $\mu mol \cdot m^{-2} \cdot s^{-1}$ to a daily light integral (DLI) cumulative unit in $mol \cdot m^{-2} \cdot d^{-1}$:

$$279\ \mu mol \cdot m^{-2} \cdot s^{-1} \times 3{,}600\ s \text{ per } h \times 24\ h \text{ per day} = 24{,}105{,}600\ \mu mol \cdot m^{-2} \cdot d^{-1}$$

Since there are 1,000,000 µmol per mol, we can then convert this into $mol \cdot m^{-2} \cdot d^{-1}$:

$$24{,}105{,}600\ \mu mol \cdot m^{-2} \cdot d^{-1} / 1{,}000{,}000\ \mu mol \text{ per mol} = 24.1\ mol \cdot m^{-2} \cdot d^{-1}$$

This is the DLI delivered outdoors, since your sensor is located outside. For plant growth, we need to know what the DLI is inside your greenhouse; this depends on light transmission through the greenhouse glazing, the greenhouse structure, and overhead obstructions such as hanging baskets and lighting fixtures. The light transmission inside a greenhouse and to your crop is usually between 60 and 80% when there is no shading (whitewash or shade screen).

The transmission percentage can be determined by taking a light reading outside the greenhouse on a clear day around solar noon, then going inside and measuring light intensity in your greenhouse at plant height. You can then calculate what percentage of light outdoors is transmitted inside. In this case, any kind of light sensor can be used to determine the light transmission percentage.

For example, if you measured 1,400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ outside and 925 $\mu mol \cdot m^{-2} \cdot s^{-1}$ inside, then your light transmission percentage is approximately:

$$925\ \mu mol \cdot m^{-2} \cdot s^{-1} / 1{,}400\ \mu mol \cdot m^{-2} \cdot s^{-1} = 66\%$$

Using the example above, the indoor DLI would be 24.1 $mol \cdot m^{-2} \cdot d^{-1} \times 0.66$ = 15.9 $mol \cdot m^{-2} \cdot d^{-1}$.

The light transmission percentage of a greenhouse changes over time, especially when whitewash is applied or removed, or when new glazing is installed. Therefore, it should be measured periodically to improve accuracy of your readings.

To conclude, if your environmental control computer measures short-wave radiation and reports it in the unit of $J \cdot cm^{-2} \cdot d^{-1}$, then you can convert that value into DLI using this conversion: 1 $mol \cdot m^{-2} \cdot d^{-1}$ = 51.0 $J \cdot cm^{-2} \cdot d^{-1}$ or conversely, 1 $J \cdot cm^{-2} \cdot d^{-1}$ = 0.0196 $mol \cdot m^{-2} \cdot d^{-1}$.

For growers who do not have an environmental control computer that measures radiation sum, then the daily light integral outside can be estimated at your location by using DLI maps that are on the American Floral Endowment website at endowment.org/dlimaps (for U.S. locations) or SunTracker Technologies' website at dli.suntrackertech.com (for worldwide locations). Next, calculate the greenhouse light transmission percentage to estimate the DLI delivered to your crops inside. gpn

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