# Controlled Environment Systems
**ABE 483/583**

**Dr. Gene A. Giacomelli**
**Professor & Director**
**Controlled Environment Agriculture Center**

Department of Agricultural and Biosystems Engineering
Shantz Building, Room 504
Ph: 520 621-1412 giacomel@ag.arizona.edu

**Lecture #5A Supplemental Radiation**

Hannan: Pps 122 – 145
Aldrich & Bartok: Chapter 6, pps 92 – 101
Horticultural Engineering Website at Rutgers University http://aesop.rutgers.edu/~horteng/
<Presentations> <**Supplemental Lighting & Shading** PowerPoint slides>
others:
Phillips Lighting Application Guide -- Horticultural Lighting, Phillips Lighting Co.
GE Lighting Systems -- Lighting Fixtures, General Electric Company, Hendersonville, NC. GEA-12000D, Dec 1991

Law of the Inoptimum:
"No species encounters in any given habitat the optimum conditions for all of its functions"
-- Pierredan Serean, Canadian Biologist.

This really means we must try harder!

## SUPPLEMENTAL LIGHTING IN GREENHOUSES

Providing for good lighting conditions for plant growth and development is one of the more difficult tasks in the design and operation of a greenhouse. It can become quite costly. Furthermore procedures or techniques for energy conservation, structural design, or others, often conflict with the desired characteristics of a greenhouse with optimum lighting conditions.

A good lighting system will provide a uniform distribution of light energy across the entire growing area. This refers to the intensity (watts $m^{-2}$), or the PAR measured in quanta of light energy ($\mu$Moles $m^{-2}$ $s^{-1}$). The spectral quality of the energy provided by the light source must also be considered. The distribution of the light spectrum varies among the various types of lamps available. The most common lamps include: fluorescent, high pressure sodium, low pressure sodium, and mercury vapor.

According to Poot lighting Co, using their lamps to obtain an 80% light distribution uniformity, the following equation is applied:

*$N = (250\mu mol\ s^{-1}\ m^{-2}\ x\ 82lux\ x\ 10\ m^2) / 50{,}000\ lumen/lamp = 4.1\ HPS\ lamps$*

*or*

*$N = (250\mu mol\ s^{-1}\ m^{-2}) / 4.98\mu mol\ s^{-1}\ m^{-2} / W/m^2 = 50.2\ W/m^2 / 123\ W_{PAR,\ HPS}\ x\ 10\ m^2 = 4.1\ HPS\ lamps$*

*Where, N = number of lamps.*

*Then determine the lamp-to-lamp spacing when mounted in the 10 m2 growing area, and the height from plant canopy to lamp.*
*Equation from Poot Lighting.*

*$H = [F/(4.2\ x\ E)]^{1/2}$ and L <= 1.55 x H, and B <= 2.7 x H,*
*where '<=' means 'less than or equal to'.*
*Or*
*$H = [F/(5\ x\ E)]^{1/2}$ and L <= 1.8 x H, and B <= 2.8 x H,*
*For 80% uniformity accoding to Poot Lighting*

*Where H = height from plant canopy to lamp;*
*L = lamp to lamp spacing within a row;*
*B = spacing between rows;*
*E = lux of desired light intensity [see Thimijan and Heins publication];*
*F = lumens of output of the lamp [see Thimijan and Heins publication].*
*Where PAR $\mu mol\ s^{-1}\ m^{-2}$ is converted to lux if multiplied by 82, 71 or 74 for HPS, MH or CWF lamps, respectively.*
*And where, footcandles are converted to PAR $\mu mol\ s^{-1}\ m^{-2}$ by the following equation, footcandles = $\mu mol\ s^{-1}\ m^{-2}$ x 1000 mW/W / [10.8 lm/$m^2$ x 'a' mW/Lm x 'b' $\mu mol\ s^{-1}\ m^{-2}$ / W $m^{-2}$], and 'a' & 'b' depend on the lamp source.*

## CARBON DIOXIDE ENRICHMENT

Whenever supplemental lighting systems are utilized, enrichment of the atmosphere with carbon dioxide is usually beneficial, and sometimes a necessity. Plants are known to respond with increased growth and development when subjected to elevated $CO_2$ concentrations (>1000ppm). Normal atmospheric $CO_2$ concentrations (355ppm) can be maintained by proper ventilation of the greenhouse, however, if lighting during winter conditions, ventilation may not be desirable, thus a system for generation and distribution of carbon dioxide is necessary.

## $CO_2$ SOURCES

* bottled (99.8% or purer), primarily for growth chambers use. GC's may or may not be airtight (a relative term). Typical greenhouses have 1 volume air change per hour. Many commercial GC's are vented. Too expensive for greenhouses of any size
* generator -- from natural gas, or propane (propane fairly expensive)

unorthodox source (not developed, yet)
* from biomass composter – output depends on activity of composter.

**Estimation of light intensity inside growth chambers**
**By Dr. Chieri Kubota**
**02/27/03**

Unlike greenhouse light calculation, estimation of light intensity inside the growth chamber needs to consider reflections from inner surfaces of growth chamber. The growth chamber inner walls are often finished with reflecting materials, which can provide significant increase in light intensity inside the growth chamber. Instead, changes in reflectance of either of the surfaces would cause significant reduction of PPF received by the same surface [such a difference often seen between PPF measured with empty chamber and with full canopy is a good example, since plant canopy has very small reflectance in PAR region (about 20% or so)].

Light intensity is theoretically estimated using the following equation.

$$P = k_L \cdot \frac{F \cdot U \cdot M \cdot N}{R_A} \qquad (1)$$

where $P$ is PPF received by floor surface (μmol $m^{-2}$ $s^{-1}$); $k_L$ is a conversion factor from lumen $m^{-2}$ (=lx) to μmol $m^{-2}$ $s^{-1}$ [i.e., 0.012 (μmol $m^{-2}$ $s^{-1}$)/lx for HPS lamps according to Thimijan and Heins, 1983]; $F$ is lumen per light fixture (i.e., 50,000 lm for 400-W HPS, according to Bartok, 1988); $U$ is a coefficient of utilization (see Table 1) estimated according to the reflectance of inner walls and shape of the growth chamber (room index); $M$ is a maintenance factor ($M \leq 1.0$), which is a ratio of current lumens over the initial lumens due to aging and dust accumulated on the lamp surface; $N$ is the number of light fixtures placed in the growth chamber; and $R_A$ is the floor area ($m^2$).

Room index ($R$), which is needed for estimation of $U$ (Table 1), is given using the following equation.

$$R = \frac{R_L \cdot R_W}{R_H \cdot (R_L + R_W)} \qquad (2)$$

where $R_L$, $R_W$, and $R_H$ are inner length (depth), width, and height of your growth chamber.

*Note: Table 1 is provided from Matsushita Electric Works and the range of reflectance is based on what we normally have in offices and houses. With growth chambers covered all surfaces with high reflectance (e.g., over 95% for all surfaces including floor), U could exceed 1.00 (or 100%). For estimating U at given reflectance, we need a reference and I am getting this.*

Table 1. Coefficient of utilization for lighting as affected by reflectances of ceiling, wall and floor, and room index (Matsushita Electric Works, Ltd., FA81064P).

| Reflectance | Ceiling | 8 0% | | | | 7 0% | | | | 5 0% | | | | 3 0% | | | | 0% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wall | 70% | 50% | 30% | 10% | 70% | 50% | 30% | 10% | 70% | 50% | 30% | 10% | 70% | 50% | 30% | 10% | 0% |
| | Floor | 1 0% | | | | 1 0% | | | | 1 0% | | | | 1 0% | | | | 0% |
| Room index | | Coefficient of utilization (×0.01) | | | | | | | | | | | | | | | | |
| 0.6 | | 44 | 32 | 25 | 20 | 42 | 31 | 24 | 19 | 37 | 28 | 22 | 18 | 33 | 25 | 20 | 16 | 13 |
| 0.8 | | 52 | 41 | 33 | 27 | 49 | 39 | 32 | 26 | 44 | 35 | 29 | 24 | 39 | 32 | 27 | 22 | 18 |
| 1.0 | | 58 | 47 | 39 | 33 | 55 | 45 | 37 | 32 | 49 | 40 | 34 | 30 | 43 | 36 | 31 | 27 | 22 |
| 1.3 | | 63 | 53 | 45 | 39 | 60 | 50 | 43 | 38 | 53 | 46 | 40 | 35 | 47 | 41 | 36 | 32 | 27 |
| 1.5 | | 67 | 58 | 50 | 44 | 63 | 55 | 48 | 42 | 57 | 50 | 44 | 39 | 50 | 45 | 40 | 36 | 30 |
| 2.0 | | 72 | 64 | 57 | 52 | 69 | 61 | 55 | 50 | 61 | 55 | 50 | 46 | 55 | 50 | 46 | 42 | 35 |
| 2.5 | | 76 | 68 | 62 | 57 | 72 | 65 | 60 | 55 | 65 | 59 | 55 | 51 | 58 | 54 | 50 | 46 | 39 |
| 3.0 | | 78 | 72 | 66 | 61 | 74 | 68 | 63 | 59 | 67 | 62 | 58 | 54 | 60 | 56 | 53 | 50 | 42 |
| 4.0 | | 81 | 76 | 71 | 67 | 78 | 73 | 68 | 64 | 70 | 66 | 63 | 59 | 63 | 60 | 57 | 54 | 46 |
| 5.0 | | 84 | 79 | 75 | 71 | 80 | 75 | 72 | 68 | 72 | 69 | 66 | 63 | 65 | 63 | 60 | 58 | 49 |
| 7.0 | | 86 | 82 | 79 | 76 | 82 | 79 | 76 | 73 | 75 | 72 | 70 | 67 | 68 | 66 | 64 | 62 | 53 |
| 10.0 | | 88 | 85 | 83 | 80 | 84 | 82 | 79 | 77 | 77 | 75 | 73 | 71 | 70 | 68 | 67 | 65 | 56 |