

Indoor Lighting for Plant Growth

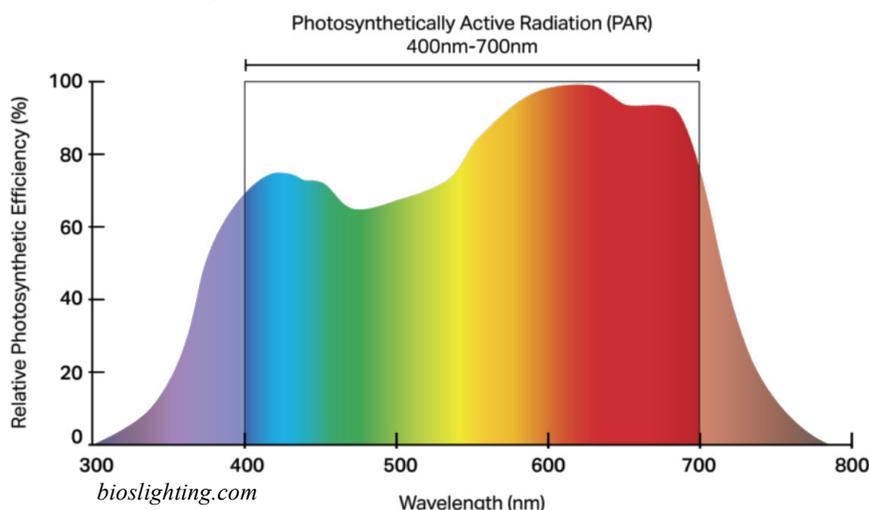
William A. Kealy, PhD

Hello winter, goodbye potted annuals! You may have already moved these plants indoors, placing them near a clean window for enough light. An alternative to this is the use of artificial lighting to keep your annuals growing until springtime. Artificial lighting actually gives you more control of lighting variables than sunlight. For example, the distance between your plants and the light source can be varied, as well as the light's intensity and duration. But how do these different variables affect the growth of different plants and how can they be measured?

If you decide to make use of artificial lighting, there are several things to consider. One is the type of light to get. In this article, I briefly cover the different type of lights and the pros and cons of each. But before I do, I need to present a few lighting terms that, without getting too nerdy, are important for understanding how to use a free smartphone app for measuring lighting.



For the sake of simplicity, white sunlight contains a full spectrum of colors that we see as a uniform rainbow like the image shown to the left.



Plants, on the other hand, respond to light differently, with some parts of the spectrum more useful than others for photosynthesis. The McCree curve (see left) indicates the portion of the spectrum, between 400 and 700 nanometers (nm), that plants use for photosynthesis; defined as *photosynthetically active radiation* or PAR.

You can see from the image to the left that red and blue are especially useful to plants. Some lights incorporate just red and blue light-emitting diodes (LEDs) that produce a purple color (the lights are called “blurples”). These LEDs efficiently turn electricity into light and are less expensive. While this can be a low-cost entry-level lighting solution, over the long term these



lights can result in plant “stretching” if they provide insufficient intensity, especially in the blue spectrum. Prolonged use of blurples seriously reduces visual acuity; special eyeglasses are available for working in these conditions. Additionally, the purple lighting can hide gardening problems such as pests, molds, and nutritional deficiencies. The best lights, therefore, are full spectrum lights that can mimic natural sunlight.



homedepot.com

Nevertheless, I like using a single purple bulb, but just for germinating seeds and rooting cuttings. I simply tie the bulb to the rack in my clothes closet (a necessary accommodation for living in a small condo).

I couldn't identify this specific brand of bulb that I currently use, but you can obtain the equivalent 24-inch bulb at a local big box or hardware store as well as online (just type "purple" in your web browser).



The use of purple lights can also be handy if growing plants indoors with natural light (e.g., by a sunlit window or in a greenhouse). In this case the lighting is enhanced by boosting the specific red and blue wavelengths that the purple lights provide.

Photo by William A. Kealy

As I mentioned earlier, red and blue light are great for driving photosynthesis but other colors also contribute to plant growth. Green light, for example, which some mistakenly believe doesn't aid photosynthesis, is actually pretty useful for plants growing at the forest floor below the tree canopy. The table below identifies the effect various colors have on plant growth:

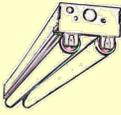
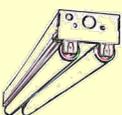
PAR colors	Positive Effect of PAR wavelengths (colors) on Plants
Violet	Stimulates photosynthesis
Blue	Stimulates photosynthesis • Boosts chlorophyll production • Improves biomass • Reduces height • Prevents stretching • Creates more compact plants
Cyan	Stimulates photosynthesis
Green	Stimulates photosynthesis • Penetrates canopy deeply • Prompts shade avoidance • Promotes stretching
Yellow	Stimulates photosynthesis
Orange	Stimulates photosynthesis • Initiates carotenoid creation
Red	Stimulates photosynthesis • Promotes growth • Induces flowering • Triggers fruiting Manages seed germination • Encourages root propagation
Far-Red	Stimulates photosynthesis • Promotes growth • Induces flowering • Improves total biomass Penetrates canopy deeply • Increases leaf area • Prompts shade avoidance

yourindoorherbs.com

As you can guess, I'm a big fan of full-spectrum LED lights which, compared to other sources of light (e.g., incandescent bulbs), produce less heat while supporting all stages of plant growth.

Other types of lights, besides LEDs, are used in commercial greenhouses and by a few private indoor gardeners. But, in general, LEDs and compact fluorescent lights (CFLs) are most ideal for home use when the lighted space is small. For larger home growing spaces, such as a hothouse, garage, or cellar/attic, T8 and especially T5 fluorescent tubes are best.

Other artificial lights, used primarily in commercial operations, are high-intensity discharge (HID) bulbs, including high-pressure sodium (HPS), metal halide (MH) and ceramic metal halide (CMH) lights. Here are all the lighting options; ones highlighted in yellow are ideal for home use.

INDOOR ARTIFICIAL GROW-LIGHT OPTIONS							
	FLOURESCENTS			HIGH-INTENSITY DISCHARGE			LEDs
	CFL	T8	T5	HPS	MH	CMH	LED
	compact fluorescent	linear tube	linear tube	high-pressure sodium	metal halide	ceramic metal halide	light-emitting diode
							
Spectrum	balanced	balanced	well balanced	warm (yellow-red)	cool (blue-green)	well balanced	custom (balanced)
Initial Cost	low	low	medium	medium	medium	medium-high	low-high
Power Draw	low	low	medium	medium-high	medium-high	medium-high	low-high
Efficiency	fair	good	good	better	better	best	good-best
Application	good for short term use in small spaces to augment a low wattage LED or a bright window	offer better coverage than CFLs for several seeding trays but special full-spectrum tubes are required since standard fluorescents aren't effective for plant growth		yellow-red light typically used for a flowering stage by large plant growers vs for home indoor gardens	used primarily by big growing operations for the vegetative stage vs for home indoor gardens	lower heat and more costly with broad spectrum for use in all growing stages	wide spectrum allows use for all growing stages: energy efficiency best with high-end models
Uses	seedlings, cuttings, & lettuce	seedlings, cuttings, lettuce and small herbs (T5 = better growth)		flowering and fruiting among mature plants	vegetative stage with large plants	vegetative and flowering stages	vegetative and flowering stages

adapted/modified from albopepper.com

After selecting the type of light...

The **wavelength** (or color) of a light that a plant can use is only one thing to consider for indoor growing. Another consideration is the **amount** of light hitting a plant, which varies in many ways: (a) the intensity of the light, (b) how close it's placed to a plant, and (c) the size of the planting area. The **duration** or amount of time a plant is lighted is also a factor but I'll get to that later. The standard measure for the amount of light hitting a plant is the number of photons covering a square meter every second—micromoles per square meter per second ($\mu\text{mol}/\text{m}^2/\text{s}$). This measure is the *Photosynthetic Photon Flux Density* or PPF. So, **PAR** = the wavelength or quality of light, whereas **PPFD** = the amount of light.

Different kinds of plants require different PPF levels...

Mushrooms	Very Low Light Plants	Low Light Plants	Moderate Light Plants	High Light Plants	Very High Light Plants	Full Sun Plants
<15 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	20-40 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	40-80 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	80-150 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	150-350 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	350-600 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>	600-2,200 <small>$\mu\text{mol}/\text{m}^2/\text{s}$</small>
	BEGONIA PAVONINA	PAPHIPEDILUM (MOTTLED LEAF) PAPHAENOPSIS	PHALAENOPSIS PHRAGMIPEDIUM	EPIDENDRUM PAPHIPEDILUM (STRAP LEAF) ONCIDIUM CATTLEYA	VANDA	CITRUS TREE EUCALYPTUS TREE

Adapted from herebutnot.com and highdesertorchids.com with permission

There are clearly several ways to increase or decrease the PPF of a light. One way is to change the distance between light and plant; moving the light farther away decreases the amount of photons on the plant surface. A plant directly below a light gets more photons (a higher PPF) than plants on the periphery.

MF1000 PPFD MAP - Tested in a 2x2 ft Grow Tent

Distance: 12" (30cm)

355	average PPFD = 569		363
449	878	894	535
446	1012	882	538
369	518	530	401

Distance: 14" (35cm)

www.maxsisun.com

342	average PPFD = 538		375
507	726	749	575
518	821	751	582
381	483	494	438

You can see the average PPFD for the light 14" from the plant canopy (seen on the right) is much lower than for the light hung 12" away. Also, in both cases, PPFD is higher in the middle than along the edges of the lighted area. There are a couple of strategies for addressing this imbalance. One is placing plants requiring lower PPFD (e.g., begonias) along the edge of the lit area and putting plants needing higher PPFD (e.g., vanda orchid) in the center. Plants along the edges can also be placed on small boxes to raise them closer to the light.



Photo by William A. Kealy

Another strategy is to reflect the light's illumination to the periphery. A few years ago, I purchased a grow tent (2' x 2' x 4') and, like mine, most of them have sides that use a reflective coating. The bounced light will, to some degree, increase the PPFD along the margins of the growing area. But you can achieve the same result by simply placing aluminum foil around the exterior of the growing area.

PPFD can also be modified by changing the *intensity*

DIMMER	-	MAX PPFD
100%	-	100% (1000 μ mol/m ²)
90%	-	95.0% (950 μ mol/m ²)
80%	-	87.3% (873 μ mol/m ²)
70%	-	77.0% (770 μ mol/m ²)
60%	-	67.8% (678 μ mol/m ²)
50%	-	56.9% (569 μ mol/m ²)
40%	-	45.9% (459 μ mol/m ²)
30%	-	34.6% (346 μ mol/m ²)
20%	-	21.5% (215 μ mol/m ²)
10%	-	8.3% (83 μ mol/m ²)

of the lighting, and some LED lights include a remote control that allows you to vary the light intensity. The better lights will also include a report (seen to the left) showing how dimming the light will affect the maximum PPFD possible.

www.maxsisun.com

Basil (*Ocimum basilicum*)

PPFD $\mu\text{mol}/\text{m}^2/\text{s}$
220 – 500

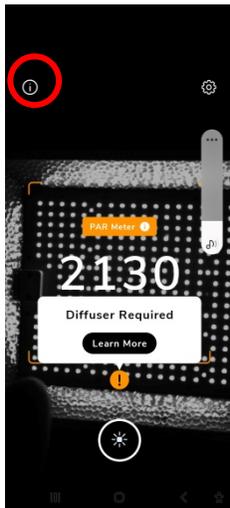
plantlightdb.com

There are useful guides on the internet that will specify the ideal PPFD for a particular plant. One is the Internet's Source of Plant Light Requirements. Here, for instance, is the recommended PPFD for basil.

But with so many variables, how would you know that your light's PPFD is in the ballpark range for a given plant? Fortunately, if you have a smartphone there are apps for both iPhone and Android models that let you directly measure PPFD. Two popular ones are

Photone growlightmeter.com and **PPFD Meter** <https://ppfd.app/> that use the phone's front-facing camera to measure the light hitting a plant. A technical analysis of the two meters by [Micro Grow Lights](#) reports both apps are equally very accurate when using an iPhone due to the consistent sensitivity of its camera. With an Android phone, however, Photone yields better performance than PPFD Meter. Personally, I like using Photone because of its straightforward simplicity (and because I own an Android phone).

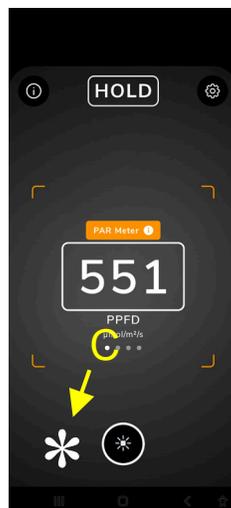
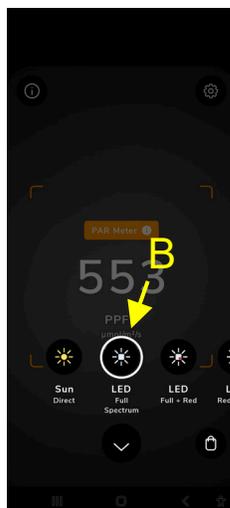
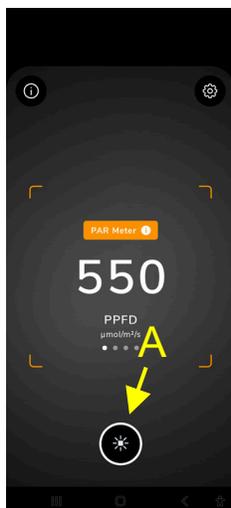
PPFD readings have a variance of about 20% from those of a scientific device. Here, I'll detail the use of Photone and later discuss PPFD Meter.



For an in-depth guides on Photone and numerous other subjects, touch the info icon identified by a red circle on the photo to the left. After installing and starting the app, you'll see this display. In this example my cellphone is 14 inches from the LEDs of my grow light (at 100% illumination) to the top of the plant placed in the center of the light. In the middle is a notice that says "Diffuser Required". This is because the sensor cannot absorb all the light emitted. A diffuser scatters the incoming light, thereby making the PPFD measurements more accurate. You can purchase a top-of-the-line diffuser or build one yourself in a couple minutes or less. The homemade version is 10-12% less accurate than a paid diffuser...but good enough:

1. Cut 1/2 " strip of standard white printer paper long enough to wrap around the top of the phone. Photone suggests using white printer paper in 22 lbs. / 80 GSM thickness. For this example I used 20 lbs. / 75 GSM paper.

2. Cover the phone's front-facing camera and tape the loop at the back of the phone. Slide the loop down the top of the phone to just where the "Diffuser Required" notice disappears.



Next, click the star icon at the bottom of the screen (A).

From the horizontal menu, swipe left or right to locate the type of light you're using (B). In this example it's a full-spectrum (i.e., broad) LED light.

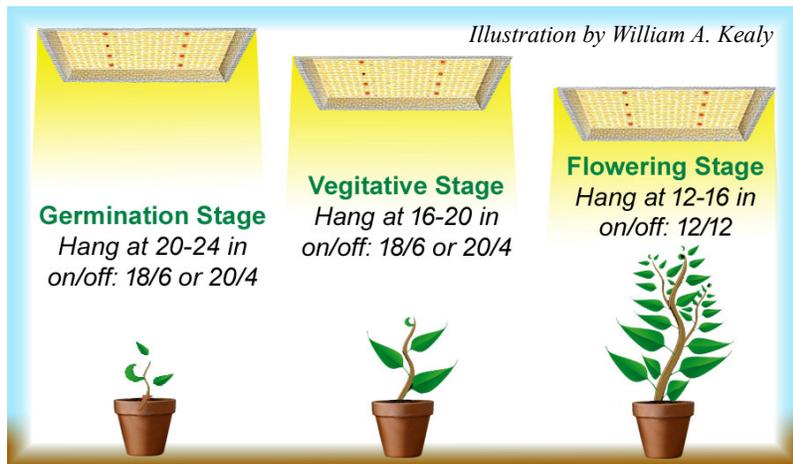
Hold the cellphone directly over the top of the plant(s) to see the PPFD reading on Photone.

Pressing your thumb anywhere on the screen (C) will freeze the PPFD reading.

www.growlightmeter.com

The Daily Light Integral (DLI)

If you light a plant for 12 hours it will be bombarded with fewer photons than if it's exposed to a light for 18 hours, assuming the PPF is the same in both cases. This introduces a lighting measurement called the *Daily Light Integral* or DLI. DLI equals the PPF times the number of



hours of illumination times 3600 (number of seconds in an hour) all divided by 1,000,000 (to convert moles to micromoles). If the DLI is too great the plants can experience stress and burn. If the DLI is too small, plant growth will suffer with reduced growth and vigor. Generally, the photoperiod (hours lighted) is shorter during plant germination and vegetative stages and longer during the flowering and fruiting stages. For

indoor artificial lighting, however, one must also consider the intensity of the light, which can vary by changing the distance between the plant and light source. The DLI, hence, is a product of the distance between light and plant and the photoperiod:

MF1000 lighting guide	Height above plant	Using Hours	Brightnessn.com
3-5 Days Acclimation Period	24"-28"	18 on /6 off	40%
Seedlings/Young Vegetative	20"-24"	18 on /6 off	60%
Vegetative Stage	16"-20"	18 on /6 off	100%
Flowering Stage	12" · 16"	12 on /12 off	100%

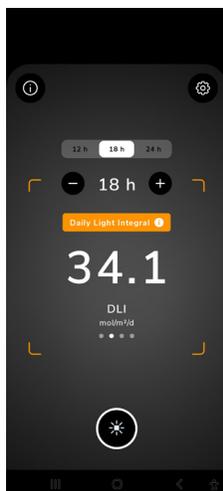
The **Internet's Source of Plant Light Requirements** mentioned earlier not only shows the ideal PPF for a given plant, but also both the suggested DLI and the photoperiod:

Basil (*Ocimum basilicum*)

PPFD $\mu\text{mol}/\text{m}^2/\text{s}$	DLI $\text{mol}/\text{m}^2/\text{d}$	Photoperiod hours
220 – 500	12 – 26	8 – 16

plantlightdb.com

Measuring the DLI with Photone



25 $\text{mol}/\text{m}^2/\text{d}$

- ▶ Cactus, Citrus, Aloe
- ▶ Palm Trees, Flowering Plants, Succulents
- ▶ Croton, Jasmin
- ▶ Monstera, Aglaonema
- ▶ Ivy
- ▶ Dracaena
- ▶ Parlor Palm
- ▶ Fern
- ▶ Aspidistra, Dragon Tree, ZZ Plant
- ▶ Snake Plant, Spider Pant, Peace Lily
- ▶ Orchids

DLI

5 $\text{mol}/\text{m}^2/\text{d}$

www.growlightmeter.com

Besides measured PPF, the Photone app (see left) also provides the DLI; simply swipe the screen to the left to reveal the DLI interface. The display retains the light type that you specified earlier, so all you have to do is enter the photoperiod (the number of hours the light will be on) by clicking the plus or minus sign to change the value. Then, hold the phone directly above the plant to obtain the DLI.

To change DLI, modify the light's distance, duration, or intensity (see <https://youtu.be/dQIOJ1zvoPI> for the excellent video *Photoperiod Versus Intensity*).

There are several places on the Internet where you can find suggested DLI values for different kinds of plants, such as the chart on the previous page, showing high DLI recommended for cacti and low DLI recommended for orchids and peace lilies.

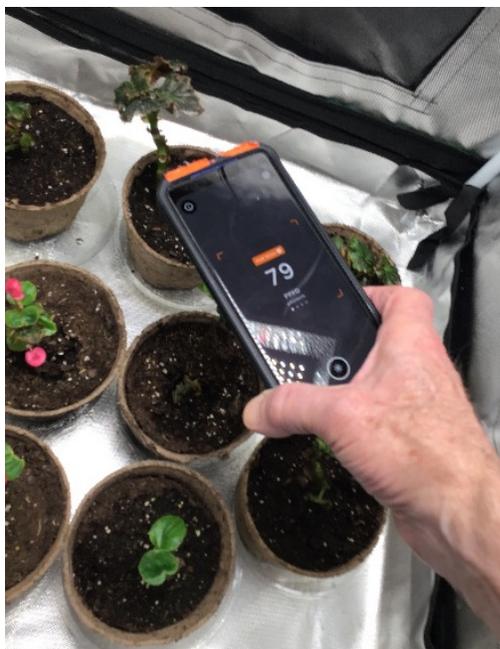


Photo by William A. Kealy



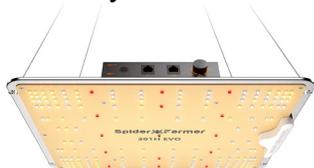
PPFD Meter

In the photo to the far left I am demonstrating the use of Photone to measure the PPFD of the light striking my young begonias. Notice that here a diffuser is not needed. There are other apps for measuring and adjusting indoor lights for plants. An excellent one—for either iPhone or Android—is called **PPFD Meter** shown to the left (get it <https://ppfd.app/>). This shows PPFD and DLI simultaneously as well as other lighting measurements such as lux. It has a very good guide on how to calibrate the app to get more

accurate readings. [Micro Grow Lights](https://microgrowlights.com/) also has a very good guide on the use of this app. PPFD Meter offers several unique features such as the ability to create a PPFD map for the specific light that you're using. PPFD readings will vary between Photone and PPFD Meter...I say use both.

Comparison of LED lights...which one is best for you?

After scouring the Internet (endlessly...for days!), I finally settled on the Maxsisun MF1000, which is a full spectrum LED light that is suitable for a 2' x 2' grow tent. Alas, the light is currently unavailable. While disappointing, there are some very good alternatives.



spider-farmer.com

I recently saw an excellent review of three lights: Spider Farmer, Mars Hydro, and Maxsisun (my unit). The reviewer is Al Gracian III (check out his website) (<https://albopepper.com/>) who is a *master* urban gardener. His review at <https://youtu.be/g6n8VhVGKDY> is somewhat nerdy but, hey, you might like that! Spoiler alert...other than the Maxsisun, the best bet from the review is the Spider Farmer SF1000 (*not* the SF1000D model). Note that the Spider Farmer dimmer (see left) is on the light itself, not on a remote unit as with some Maxsisun models.

In summary, I'll quote the final words of Johann Wolfgang von Goethe and wish you "*More light!*"

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Internet's Source of Plant Light Requirements

<https://plantlightdb.com>

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Common Plant Problems

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Factor Affecting Plant Growth - Light

<https://marshydro.eu/blog/factor-affecting-plant-growth-light/>

Green Light Drives Leaf Photosynthesis

Plant Cell Physiol. 50(4): 684–697 (2009)

Orchid & Houseplant Suggested Light Ranges PAR/PPFD Estimated Targets

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METRICS

PAR Light & Spectral Quality

<https://albopepper.com/PAR-light-spectral-quality-in-horticulture.php>

PPFD, PAR, Foot-candle or Lux: What Is the Difference?

<https://growlightmeter.com/ppfd-or-lux-what-is-the-difference/>

What is PAR in Grow Lights

<https://www.yourindoorherbs.com>

Positive Effect of PAR wavelengths

<https://yourindoorherbs.com>

Photosynthetically Active Radiation

<https://bioslighting.com>

DLI (Daily Light Integral)

<https://youtu.be/dQIOJ1zvoPI>

Understanding DLI

<https://blog.growlink.com/understanding-dli-daily-light-integral>

LIGHT SELECTION

Best Grow Lights

<https://gardenerspath.com/gear/best-grow-lights/plantperiodization>

Indoor Artificial Grow-Light Options

<https://albopepper.com>

Light Comparison

<https://youtu.be/g6n8VhVGKDY>

Light Quality (blurple vs white)

<https://youtu.be/kUpEQ4kU148>

LED vs T5

<https://youtu.be/RXbR-hcXeQ4>

MEASUREMENT

PPFD Meter

<https://ppfd.app/>

Photone Light Meter

<https://growlightmeter.com>

How to Measure Light With Photone

<https://growlightmeter.com/guides/web/>

Internet's Source of Plant Light Requirements

<https://plantlightdb.com>

How Much PPFD Do Your Indoor Plants Need?

<https://www.mars-hydro.com/info/post/how-much-ppfd-for-indoor-plants-in-each-growth-stage>

Best DLI Calculator

<https://albopepper.com/dli-ppfd-calculator.php>

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