Measuring LED Lighting Systems and Developing Guidelines for Evaluation, Comparison and Use

SCRI-LED
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Electromagnetic radiation spectrum

Ionizing radiation: able to detach an electron

http://www.sura.org
• Light, sensors, and units

➤ Light:
  - Visible (380-770 nm)
  - PAR (400-700 nm)
  - Sunlight (280-2,800 nm)

➤ Sensors:
  - Foot-candle or Lux meter (Visible)
  - Quantum sensor (PAR)
  - Pyranometer (Sunlight)

➤ Units:
  - ft-cd or lux
  - µmol/(m²*s) or mol/(m²*d)
  - W/m² (Note: radiant Watt)

1 ft-cd = 1 lumen/ft²
1 lux = lumen/m²
1 ft-cd = 10.76 lux

• Comparing human and plant sensitivity to light

References: Sager et al. (1988) Transactions of the ASAE 31(6):1882-1889; CIE
• Effect of green light on plants?


• Light measurements
  - Photometric: Visible (lux, ft-c)
  - Quantum: PAR (µmol/(m²s))
  - Radiometric: Energy (W/m²)
  - Light intensity is inversely proportional to the square of the distance from the source

http://imagine.gsfc.nasa.gov
• Directional light meters

http://img.directindustry.com

http://www.envcoglobal.com

http://img.directindustry.com

• Omni-directional light sensor: integrating sphere

http://www.nytimes.com
• Measuring light spectrum: spectroradiometer

• Spectral output of various lamps
• Transitioning to LED lighting for horticulture

- Effects of LED dimming?
  - Is it desirable for horticultural applications?
  - What does it do the efficacy?
  - Does it change the spectral output?

http://www.electronics-lab.com
• Effects of LED junction temperature (Is this an issue?)

![Graph showing LED junction temperature and L70 lifetime prediction](http://www.electronics-lab.com)

http://ewh.ieee.org

http://www.electronics-lab.com

L70 = lumen depreciation to 70% of initial lumen output
(By the way, is this acceptable for horticultural applications?)

• Planned LED lighting system evaluations

- Supplemental lighting: Spectral distribution (350-800 nm; percentages of B, G, R, FR), luminaire location (above and/or within the canopy), PAR intensity (for targets of 50, 100, 150, and 200 \( \mu \text{mol/(m}^2\text{s}) \)) and distribution (both these requirements vary by crop) for a specific mounting height and luminaire spacing pattern, directionality of the emitted light (evaluating for light pollution)
- Photoperiod lighting: R:FR ratio, intensity (target 1-2 \( \mu \text{mol/(m}^2\text{s}) \)) and distribution for a specific mounting height and luminaire spacing pattern (continuous or cyclic operation)
- Electric power consumption per luminaire and supply voltage
- Luminaire dimensions and weight
- Luminaire life expectancy (estimated, based on equipment components and light depreciation)
- Design features that allow for operation in greenhouse environments (moisture, heat, chemicals)
- Cost (installation and operation)
Additional considerations

Introduction

Condition for controlled atmosphere growth rooms and chambers (CE units) should be provided in detail for comparison of results and replication of experiments. The minimum guidelines above, along with these notes, should help extend these, indicating a precise sequence on amount of information that should be provided. They may also highlight permission that could be obtained, but may not have been considered for measurement.

Average measurements should be provided, including their standard deviation in (%).

All sources should be cited clearly referring to the manufacturer's procedure and suggested frequency.

Radiation

- Output of all calibrated cameras, with issues on the output of e.g. 20% RHECTP, may drop 10% after first 5 minutes of use.
- Irradiance units should be given as the growing area in mW/cm².
- Vertical gradient indicates growth in all CE units, depending on surface area and other factors.
- Sources from one long exposure may cause a decrease of 40% of the final result. One could not be used if light is not being reflected by the glass plate.

Temperature

- Differences may exist between the temperature of the air and glass, especially with high collector loads.
- Other small temperature differences must be at least 5°C variation from the set-point temperature.
- Vertical temperature gradient is seen in CE units, depending on surface area and other factors.

Atmospheric moisture

- Air humidity affects plant CE units directly (via transpiration and gas exchange) and indirectly (via the plant's physiological balance and physical and biological environment).
- Humidity and growing rates varying 10±5% decrease relative humidity by 20±5%.
- Humidity is defined by the growth rate to maintain the humidity of the air to maintain the relative humidity by 20±5%.

Carbon dioxide

- Carbon dioxide (CO₂) is probably the least essential component of CE units. Unfortunately, the use or lack of CO₂ in air is difficult to assess when using these measurements.

Experimental design

- Likely a small CE unit should be the smallest automatic replicate, assuming the replicates are using multiple CE units, or repeated measurements in each CE unit, but each should span the entire growing season.

Example of a report suitable for publication

The experiment was conducted over a 3-year period in a greenhouse with a daily range of temperatures from 25°C to 40°C during the light period. The water stress varied from 60% to 80% RH. The plants were growing in a 1:1 peat and perlite mixture with a 0.3% N solution. The plants were watered daily with a 0.5% N solution. The plants were 10 cm tall before harvest. A 10 cm tall plant was measured for height and leaf area.

International Committee for Controlled Environment Guidelines

Minimum Guidelines for Measuring and Reporting Environmental Parameters for Experiments on Plants in Controlled Environment Studies

Parameter to measure | Units | Where to measure | When to measure | What to report
--- | --- | --- | --- | ---
Temperature | °C | Inlet of the growth chamber | At least once during the experiment | Average and standard deviation
Humidity | % | Inlet of the growth chamber | At least once during the experiment | Average and standard deviation
Carbon dioxide | ppm | Inlet of the growth chamber | At least once during the experiment | Average and standard deviation
Light intensity | μmol/m²·s | Surface of the growth chamber | At least once during the experiment | Average and standard deviation

![Diagram](image-url)