Light emitting diode (LED)
Lighting for Greenhouse Crops

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Electromagnetic radiation spectrum

http://www.zulyzami.com

http://upload.wikimedia.org
• Why do plants need light?

➤ Photosynthesis (growth and development)

Other processes:

▪ Photoperiodism (daylength)
▪ Photomorphogenesis (light affects shape)
▪ Phototropism (sunflower)
▪ Photodormancy (seeds)

*Note*: Without the ability of plants to convert light into biomass, many living organisms would not survive on our planet, including us!

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**Relative Quantum Efficiency and Eye Sensitivity**

![Graph showing relative quantum efficiency and eye sensitivity](image)

*Disputed (CRC Handbook of Fundamental Spectroscopic Correlation Charts, CRC Press, 2005)*
• 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) (recommended)
      i.e., instantaneous or integrated (DLI)
    ▪ W/m² (note: radiant Watt, not electric Watt)

• Preferred light sensors (horticultural applications)
  Quantum sensor (400-700 nm) measures PAR
  Pyranometer (280-2,800 nm) measures solar radiation

http://www.envcoglobal.com
http://img.directindustry.com
**Daily light integrals for Newark, NJ**

- Average daily light integrals

Data source: National Renewable Energy Laboratory

**Average daily light integrals**

Dr. Jim Faust, Clemson University

Outdoor average daily light integral (mol m⁻² d⁻¹)

- 6 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45
- 45 - 50
- 50 - 55
- 55 +
• Supplemental lighting (promote photosynthesis)

Benefits:
- Improves crop production (quality, duration)
- Improves crop timing

But:
- Impacts other crop production systems, e.g.:
  - Environmental control
  - Irrigation and fertilization
- Increases capital investment
- Increases overall greenhouse energy use

• Inverse square law

- Light intensity is inversely proportional to the square of the distance from the source

http://imagine.gsfc.nasa.gov
Common supplemental light sources:
- Incandescent (photoperiod control)
- Fluorescent (growth and germination rooms)
- High Intensity Discharge (HID):
  - High Pressure Sodium (HPS), yellowish light
  - Metal Halide (MH), white light
- Light emitting diode (LED), new technology (R&B)
- MH compared to HPS:
  - More blue light (plant development)
  - Shorter lamp life (6,000 versus 16,000 hrs)
  - Less efficient (25% versus 30%)
• Photoperiod lighting with LEDs

Image courtesy of Philips Lighting, http://www.lighting.philips.com

• Fluorescent
• LED lighting in a multi-tier germination facility

Image courtesy of Philips Lighting, http://www.lighting.philips.com

• High-pressure sodium
Mixed mode: Metal halide and high-pressure sodium

LED lighting (horizontal arrays)
• LED lighting (vertical arrays)

• Spectroradiometer

http://www.apogeeinstruments.com
• Spectral output of various lamps

Graphs showing the spectral output of different types of lamps, including IRC, MH, HPS, Blue LED, and Red LED.
• Integrating sphere (φ 76” or 2m) (Ulbricht sphere)

- Inside of the sphere reflects and uniformly diffuses light (the surface is considered Lambertian; coated with a BaSO₄ compound)
- Test lamp surface area should be <2% of sphere surface area
- Maximum test lamp characteristics: 51” (1.3 m) long, 5,000 W power

• Questions regarding horticultural applications:
  - Testing compliant with LM-79, LM-80?
    Q: PAR instead of visible light measurements?
  - L₇₀ (TM-21 compliant)?
  - Spectral output (300-800 nm)?
  - PAR distribution (at a specific mounting height)?
  - Conversion efficiency (μmol/J)?
  - Experience from commercial installations?
  - System warranty?

  Q: Do we need our own ‘Lighting Facts Label’?

Lighting Facts
- Brightness: 870 lumens
- Estimated Yearly Energy Cost: $1.47
- Life: 5.5 years
- Energy Used: 13 watts
- Contains Mercury
  For more on clean up and safe disposal, visit epa.gov/cfl
• Multiple light sources
  ➢ Sunlight (overhead)
  ➢ HPS (overhead)
  ➢ LED (intracanopy)

How best to characterize the plant light environment?

Image courtesy of Philips Lighting
http://www.lighting.philips.com

Thank You!
Questions?
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