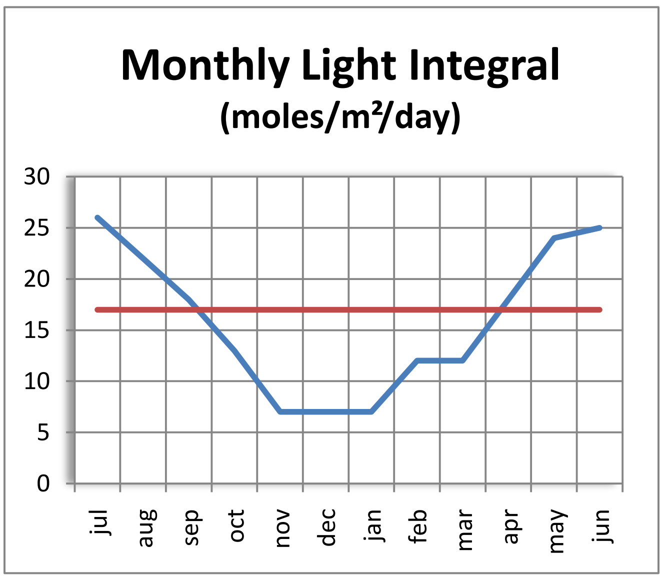
Sunlight is free?

By Ed Harwood © 2010

The intensity or luminance of light supplied to a plant canopy is both instantaneously and cumulatively quantified using Photosynthetic Photon Flux (PPF). The instantaneous measurement (µmoles·m^{-2}·sec^{-1}) plotted on a grid can be used to graph the uniformity of luminance provided to the plant canopy. Variance of intensity occurs with obstructions that create shade and with construction of bulb and reflector in artificial lighting situations. The accumulation of PPF is called the daily light integral (DLI).

In sunlit situations DLI is impacted by the variation caused by cloud, diurnal, and seasonal conditions. In artificial situations where variation is generally absent, it is most often calculated using the instantaneous measure multiplied by time. Work with strawberries[1] proves that the DLI is more important to plants than any peak intensity during a 24 hour period.



It is useful to compare the complexity of using sunlight to using artificial lighting. Most plant species require from 9-20 moles/m²/day to grow well. The figure to the left graphs the average monthly DLI over the year at latitude 42° in New York under average cloud conditions. If the targeted daily integral is 17 moles/m²/day (red line), this target is met only for a few weeks during the year. The complexities and costs of managing the variation in natural light provides the reason for utilizing luminaires as opposed to sunlight.

When the DLI is above the target and commensurate increases in nutrient availability are not made, the plants will suffer a number of anomalies (tip burn and bolting). The anomolies decrease yields and make plants potentially unsalable. Exacerbating the detrimental impact of a high DLI is the considerable radiant heat generated in a greenhouse structure. The sun produces short wave radiation from wave length 290 to 2500 nm. All of this energy can be degraded to heat. This heat makes personnel uncomfortable, some plants less productive, and carbon dioxide supplementation extremely difficult and/or expensive. Computerized control of motorized shading has brought high DLI under control.

[1] Chabot, B. F., Jurik, T. W., & Chabot, J. F. (1979). Influence of Instantaneous and Integrated Light-Flux Density on Leaf Anatomy and Photosynthesis. *Am. J. Bot.* , 66:8:940-945.

Insufficient DLI will alter plant growth undesirably with “reaching” (etiolation) and lack of photosynthetic capacity (chlorosis). During the winter months at latitude 42° the DLI is lower than the target (below the red line). Also at this latitude low DLI months require supplemental heating in a structure not well suited to heat retention.

The traditional greenhouse using a “free” resource – the sun - is an expensive building (a special use facility with a short life span and high maintenance costs), and requires additional equipment and energy to optimize the internal climate for yearlong use in northern latitudes.

Some plants have a requirement for a dark period in order to thrive. Most leafy greens do not have a dark period requirement allowing 100% photoperiod and consequent yield enhancement.

In conclusion, the management of sunlight and the associated costs of use, including structure and maintenance, temperature modifications, and shading and supplementation, present the potentially more advantageous opportunity to utilize artificial light.

In a Controlled Environment Agriculture, supplemental light (supplemental to the sun) is produced by a number of different luminaires. A luminaire is the bulb, ballast, and reflector, i.e., a complete assembly providing illumination. The type of luminaire used for growing plants variably include fluorescent, high pressure sodium (HPS), and metal halide (MH). The latter two luminaires are types of High Intensity Discharge (HID) lighting. The table[2] to the left includes some characteristics of these luminaires.

Source	Total Wattage consumed (W)	Average Life (hrs)	Efficiency (lumens·watt^{-1})
Incandescent	40	750	12
LED	0.025	50,000	35
Fluorescent	48	20,000	66
MH – 400	425	15,000	94
MH – 1000	1,060	10,000	118
HPS – 400	425	24,000	117
HPS – 1000	1,060	24,000	132

Luminaires vary in intensity, spectrum, and life affecting both the quantity and quality of the light provided. All luminaires attenuate (lose intensity) over time. HID luminaires do not attenuate appreciably until very near the end of life.

The energy consumed per

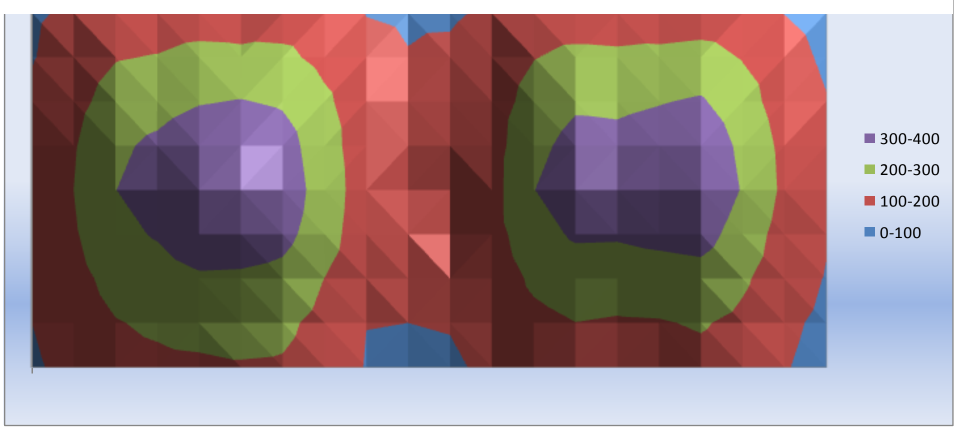
[2] Aldrich, R.A, and J.W. Bartok Jr. 1994. Greenhouse Engineering. NRAES, Ithaca, NY. Page 99.

luminaire, generally indicative of the intensity of the light, can range from less than 250 watts to 1,000 watts. For HID and fluorescent luminaires, the ballast consumes some of the energy supplied and other engineering differences alter efficiency. The efficiency can vary considerably with type and wattage as seen in the table. HIDs are the more typical luminaire chosen for supplemental light. Fluorescents do not make good choices for commercial facilities as they produce little light per individual luminaire, when broken create a toxic spill, and greatly interfere with use of sunlight.

Typical choice of luminaire is based mostly on desired light intensity (derived from the mounting distance from canopy and bulb wattage) and economics. For a greenhouse where the luminaire itself shades the plants, higher wattage is used to allow greater mounting height and lower density of luminaires. The higher wattage also obtains an improvement in individual luminaire efficiency. The voltage and phase of the electrical supply can also impact the total energy consumption of a luminaire. Distance has a big impact, reducing light intensity proportional to the square of the distance.

Reflectors used in luminaires are an attempt to provide a uniform intensity over a canopy of plants. These reflectors vary considerably in how effectively they create this uniform surface as can be seen in Figure 1 which was made using two 400 watt metal halide bulbs mounted 100 cm above the measured surface grid of 15 cm squares. The design problem for a reflector is complex due to the need to avoid reflecting light onto the filament, to manage the varying output from the element's glass globe, and to fill the area to be illuminated evenly. When a luminaire is placed within a chamber having reflective surfaces surrounding the luminaire, these surfaces can also affect the uniformity of light. Although most reflectors are made of shiny metal, clean white surfaces reflect light best.

Figure 1. Light intensity (µmoles·m^{-2}·sec^{-1}) of 2 HPS luminaires



The above indicate significant opportunities may come from adopting LED as the lighting source. LEDs are not as efficient as HIDs, although recently efficiencies of over 100 lumens/watt have been achieved. Despite this our application will be more power efficient by 2-3 times by:

Managing the light delivered:

- Only providing the spectra needed by leafy greens – blue/red/UV-A.
- Providing uniform light to the plant canopy – HIDs create a puddle of light irrespective of advancements in reflector design.
- Delivering only the number of photons required.

- Efficiency of converting energy to light increases with wavelength, e.g., a predominance of red vs. blue LEDs is more efficient.

Increase floor space utilization by allowing more units to be stacked vertically.

Add to the barriers the system has for pests by interfering with pest reproductive cycles.

Allow a more efficient heat management system by:

- Replacing ballasts which add heat without easy capture.
- Removing all radiant heat and much of the convectional heat via reduced energy consumed and pulsing the light.

Reduce hardware costs by:

- Not requiring large power transmission equipment.
- Requiring less electrical distribution (wire, outlets, conduit, etc.) within a machine.
- Removing the need for large heat ducts.
- Removing the danger of accidental burns from HIDs.
- Reducing maintenance costs by reducing frequency and labor of maintenance – they last from two to three times as long as HID bulbs.

Proposed LED disadvantages

- LEDs including the lamps, control and power supply, are costly, although costs continue to decline based on increasing usage.
- LEDs have considerable variation in efficiency from 30 to 130 watts/lumen.
- LEDs are equally inefficient in heat production to other luminaires giving off 70% of their energy as heat. This heat needs to be removed from the plant growing environment.
- LEDs are deleteriously impacted by moisture unless coated.
- If pro-active cooling is removed, LEDs:
    - shift 10 nm for blue and 15 nm for red toward longer wavelengths
    - lose intensity by as much as 30-40% for red and 10% for blue
    - lose life, i.e., L-70 (time to 70% of intensity) is reduced