AERGC
GREENHOUSE NEWSLETTER
Association of Education and Research Greenhouse Curators

Volume 11, No. 4 Winter 1998

# Light Fixture Maintenance

Theo J. Blom, PhD.

The use of supplemental lighting has become common in greenhouse production in order to increase photosynthesis and thus improve production and quality. About 20 years ago, research at the University of Guelph (Dr. M. Tsujita) prompted an increase in the use of supplemental lights for cut roses in North America. This was succeeded by the use of supplemental lighting on mother stock plants of geraniums, begonias, chrysanthemums and lately for the production of seedling plugs.

The lights were primarily high pressure sodium lights (HPS). When buying and installing a lighting system, it is important to remember that the installation is not maintenance free. The components of any lighting fixture can fail and require maintenance similar to that of a curtain system. The system can be checked by:

- measuring light levels
- checking individual components and replacing them when necessary

## Checking Light Intensities

There are a variety of light sensors on the market which measure light in different units, namely photometric, radiometric and/or quantum units. Photometric sensors measure light according to the sensitivity of the human eye. The units are usually expressed in lux or foot-candle (*1 ftcandle = 10.8 lux*). Radiometric sensors are sensitive to energy flux per unit area. These sensors are used by meteorological stations throughout the world. The units are often given in Joules/m$^2$/sec or Watt/m$^2$. The radiation measured with these sensors covers a fairly wide range (*wave length of 0.2-15µm*). Some radiometric sensors measure only the radiation in the visible light spectrum (*0.4-0.7µm*). These measurements are then presented with the notation of PAR (*Photosynthetic Active Radiation*) in addition to W/m$^2$. Quantum sensors are often used for plant growth experiments as the units correlate best with plant photosynthesis with the units expressed in mole/m$^2$/sec. These sensors operate in the visible spectrum (*0.4-0.7 µm*) only.

## Conversion of Light Measurements

The conversion of light units depends greatly on the light source.

For conversion from global radiation (*0.2-15.0µm*) to PAR, one has to remember that only one-half of the global radiation (solar source) is in the visible spectrum and therefore:

1 W/m$^2$ (global) = 2.3µmol/sec/m$^2$

instead of:

1 W/m$^2$ (PAR) = 4.6 µmol/sec/m$^2$

To check the light intensity of the installation, a lux meter can be used. The measurements should be taken at night (*so that supplemental lights are the only light source*) and also at a given height (*canopy*). It is advisable to take a grid of 4 lights and measure about 25 points within the area covered by the 4 lights.

## Light Fixtures

During the summer months, there is usually time to look at the operation and maintenance of the light fixtures. This is a job easily overlooked, but it can be costly if not addressed.

There are several components in a light fixture:

**Bulb.** There are several different bulb types but HPS (*high pressure sodium*) is the most common, while metal halide (MH) is less popular. The HPS types are most common for greenhouse applications due to high energy conversion efficiency (*electrical into light*), and longevity of the bulb. Moreover, the spectral quality of HPS bulbs, in the yellow/red range, is the

**Conversion from photometric, radiometric and quantum lights units.**

| | µmol/sec/ m$^2$ per W/m$^2$ | lux per µmol /sec/m$^2$ |
|---|---|---|
| Light Source | 0.4-0.7 µm | 0.4-0.7 µm |
| Daylight | 4.6 | 54 |
| HPS | 5.0 | 82 |
| Metal Halide | 4.6 | 71 |

*Source: HortScience, 1983.18 (6):818-822* most efficient for photosynthesis. In the greenhouse there is no need for additional blue light (*e.g. metal halide lamps*). The latter may be required in growth chambers, where there is no natural light. Bulbs are rated according to light output and power consumption:

| Bulb | Output | Input |
|---|---|---|
| 400W | 50,000 lumen | 475W |
| 430W | 53,000 lumen | 490W |
| 600W | 90,000 lumen | 675W |

An important point is that the extra requirement for the ballast (*transformer plus capacitor*) is the same for a 400W bulb as for a 600W bulb. This is important in terms of energy consumption. Each bulb requires its own ballast. There is one ballast for a 400W bulb and a different ballast for the 600W bulb. The question is, can we replace a 400W light bulb in a 400W fixture with a 430W light bulb? Generally, the answer is 'Yes', however, a 430W bulb draws an 8% higher current, which may create a problem for the breaker. This is especially true when the breakers are already loaded to the limit, a situation common in the greenhouse industry.

Another problem is that the light intensity from the bulb is slightly lower due to the lower wattage provided by the ballast in the 400W fixture. On the other hand, the bulb may last longer.

Bulbs deteriorate internally as well as externally. The life expectancy of an HPS bulb is approximately 20,000 hours. However, after 15,000 hours of burning, the light output (*lumen per light fixture*) is usually reduced by 10% and one should consider replacing the bulb.

There is not much that can be done to reduce internal deterioration, but we can prevent the decrease in light output due to reduced light transmission of the external glass surface. Light fixtures can become very dirty from dust and the application of pesticides through electrostatic application of chemicals. A 10% light loss per year is common. It is important to turn the lights 'off' whenever pesticides are applied. The cold solution is hard on the hot glass and chemicals can be burned into the glass surface. Before cleaning the bulb, turn the power 'off' and let the bulbs cool down. Cleaning is normally done using lukewarm water with a mild detergent, and drying with a soft cloth. Bulbs should be removed for this procedure unless one has a removable reflector. Prevent finger marks on the glass as well.

**Reflector.** Reflectors, which are generally made of anodized aluminum get dirty much the same as the lamps. Again, a lukewarm soap solution can be used. Reflectors can be re-anodized but this becomes an economic consideration.

**Transformer.** The transformer is designed to bring the in-house power supply (120, 208, 240, 277, 347, or 480V) to 110-120V, which is the voltage required for the operation of the light. Excessive heat will reduce the life time of the transformer. Newer housing designs allow for a better dissipation of the heat from the transformer.

Although the life expectancy of the transformer is between 10 and 15 years, some aging may occur. It is not easy to test the operation of the transformer, but follow the instructions on the diagram (see next page.)

**Capacitor.** The capacitor functions are a safeguard between the transformer and the bulb. Its function is to provide a fairly constant voltage to the terminals of the bulb, by removing the high and low fluctuations in the power supply. The capacitor can be checked with a capacitance meter. The reading for the transformer and the capacitor should be the same as noted on the capacitor.

**Ignitor/Starter.** The ignitor starts the lights by providing a high voltage (25,000V) to the light socket. Although a normal ignitor can run many cycles (200,000-300,000), it is the least durable component of the ballast, especially when a faulty bulb is used.

## Fixture Diagnostics

In order to check which component of the fixture (bulb, transformer, capacitor or ignitor) is defunct, the accompanying diagram may be helpful for the grower who does not have a capacitance meter and only some rudimentary tools such as a screw driver, a wrench, a few spare components and a metal halide lamp. To begin, turn the power 'On' to a group of

### The *AERGC Greenhouse Newsletter*

The ***AERGC Greenhouse Newsletter*** is a publication of the **Association of Education and Research Greenhouse Curators** (AERGC). The AERGC consists primarily of greenhouse / plant growth facility managers, supervisors, and staff involved with the operation of college or university facilities used to grow plant materials for research, class use, or plant collections. Interested individuals from other institutions such as botanical gardens and private companies are welcome as members also. The AERGC sponsors an **Annual Meeting** at a member's institution. The AERGC also provides the ***AERGC E-Mail Forum***, an e-mail discussion group, as a service to its members. AERGC Membership is $15 (US dollars, $24 outside of North America) per calendar year. Members are encouraged to contribute appropriate articles and news items to:

AERGC
c/o Department of Plant Biology
University of Illinois at Urbana-Champaign
265 Morrill Hall, 505 S. Goodwin Ave.
Urbana, IL 61801-3793 USA

www.life.uiuc.edu/aergc

*AERGC Greenhouse Newsletter* Editors:

Donald J. Schmidt
Department of Biology
Illinois State University
Normal, IL 61761
309-438-3800
djschmi@rs6000.cmp.ilstu.edu

Joan Leonard
Department of Plant Biology
The Ohio State University
1735 Neil Ave., Columbus, OH 43210
614-292-7904
jleonar@magnus.acs.ohio-state.edu

Andy Andersen
L. W. Andersen Software Consultant
#5 Plumbrook Rd., Apt 302
Leamington, ONT N8H 4P6
519-322-0029
lander@mnsi.net

James D. Kramer
Department of Plant Biology
University of Illinois
1201 S. Dorner Dr., Urbana, IL 61801
217-333-3058
j-kramer@uiuc.edu

fixtures and determine which light is not functioning properly. There are 4 possibilities in a fixture:

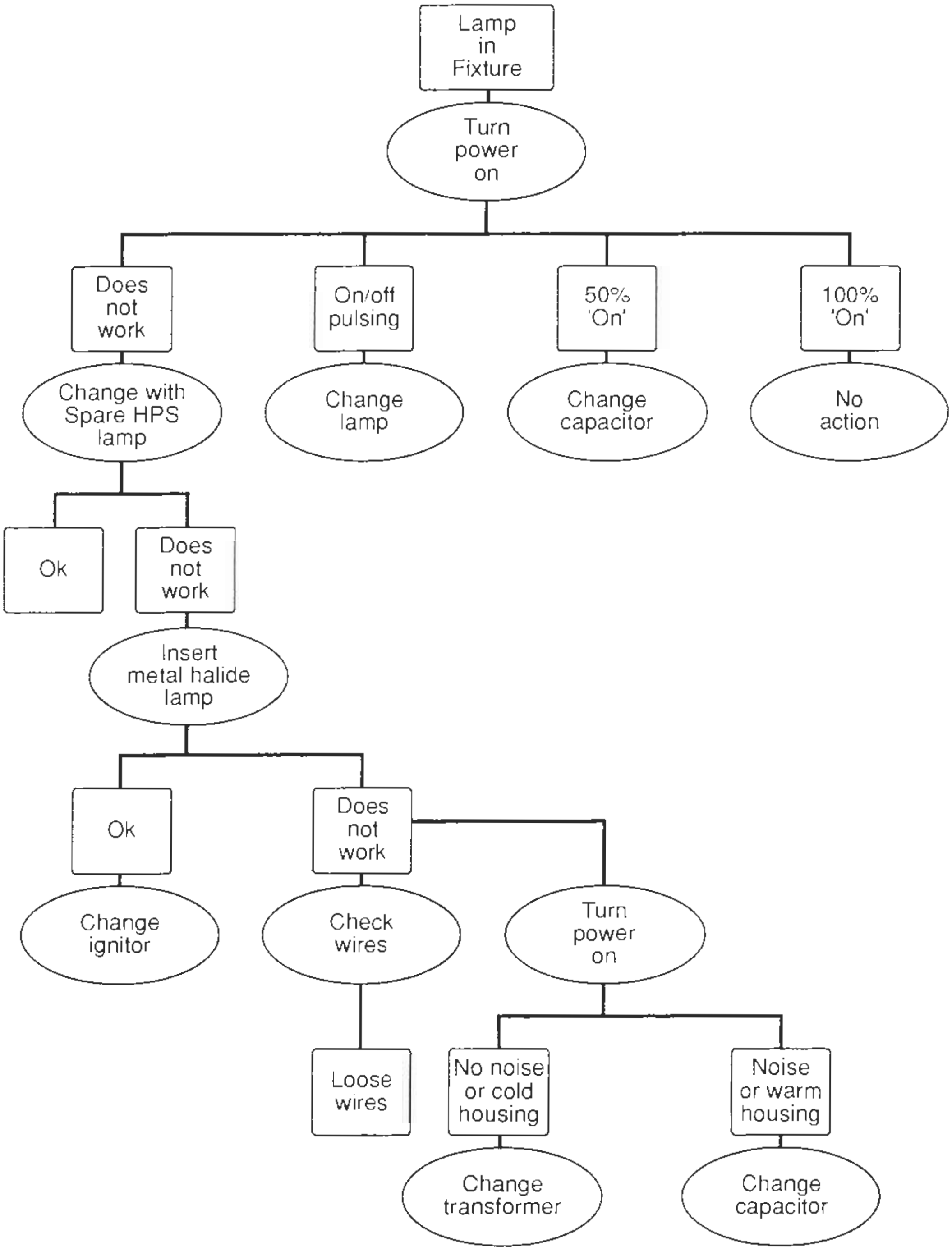
1. light does not work at all
2. light pulses On/Off
3. light provides a reduced amount of light
4. light works properly

When a bulb comes to the end of its life span, it pulses On/Off. Other symptoms are a brownish tinge on the outer glass envelope and/or blackening of the arc tube. In order to check out whether the ignitor, transformer or capacitor is failing, use the flow diagram. When replacing any of the parts, make sure that the capacitor and transformer have the same rating (µF), while the ignitor for the light is rated for a 400/430W bulb or a 600W HPS bulb.

## Summary

Understanding the components and operation of an HPS light fixture is important for the proper operation and maintenance of a supplemental lighting installation. A preventative maintenance schedule for light fixtures should be followed perhaps as a job to do during the summer.

Dr. Theo J. Blom is at the Horticultural Research Institute of Ontario, Dept. of Plant Agriculture, University of Guelph, Vineland Station, ON L0R 2E0. This article reprinted with permission from the August 1998 Issue of Priva Computers, Inc. *Priva Info* Newsletter.



# HID Lighting in Greenhouses

David Brault, PE and Richard Denis, PE
*Agritechnove, Inc., St. Anselme PQ, G0R 2N0 Canada*

## 1.0 Introduction

The objective of this presentation is to demonstrate the fundamental and practical considerations used at Agritechnove when designing a supplementary lighting system in a research greenhouse. Some fundamental concepts and definitions are reviewed to provide a common vocabulary and frame of reference. The practical aspects of the selection and layout of HID luminaries are then discussed in terms of performance and cost. Finally some of the upcoming lighting technologies are presented.

## 2.0 The Basics of Light

A review of some of the basic concepts of the physics of light will provide a common vocabulary for understanding the following discussion.

Light is an electro-magnetic phenomenon where energy packets called photons or quanta are moved through space in waves. Mathematically the relationship of energy and wavelength is:

$$E = \frac{h\ x\ c}{w}$$

Where:

E: energy of a photon
c: speed of light 2.98 x $10^{8}$ m/s
h: Planck's constant 6.62 x $10^{34}$ J s
w: wavelength in m

This means that the energy content of the quanta or photons will vary with its wavelength. Light as humans see varies in wavelength from 300 nm[1] (blue) to 800 nm (red). Wavelengths outside this range exist, but are not visible. The whole range of possible wavelengths is referred to as the electromagnetic spectrum and is illustrated in Figure 1. Light is defined as the radiation that can be perceived by the human eye from 380 nm to 720 nm.

The sensitivity of the human eye to light varies with wavelength. This means identical quantities of light will be perceived differently by the human eye depending on the color. Figure 2 illustrates the relative sensitivity of the human eye to light. Lighting units and lighting calculations are based on this response curve.

### 2.1 Lighting for plant growth

Plants require light for various life sustaining processes which are:

1. Photosynthesis: carbon dioxide and water are taken up by the plant and with light as the energy source, carbohydrates (building blocks) and oxygen are formed.
2. Photoperiodism: plants are able to measure the daily dark period, classifying them into short-day, long-day and day-neutral plants. Short-day plants flower only if the length of the dark period exceeds a certain critical value. Long-day plants flower only if the length of the dark period drops below a certain critical value.

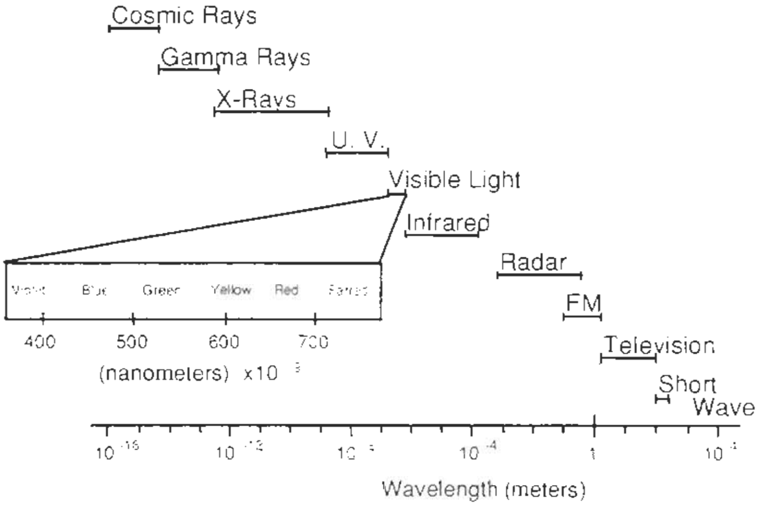


**Figure 1.** The electromagnetic spectrum

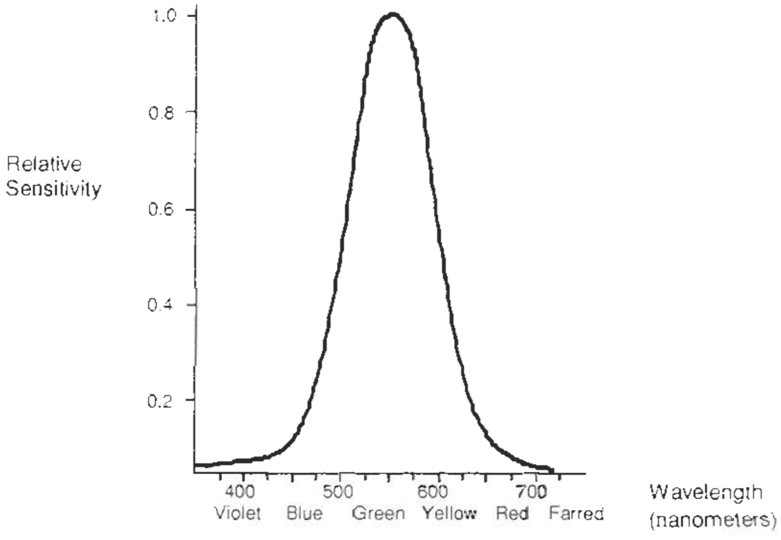


**Figure 2.** Relative sensitivity of the human eye to light

---

[1] nm = namometer = $10^{-9}$ meter

Flowering of day-neutral plants is not affected by the length of the dark period.

3. Photomorphogenesis: effect of light on the shape of a plant. For example, some seeds germinated in the dark develop elongated stems with underdeveloped foliage leaves.
4. Phototropism: plants are able to determine the direction of light and orient their leaves, stems and flowers towards or away from it (e.g., sunflower).
5. Photodormancy: some seeds need light to germinate. (Booth 1994)

In a totally enclosed environment the amount, duration and spectral quality (wavelength and relative proportions ) of the light provided can affect many of these functions. In a greenhouse the lighting system is used to supplement natural sunlight for photosynthesis and photoperiod control. The design considerations for a lighting system in the former case are thus more complex. This discussion will be limited to the considerations for supplemental lighting in a greenhouse.

Plants do not respond to the same light as people. Plant sensitivity is also different. Figure 3 illustrates the relative quantum efficiency curve as determined by the average plant response for photosynthesis. (McCree 1972). The spectral band between 400 nm and 700 nm is referred to as Photosynthetically Active Radiation (PAR).

At this point it becomes important in our discussion to define units and nomenclature. There are three systems of light measurement that are in use by suppliers and users of various lighting systems:

1. Photometric: These units are used for human lighting applications. The units are Lux or lumen per square meter, or foot-candles (lumen per square foot).
2. Irradiance: These units are based on energy fluxes. The units are W per square meter. When the energy of the light in the PAR spectral band is being considered the units are referred to as Watts per square meter PAR.
3. Photon flux density: Based on the number of photons. Photosynthetic Photon Flux density is the number of photons within the PAR spectral band. Units are micro-moles per square meter per second (µmol $s^{-1}$ $m^{-2}$), formerly known as microEinstein. This is the preferred units when referencing light supplied to plants.

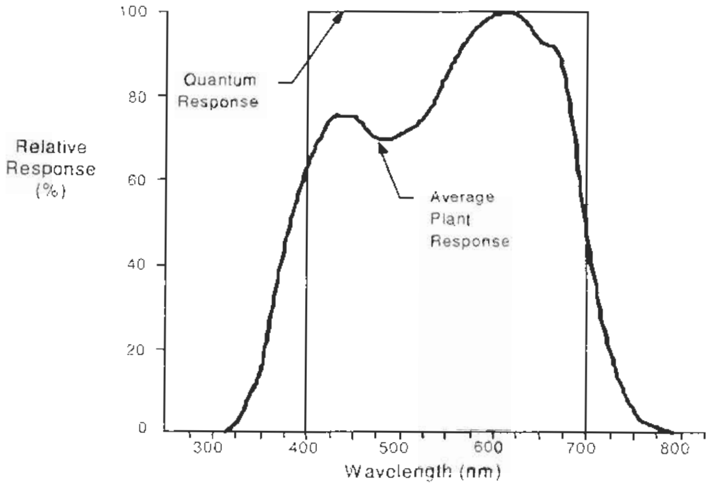


**Figure 3.** Relative quantum efficiency curve

It is important to note here that measuring light sources measured in photometric units (as seen by the human eye) is not a good means of comparison. The conversion factors developed by Thimijan and Heins (1983) to convert Lux to µmol $s^{-1}$ $m^{-2}$ for different light sources are presented in Table 1. Deitzer (1994) has developed similar conversion factors. For example 10,000 Lux of light from a high pressure sodium lamp represents 122 µmol $s^{-1}$ $m^{-2}$, while 10,000 Lux of light from a cool white fluorescent lamp represents 135 µmol $s^{-1}$ $m^{-2}$. In both cases the human eye perceives the same amount of light, but to a plant there is 10% difference. These conversion factors are also useful when designing a lighting system as all design software and performance data of lamps and luminaries are provided in photometric units (lux or foot-candles).

### 2.2 Sunlight and Natural Light Levels within a Greenhouse.

As the present discussion is concerned with supplemental lighting it is important to understand what is being supplemented. Figure 4 illustrates the spectral irradiance of solar radiation at sea level. Approximately 35 to 45% of this solar energy is within the spectral band of PAR. The exact percentage varies with atmospheric conditions. Also the total amount of solar radiation will vary throughout the year and from place to place.

Table 2 presents average solar radiation data for some representative cities across North America. Greenhouses in more southern latitudes will not necessarily benefit from supplemental lighting from a commercial crop perspective. However, research work may be hindered by several days of low solar radiation. For example Davis California can be subject to fog for several days.

The data presented are average values and demonstrate the variation in light received throughout the year. In northern latitudes cumulated solar energy received

**Table 1:** Conversion factors for converting Lux to µmol $s^{-1}$ $m^{-2}$

| Light source | Lux per µmol $s^{-1}$ $m^{-2}$ |
|---|---|
| Sun and sky | 54 |
| Blue sky only | 52 |
| High pressure sodium | 82 |
| Metal halide | 71 |
| Fluorescent (cool white) | 74 |

(ref. Thimijan and Heins, 1983).

in the summer and winter can differ by a factor of 5. Plants that do well under summer light conditions may not receive enough natural light in the winter. Thus the need for supplemental light.

We must note here that the previous data is for incident solar radiation outside the greenhouse. The solar radiation that gets to the plant in the greenhouse is a function of the covering material.

Figure 5 presents the transmissivity of different greenhouse covering materials. This data does not take into consideration the shading effect of the structure and equipment within the greenhouse nor the greenhouse's ridge line orientation. These factors can vary considerably between greenhouses. Our cumulated experience is such that an overall transmissivity of 60 to 70% is used when designing the greenhouse systems. Consequently the incident light energy received in the greenhouse per Table 2 is actually about 65% of the values shown.

The need for supplemental light can also be better understood when considering the instantaneous light levels within the greenhouse. Table 3 summarizes two estimates, high and low, of the light level that can be reached in a greenhouse.

As a frame of reference for these numbers, wheat leaves are reported to effectively use up to 1,000 μmol $s^{-1}m^{-2}$ for photosynthesis and wheat canopies saturate at 2,000 μmol $s^{-1}m^{-2}$ (Bugbee, 1994) Consequently the calculations in Table 3 demonstrate how insufficient low winter light levels can be for certain crops.

Before considering the issue of how much supplemental light should be supplied, we also note that plants are light integrators, such that a lower light level can be compensated by a longer photoperiod.

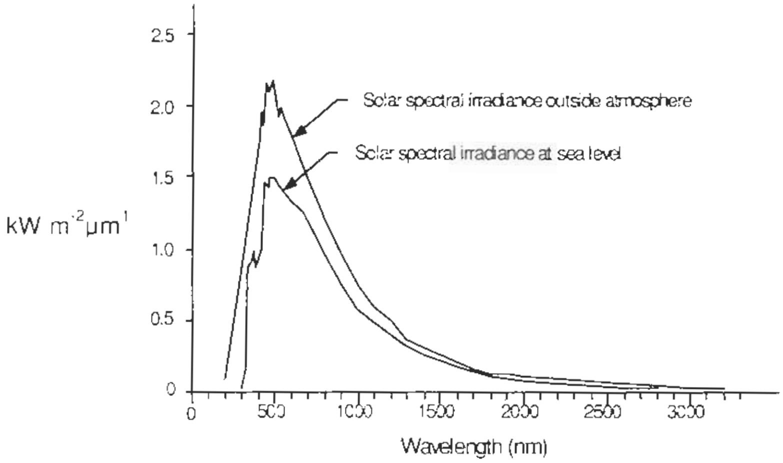


**Figure 4.** Solar spectral irradiance

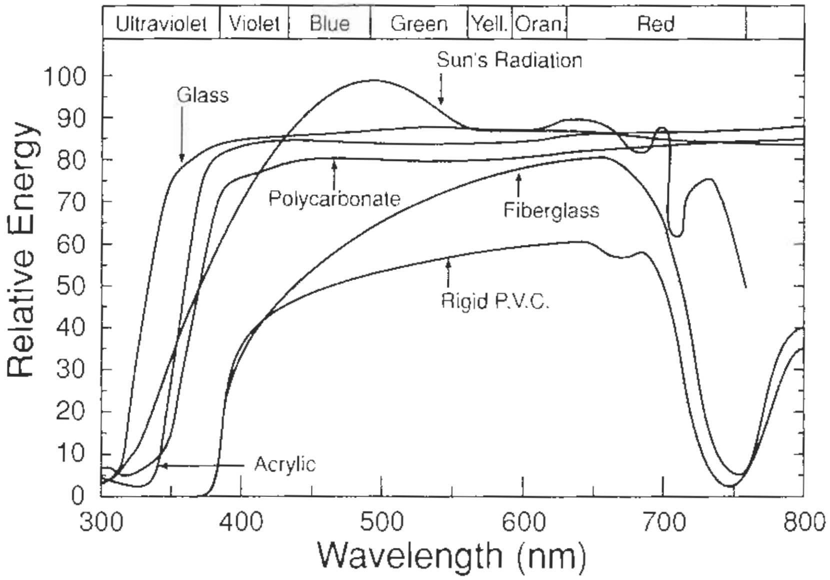


**Figure 5.** Tranmissivity of various greenhouse covering materials. (Ref. ASAE)

### 2.3 Supplemental light within a research greenhouse

The preceding discussion has highlighted the following factors that will affect the amount of supplemental light to be provided in a research greenhouse:

- natural light levels
- transmissivity of the greenhouse structure and glazing
- Physical characteristics of the greenhouse
- type of plants requiring supplemental light
- acceptable photoperiod

These parameters could be integrated into a complex engineering formula that would determine the light level to provide. Much work has been done for commercial applications to optimize the best economic supplemental light level for various greenhouse crops (Gosselin 1988).

However the essence of the past ten years of design experience at Agritechnove with respect to supplemental light levels be provided in research greenhouse based on:

- the previous experience of the users
- the experience of other research facilities doing similar work
- the amount of money available for the project.

The supplemental light levels installe and observed at various facilities across North America in the last 10 years allow us to categorize the required light levels follows:

**Table 2A.** Average daily horizontal solar radiation (MJ/square meter) (Ref. ASHRAE 1995)

| Location | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Montreal, QC | 5.3 | 8.7 | 12.4 | 16.0 | 19.0 | 20.3 | 21.0 | 17.3 | 13.5 | 8.1 | 4.6 | 3.9 | 12.5 |
| Portland, OR | 3.5 | 6.4 | 10.1 | 14.8 | 18.9 | 20.1 | 23.2 | 19.1 | 13.9 | 8.2 | 4.4 | 3.0 | 12.2 |
| St-Louis, MO | 7.1 | 10.1 | 13.7 | 17.7 | 21.2 | 23.8 | 23.3 | 20.6 | 16.6 | 12.5 | 8.1 | 6.0 | 15.1 |
| Boston, ME | 5.4 | 8.0 | 11.6 | 14.9 | 18.4 | 20.6 | 19.9 | 16.9 | 14.3 | 10.0 | 5.7 | 4.6 | 12.5 |
| Los Angeles, CA | 10.6 | 13.7 | 18.4 | 22.2 | 23.6 | 24.0 | 26.6 | 23.3 | 18.9 | 14.9 | 11.4 | 9.7 | 18.1 |

(ref. ASHRAE 1995)

**Table 2B.** Average day length (hours)

| Location | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Montreal, QC | 9.2 | 10.5 | 12.0 | 13.6 | 14.8 | 15.4 | 14.9 | 13.7 | 12.0 | 10.6 | 9.2 | 8.6 |
| Portland, OR | 9.2 | 10.5 | 12.0 | 13.6 | 14.8 | 15.4 | 14.9 | 13.7 | 12.0 | 10.6 | 9.2 | 8.6 |
| St-Louis, MO | 9.8 | 10.9 | 12.0 | 13.2 | 14.2 | 14.6 | 14.3 | 13.3 | 12.0 | 10.9 | 9.8 | 9.4 |
| Boston, ME | 9.4 | 10.7 | 12.0 | 13.4 | 14.6 | 15.1 | 14.6 | 13.5 | 12.0 | 10.7 | 9.5 | 8.9 |
| Los Angeles, CA | 10.1 | 11.0 | 12.0 | 13.1 | 13.9 | 14.3 | 14.0 | 13.1 | 12.0 | 11.0 | 10.1 | 9.7 |

**50-100 µmol $s^{-1}m^{-2}$**

This level is most often used wherever work is done on greenhouse crops as the research stays mostly with industry levels. (10-20 W/sq.m. for HPS)

**100-200 µmol $s^{-1}m^{-2}$**

This level is most often used in the Northeast for work with vegetable, fruit and forage crops. Few users in this category are adamant about the light source. HPS is acceptable. (20-40 W/sq.m. for HPS)

**300-400 µmol $s^{-1}m^{-2}$**

This level is used for cereal crops and oil seeds, often in the mid west. Some users may want to have metal halide for its spectral qualities. Lamps are often suspended closer to the bench to increase the light intensities. (60-80 W/sq.m. for HPS)

## 2.4 Supplemental light sources for greenhouses

Rather than present the spectral output of all possible lamps that can be used in a greenhouse setting we shall limit our presentation here to the lamps that are requested within our projects. They are in order of importance: High Pressure Sodium (HPS), Metal Halide (MH) and Fluorescent. Figure 6 presents their spectral output in terms of relative quantum yield.

HPS and fluorescent lamps provide their energy in the spectral band where plants are most efficient in using it. MH lamps provide their energy over a wider spectral band. Because the energy is more evenly distributed MH lamps can be preferred when more blue light is required for growth regulating functions. The same can be said for fluorescent light.

The request for MH and fluorescent lamps are relatively rare. The majority of projects we have been involved in have used HPS lamps. Within the approximately 50 programming and design mandates in the last 10 years we have not met any users who were adamant about the need for MH or fluorescent lamps in a greenhouse. Nor did these researchers have any empirical data to justify their requirement. Their preference was based on the fact that these light sources worked well in the past and they wished to continue with them.

HPS lamps are the most efficient in terms of energy conversion into light followed by MH and fluorescent lamps. Their respective conversion efficiencies (ballast included) are 28%, 27% and 19%. (ref. Both 1994).

**Table 3.** Range of light levels in a greenhouse

| | High estimate | Low Estimate |
|---|---|---|
| (1) Exterior solar radiation | Bright summer day:<br>1,000 W/square meter | Overcast winter day<br>no direct sun:<br>400 W/square meter |
| (2) Overall transmissivity of greenhouse | 70% | 60% |
| (3) Fraction of solar radiation as PAR | 0.45 | 0.35 |
| (4) µmol $s^{-1}m^{-2}/Wm^{-2}$ PAR | 4.57 | 4.24 |
| µmol $s^{-1}m^{-2}$ in the greenhouse (1)*(2)*(3)*(4) | 1,459 | 415 |

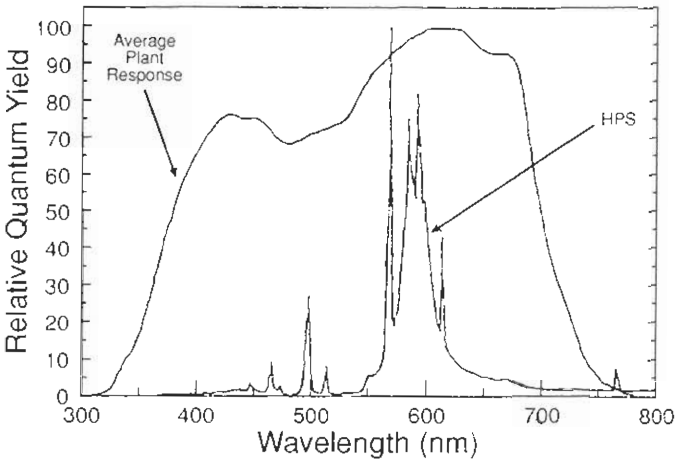


**Figure 6a:** Spectral output of High Pressure Sodium lamps. (from Bugbee 1994)

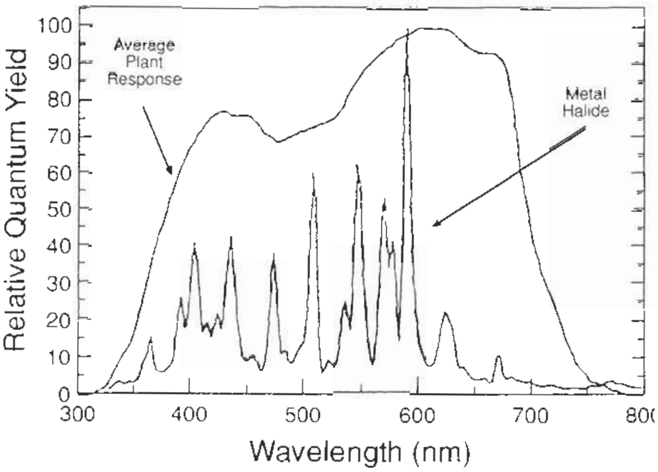


**Figure 6b:** Spectral output of Metal Halide lamps. (from Bugbee 1994)

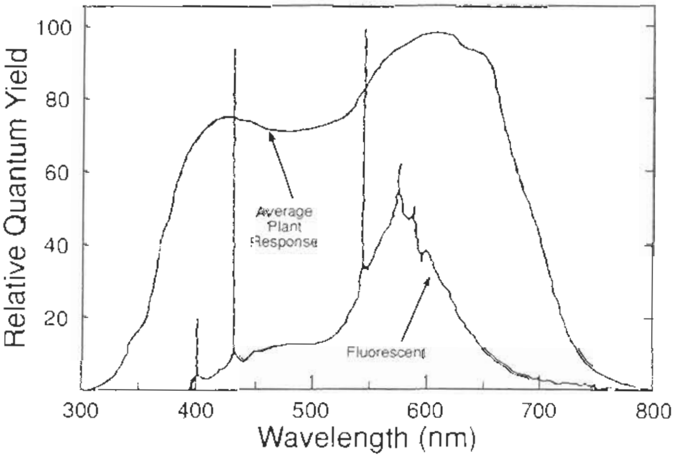


**Figure 6c:** Spectral output of Fluorescent lamps. (from Bugbee 1994)

HPS lamps have by far the major portion of the market with several suppliers available. The efficiency of the reflector and its maintenance will affect the luminaries overall efficiency. Also it should be noted that most MH lamps require a barrier under the lamp for safety reasons and this can reduce the light being supplied.

## 3.0 Lighting system design

The design of a supplemental lighting system will normally have two objectives: intensity and uniformity . The required intensity must be defined for a given distance from the lamps. We try to obtain the required intensity at the bench top or at mid-plant height. In the former case the design is conservative as the plants will be subject to higher levels as they grow (Intensity will increase with height). It is important to check that the uniformity remains acceptable with the maximum design plant height. In many cases the requirement of adequately lighting the plant canopy to its maximum height pushes the greenhouse eave to 4.3 meters (14 feet). When very high intensities are required the luminaries can be installed on a mobile canopy to keep them at an canopy. We should also mention the importance of keeping a minimum distance between the tip of the plants and the lamp bulbs.

## 3.1 Luminary layout and uniformity

Luminaries normally have characteristic photometric curves that describe the intensity of the light cast as a function of distance. This data is used to calculate the intensity of the light supplied by a given layout of luminaries. Figure 7 shows a typical photometric curve for a greenhouse luminary reflector.

Calculations of light intensities with photometric data can be done with specialized software. Most major lighting manufacturers have developed sophisticated software to help building designers and architects design lighting systems for buildings. These programs take the luminary layout and photometry into consideration as well as the physical layout of the room including the reflection from the walls. These programs can be used to calculate the lighting intensity and uniformity in a greenhouse compartment.

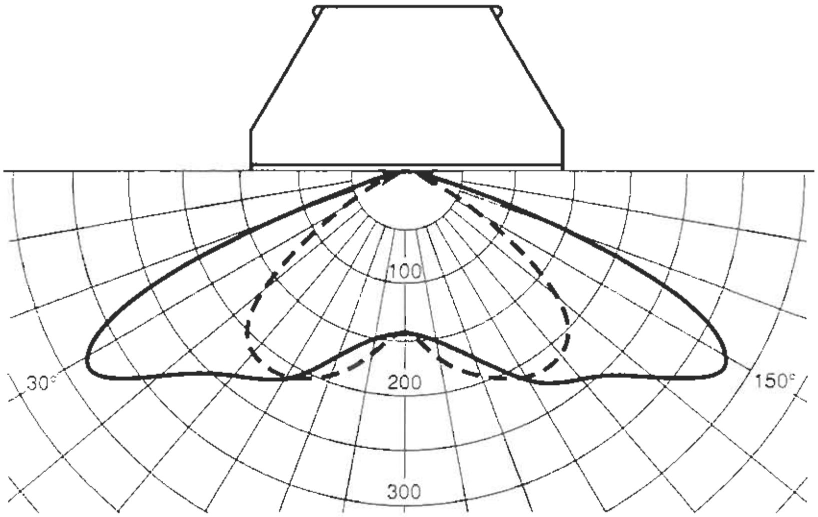


**Figure 7**. Typical photometric curve for a greenhouse luminary.

A simplified version of these programs is used for parking lot design. These programs assume an infinite grid of luminaries, such that they neglect border and ceiling effects. Greenhouse luminary manufacturers who provide design calculation often use this type of program. This approximation is valid in a production greenhouse. Calculations for a small greenhouse compartment with a "parking lot type" program can be done with certain assumptions and adjustments. The end result may not be as precise as using the sophisticated "room" calculations.

The less precise calculation remains acceptable because the objective is to obtain the best uniformity with the required intensity. Any research greenhouse compartment is relatively small and will not have a very good uniformity (compared to a production greenhouse with a virtually infinite grid of luminaries). The exercise of doing the calculation is aimed at determining the relatively better layout and not the precise results.

Uniformity is measured in lighting calculations as the ratio of the Minimum and Maximum intensities calculated as well the ratio of the Minimum and Average intensities. This differs from a statistical uniformity calculation. Again we note our objective is to determine the best layout in a relative fashion.

Figure 8 shows an extract of design program calculation for a large and small compartment. The difference in uniformity is about 13% .

### 3.2 Wiring and control

The design of the electrical distribution for lighting system will be based on the supply voltage that is used. As shown in Table 4. the higher the voltage the more lamps that can be carried on a 15 amp circuit.

Our standard practice is to use 208 V or 240 V. Higher voltages are not recommended because of the danger to users in an institutional situation where lamps are moved around.

In terms of control, the lights are normally powered through an electrical panel and switched through a motor control center with contactors activated by the control system. We have developed the use of motorized breakers on the panel boards to minimize cost and save on electrical room space, which in the former case increase dramatically because the large number of lights normally used.

**Table 4**: Lamps per 15 amp circuit as function of voltage.

| | Lamp | | | |
|---|---|---|---|---|
| Voltage | 430 W HPS current draw (amperes) | 600 W HPS current draw (amperes) | 430 HPS / 15 A circuit | 600 W HPS / 15 A circuit |
| 120 | 5.7 | 5.2 | 2.1 | 2.3 |
| 208 | 3.3 | 3.0 | 3.6 | 4.0 |
| 240 | 2.9 | 2.6 | 4.1 | 4.6 |
| 277 | 2.7 | 2.3 | 4.4 | 5.2 |
| 347 | 2.1 | 1.8 | 5.7 | 6.6 |
| 480 | 1.5 | 1.3 | 8.0 | 9.2 |

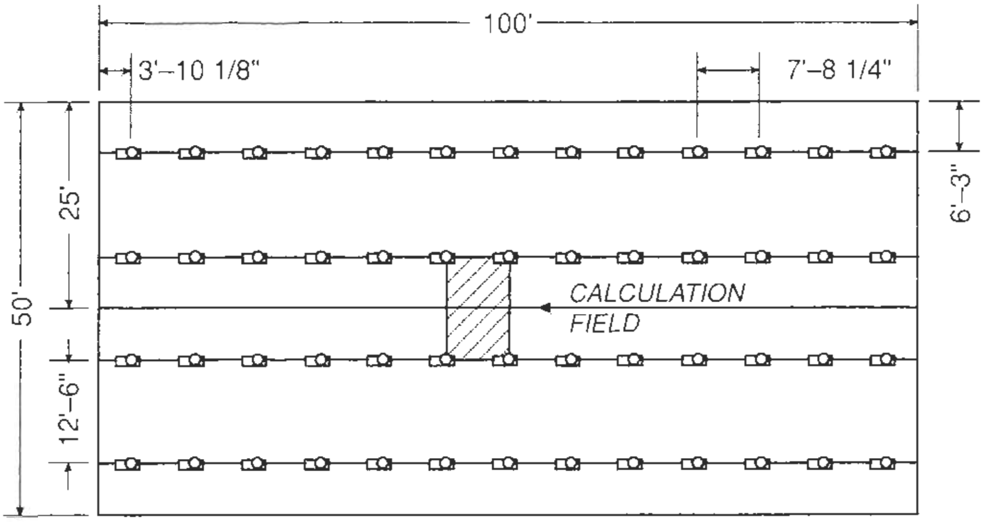
### 4.0 Lighting for insects

Insect rearing in greenhouses is an activity requiring special consideration. The considerations used so far in the design of a supplementary lighting system hold little value when it comes to insects.

More often than not, insects need UV radiation in order to see their food, to engage in mating practices and to generally function like any other insect free in nature. The usual supplementary lighting sources used in research generate very little if any UV radiation. As will be seen in the upcoming light source section of this document, new light sources not yet in general use do provide UV radiation. Of course, the use of available UV lighting equipment is always possible.

The problem is compounded by the fact that most glazing material for greenhouses remove most UV light contained in the sun's spectrum. A single layer of glass, for instance, will cut between 40% and 50% of the available UV radiation. Local construction codes will often prescribe the use of laminating films to ensure shards of glass will not fall on workers. These films, almost without exception, will absorb more than 90% of the available UV from the sun. The net result for the insects is an almost permanent near "darkness" inhibiting their behavior.

In our experience, researchers leading scientific programs involving insects have learned to deal with this and can still generally obtain acceptable results. It remains nonetheless that insect rearing in



Illuminance in the Calculated Area

| | 1* | 2* | 3* | 4* | 5* | 6* | 7* | 8* | 9* | 10* | 11* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- | 760.0 | 759.8 | 758.2 | 755.5 | 753.7 | 752.8 | 753.7 | 755.6 | 758.2 | 759.8 | 760.0 |
| 2- | 763.1 | 763.6 | 763.1 | 762.7 | 761.4 | 761.0 | 761.4 | 762.8 | 763.1 | 763.5 | 763.1 |
| 3- | 750.8 | 732.0 | 755.9 | 758.8 | 760.3 | 761.0 | 760.3 | 758.8 | 755.9 | 752.0 | 750.8 |
| 4- | 739.1 | 741.7 | 747.1 | 752.7 | 759.5 | 762.5 | 759.4 | 752.7 | 747.2 | 741.7 | 739.1 |
| 5- | 746.8 | 749.9 | 757.5 | 766.8 | 776.6 | 780.5 | 776.5 | 766.7 | 757.4 | 749.9 | 746.8 |
| 6- | 762.7 | 766.2 | 773.9 | 787.3 | 795.9 | 799.6 | 795.8 | 787.1 | 773.8 | 766.1 | 762.7 |
| 7- | 746.8 | 749.9 | 757.5 | 766.8 | 776.6 | 780.5 | 776.5 | 766.7 | 757.4 | 749.9 | 746.8 |
| 8- | 739.1 | 741.7 | 747.1 | 752.7 | 759.5 | 762.5 | 759.4 | 752.7 | 747.1 | 741.7 | 739.1 |
| 9- | 750.8 | 752.0 | 755.9 | 758.8 | 760.3 | 761.0 | 760.3 | 758.8 | 755.9 | 752.0 | 750.8 |
| 10- | 763.1 | 763.6 | 763.1 | 762.7 | 761.4 | 761.0 | 761.4 | 762.8 | 763.1 | 763.5 | 763.1 |
| 11- | 760.0 | 759.8 | 758.2 | 755.5 | 753.7 | 752.8 | 753.7 | 755.6 | 758.2 | 759.8 | 760.0 |

Illuminance: Emin = 739.1 Footcandle Emax = 799.6 Footcandle Eav = 760.2 Footcandles

Uniformity: UG (Emin/Emax) = 92% UO (Emin/Eav) = 97%

Emin. = Minimum light level in the field
Emax.= Maximum light level in the field
Eav.= Average light level in the total field

UG. = Emin. / Emax. (2 points in the field)
UO. = Emin. / Eav. (real uniformity)

**Figure 8A.** Lighting System Design for a Large Area (Ref. PL Light)

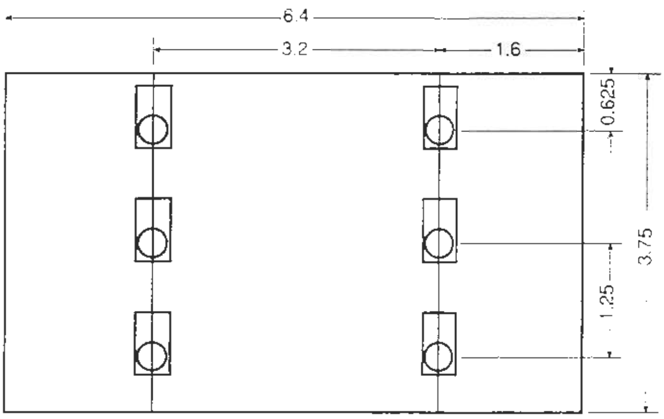
research greenhouses or in growth chambers could use some innovation regarding the UV light available to them.

## 5.0 Upcoming light sources

Two upcoming new light sources that could be of interest for supplemental light in greenhouses are presented here. Note that the greenhouse industry is not sufficiently large to incite new lighting technologies. These are normally developed for other markets and if they are useful in greenhouse they will eventually find their way to this market.

### Microwave Sulfur Lamps

- Commercial units for greenhouse industry became available in 1997. Lamp was first created in 1990 after 20 years of research and development. As of March 1998, unit still not UL approved. Sold under the name "Light Drive 1000" by Fusion Lighting, Inc. For Horticultural applications, contact Bob Edberg, at Bio Logic Technologies in San Jose, California (Ph.: 408-873-1619) (Fax: 408-873-1610).
- Already tested at several locations, including Duke University, Cornell, University of Wisconsin, NASA, USDA, Guelph University, at several private grower facilities and at various locations in Japan, the Netherlands and Sweden. Several non-horticultural projects completed so far, including museum, auto plants, clean room, highway signage, aquarium lighting, shopping centers, subway stations, etc...
- Operates on the excitation of sulfur and argon using microwaves. Sulfur creates a white brilliance very similar to sunlight but with much less UV and IR. From an AC source, a power supply feeds a magnetron generating microwaves exciting the bulb. A small blower wheel ensures ventilation of the unit.
- Longer life expectancy than other horticultural light sources: no electrode, no filament. Magnetron needs replacement every 20,000 hours. 2 magnetrons supplied with each fixture.
- 73% of output in visible light, 27% of output UV (0.14% under 380 nm) and IR (8% of output above 780 nm). Lamps produce 60% less total heat than metal halide fixtures. Seems perfect for growth chambers: adds less to cooling load than any other type of light.
- High conversion rate, in the range of 90-110 lumen per watt, higher than other light sources except new HPS lamps.
- Commercial unit available at 1425 W input power, 200-240 VAC @ 50-60 Hz or 277 VAC, 50-60 Hz, all single phase. Selling price to OEM around $1800-$2500. (End user should expect 30 to 40% above that). Lamp weighs 7 kg including power supply.
- Keeps its lumen output over 60,000 hours (100%) if kept clean. No observable color change over life of lamp.
- Light is "dimmable" from 100% to 30% of output with little color change.
- Several reports from Universities already report significant (2-3 times) heavier dry weight of plants, reduced seed-to-harvest time for corn, reduction in leaf temperature and heavier and larger flower buds for roses, etc.



Illuminance in the Calculated Area

| | 1+ | 2+ | 3+ | 4+ | 5+ | 6+ | 7+ | 8+ | 9+ | 10+ | 11+ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- | 6170.0 | 6280.8 | 6355.6 | 6422.1 | 6465.4 | 6485.7 | 6455.5 | 6393.7 | 6326.1 | 6238.1 | 6121.0 |
| 2- | 6561.1 | 6678.2 | 6740.6 | 6776.9 | 6784.5 | 6788.3 | 6781.7 | 6764.5 | 6722.2 | 6642.5 | 6502.4 |
| 3- | 6882.4 | 7025.1 | 7106.8 | 7140.6 | 7120.7 | 7107.2 | 7133.9 | 7138.5 | 7079.3 | 6978.1 | 6826.2 |
| 4- | 7143.0 | 7259.8 | 7318.1 | 7344.7 | 7349.0 | 7367.5 | 7350.1 | 7335.2 | 7304.0 | 7222.2 | 7080.3 |
| 5- | 7409.9 | 7549.1 | 7595.5 | 7616.5 | 7629.4 | 7632.5 | 7627.8 | 7604.8 | 7583.0 | 7505.2 | 7347.7 |
| 6- | 7541.4 | 7658.7 | 7744.0 | 7777.5 | 7789.3 | 7787.7 | 7785.2 | 7772.0 | 7713.6 | 7622.9 | 7476.4 |
| 7- | 7409.9 | 7549.2 | 7595.5 | 7616.5 | 7629.4 | 7632.5 | 7627.8 | 7604.8 | 7583.0 | 7505.2 | 7347.7 |
| 8- | 7143.0 | 7259.8 | 7318.1 | 7344.7 | 7349.0 | 7367.5 | 7350.1 | 7335.2 | 7304.0 | 7222.2 | 7080.3 |
| 9- | 6882.4 | 7025.1 | 7106.3 | 7140.6 | 7120.7 | 7107.2 | 7133.9 | 7138.5 | 7079.3 | 6978.1 | 6826.2 |
| 10- | 6561.1 | 6678.2 | 6740.6 | 6777.0 | 6784.5 | 6788.3 | 6781.7 | 6764.5 | 6722.2 | 6642.5 | 6502.4 |
| 11- | 6170.0 | 6280.8 | 6355.6 | 6422.1 | 6465.4 | 6485.7 | 6455.5 | 6393.7 | 6326.1 | 6238.1 | 6121.0 |

Illuminance: Emin - 6121.0 lux Emax - 7789.3 Eav = 7138.9 lux

Uniformity: UG (Emin/Emax) = 79% UO(Emin/Eav) = 86%

Emin. = Minimum light level in the field
Emax.= Maximum light level in the field
Eav.= Average light level in the total field
UG. = Emin. / Emax. (2 points in the field)
UO. = Emin. / Eav. (real uniformity)

**Figure 8B.** Lighting System Design for a Small Area (Ref. PL Light)

**Figure 8A & B Note:**

This calculation is made with one exact measured light fixture in a perfect condition. Because of this you may experience some variance in light level due to voltage loss, dust, mounting, temperature, greenhouse installation and tolerance of bulb and ballast unit.

- Still some concern with potential problems created by accidental water splashes of heated lamps.

**Xenon Lamps**

- Not much information at this point as to the commercial pertinence of this type of lamps both for research and commercial applications.
- Have been on the market for several years.
- Current applications: cosmetics, dermatology, solar energy, aging tests (durability), biodegradation tests, aerospace, medicine, dentistry, environmental simulation chambers.
- Products available are confined beam applications, not very applicable to greenhouse lighting at the moment.
- Excellent color constancy throughout operating lifetime. Light source is reliable and stable.
- Control spectral output possible through use of filters an selected optics
- Xenon based lamps simulate spectrum of sun, from 250 nm to 1150 nm and above, with close to 50% of output between 400 and 700 nm. Xenon lamps' output generate much heat, that is have a significant percentage of the produced radiation in the infrared and above.
- Lamps available from 250 to 1000 W for small scale applications and from 1000 to 7000 W for larger operations.
- A standard solar simulator comes with a Xenon arc lamp, a lamp heat sink, lamp socket, a lamp power supply, lamp housing, optics, filter holder, air mass filters, beam deflection mirror and flexhose for ozone removal.
- Options are available to dissipate heat (IR radiation) and reflect UV and visible light. All kinds of other options like electronic shutters, variable iris diaphragms, etc. are available.
- Two manufacturers consulted mentioned they have no application currently running in greenhouses but both mentioned they were highly interested to discuss further this type of application.

## References

Both, A.J.,1994, *HID Lighting in Horticulture: A Short Review*, in Proceedings from the Greenhouse Systems International conference, New Brunswick, NJ, July 20-22 1994, Northeast Regional Agricultural Engineering Service pp 208-222.

Bugbee, B., 1994. *Effects of Radiation Quality, Intensity and Duration on Photosynthesis and Growth*, in Proceedings of International Lighting in Controlled Environments Workshop, NASA-CP-95-3309, pp 39-43

Degelman, L.O., 1995. *Bin and degree-hour weather data for simplified energy calculations*, American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc. RP-385

Deitzer, G., 1994, *Spectral comparisons of sunlight and different lamps*, in Proceedings of International Lighting in Controlled Environments Workshop, NASA-CP-95-3309, pp 197-199

Gosselin, A., 1988, *Profitability of high irradiance supplemental lighting for greenhouse production in Canada*. Report for Canadian Electrical Association, prepared by Centre de Spécialisation des cultures abritées. 73 p.

Thimijam, R.W. and Heins, R.D., 1983. *Photometric, Radiometric and Quantum Light Units of Measure: A review of procedures for interconversion*. Hortscience, vol 18 (6) pp 818-822

This paper was presented at the AERGC 1998 Annual Meeting in Montreal, PQ, Canada.

AERGC 1999 Annual Meeting

## *Educational Aspects of Plant Collections*

**July 28, 29, 20 and 31**
**Boulder, Colorado USA**

Hosted by the

**University of Colorado at Boulder**
and the
**Denver Botanic Garden**

# AERGC 1999 Annual Meeting

This year's event will be the AERTGC's 13th Annual. We need your input for another successful annual meeting. Some suggested topics for talks at the meeting include:

Displays
Labeling
Crops with special plant features/structures
Pest control/IPM/Biological Controls
Scheduling/timing
Costs
Services
Facilities
Collections
Special collections
etc.

Please consider contributing to the meeting by giving a talk on one of these or a related subject.

We will again have both the Plant Exchange (for USA folks only this time) and the Member Slide Session.

Tom Lemieux is working on arranging the details for the meeting including speakers, housing, field trips, sponsors, tour, etc. If you have suggestions, questions or comments about the meeting, contact Tom at:

Tom Lemieux
EPO Biology
University of Colorado
CB 334
Boulder, CO 80309 USA
303-492-7300, 303-492-8699 fax
thomas.lemieux@colorado.edu

We look forward to seeing you in Colorado this July.

### The *AERGC E-Mail Forum*

The *AERGC E-Mail Forum* is convenient and popular way to communicate with your colleagues across the continent. The Forum, an e-mail discussion group, is a free service provided by the AERGC. Subscribing is easy and the Forum is automatic once you subscribe. To subscribe to the *AERGC E-Mail Forum*, address an e-mail message to:

majordomo@life.uiuc.edu

Leave the "subject" field blank and enter a command with the following format into the body of the message:

subscribe aergc

Within a day of sending this message, you should receive an acknowledgment of acceptance as a subscriber to Forum as well as more detailed instructions of how to use the system.

You are encouraged to subscribe and participate in the Forum by posting items of interest to your greenhouse / plant growth facility colleagues and by replying to messages from other subscribers. This may include information, questions, answers and discussions on greenhouse systems, pest control, biological controls and greenhouse IPM, equipment, supplemental lighting, management policies, greenhouse environmental control systems, operating tips, current events, greenhouse design, job openings, plant culture, plant and seed exchanges, growth chambers, etc.

If you have any questions or need help subscribing to the Forum, please contact Jim Kramer at:

j-kramer@uiuc.edu or 217-333-3058

The AERGC Web Site:

www.life.uiuc.edu/aergc/

AERGC
GREENHOUSE NEWSLETTER
Association of Education and Research Greenhouse Curators

AERGC
c/o Department of Biology
University of Illinois at Urbana-Champaign
265 Morrill Hall, 505 S. Goodwin Ave.
Urbana, IL 61801-3793 USA