GLASE Technical Articles Series

Light Simulation in Greenhouses

by Michael Eaton

Introduction

Vegetable crop productivity in controlled environment agriculture operations depends heavily on light. Understanding the lighting conditions of a CEA facility can allow personnel to carry out improvement measures such as adding supplemental lighting, tuning light quality, or improving light uniformity. Characterizing lighting conditions in a greenhouse can be done through direct measurement, or modeling and simulation. One benefit of 3D modelling and light-simulation is the ability to give growers a “big picture view” of lighting conditions. Simulations can be run across a whole year, allowing the grower to understand the real life, long-term impacts of lighting decisions.

How do we model lighting conditions?

Ray-tracing is a light-modeling technique used to simulate the lighting conditions in a given space by describing the light sources, surfaces and objects in terms of geometry and optical properties, then calculating the light levels on each surface in the space. Ray-tracing techniques account for the interreflection of light between objects by solving physics equations [1]. The equations keep track of the amount of light that is reflected, transmitted through, or absorbed into any surface in the space. General information about light-modeling techniques like ray-tracing, details of algorithms, and more applications for greenhouses can be found in the supplemental reading [1,7] and a high-quality lighting blog at www.allthingslighting.org. Physics-based light-modeling software that implements ray-tracing is typically used to design lit spaces or to characterize the natural lighting conditions in architectural building design [1,2]. The light modeling techniques described above can be used for horticultural purposes to understand quantity, quality, and spatial distribution of light emitted from artificial and natural sources. Horticultural researchers have used light modeling to answer questions about the optimal orientation of a greenhouse structure for a given location [3], to estimate crop canopy light interception [4], to characterize light transmittance through greenhouse glazing [5], and to evaluate natural light resources in urban agriculture (where shading of surrounding buildings comes into play) and greenhouses [6,7].

To show how light-simulation can be used to add value to horticultural operations, a case study is presented.

Case Study: Sensor Placement

To better understand the impacts of spatial variability of light in an industrial greenhouse, we constructed three scenarios using light simulation. The three scenarios correspond to situations where electric lighting in a greenhouse is controlled via a single light sensor placed in three different locations in a greenhouse: a shady*, sunny, and average (representative) spot. To accomplish this, we constructed

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**Note: the shady spot refers to a location with frequent localized shading cause by structural components of the greenhouse.*

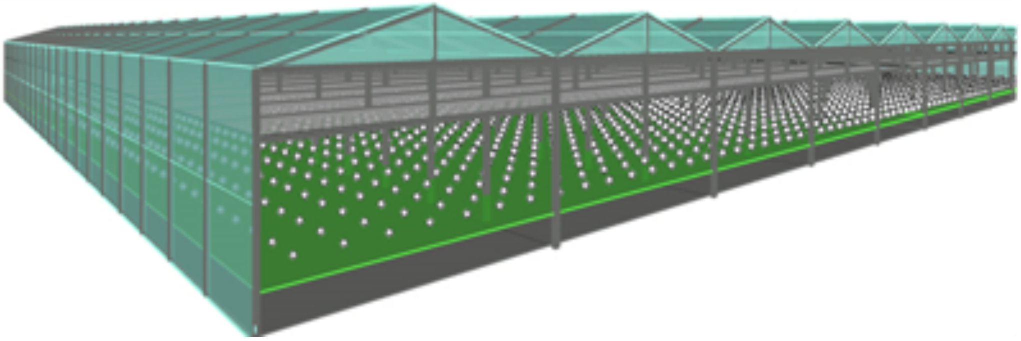


Figure 1. 3D model of industrial greenhouse with virtual light sensors placed in a grid throughout the interior of the space.

a 3D geometric model of a gutter connected deep water culture hydroponic greenhouse and placed "virtual light sensors" throughout the space, depicted in Figure 1. These light sensors were placed in a grid pattern with 1-m spacing throughout the greenhouse to record the natural light reaching each sensor every hour of a simulated year. Solar conditions for the New York location were modeled using the corresponding "Typical Meteorological Year" (TMY) dataset [8], which is made up of historical weather data and compiled by the United States National Renewable Energy Laboratory.

A simulated lighting control system made decisions to turn on electric lighting and deploy retractable shade-curtains based on readings from light sensors. The light control system simulated here implemented the Light and Shade System Implementation (LASSI) algorithm developed at Cornell University [10]. The analysis in this section compares the performance of LASSI receiving data from the "virtual light sensors" located in three different parts of the greenhouse: a shady, sunny, and average spot. The supplemental lighting simulation assumed an installed lighting design made up of 248 fixtures, 600 Watts each, totaling an installed photosynthetic photon flux density (PPFD) of 100 umol/m^2/s. These fixtures were installed throughout a 2,763 m² greenhouse, glazed with a material with average transmissivity of 76% and used a 50% shade cloth. It should be noted that we didn't model light uniformity from supplemental light but assumed it to be uniform across the growing space to focus on understanding the effects of sunlight distribution.

The daily light integral (DLI) achieved by the control system over the year for each scenario is shown in Figure 2. This plot shows the "actual DLI," as

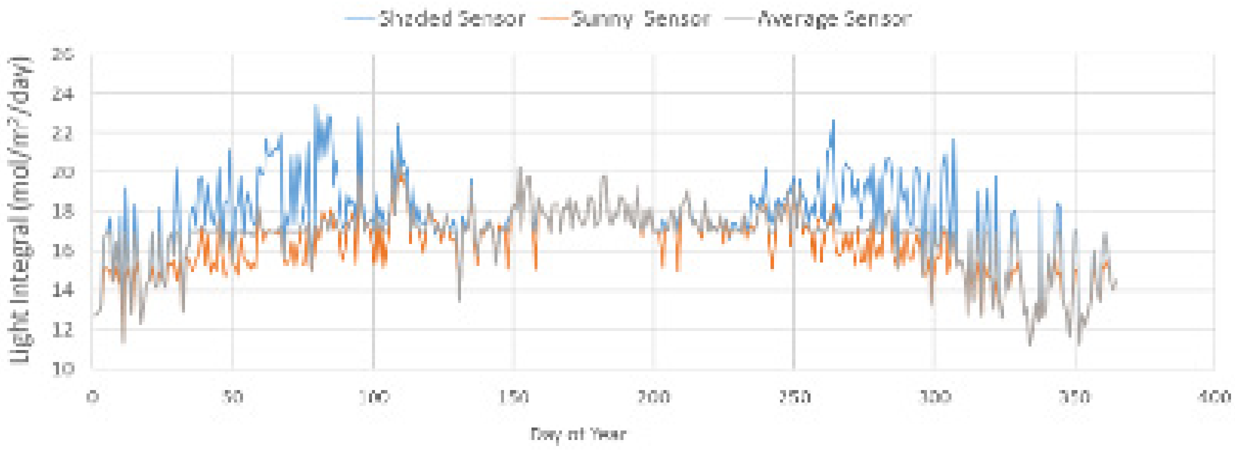
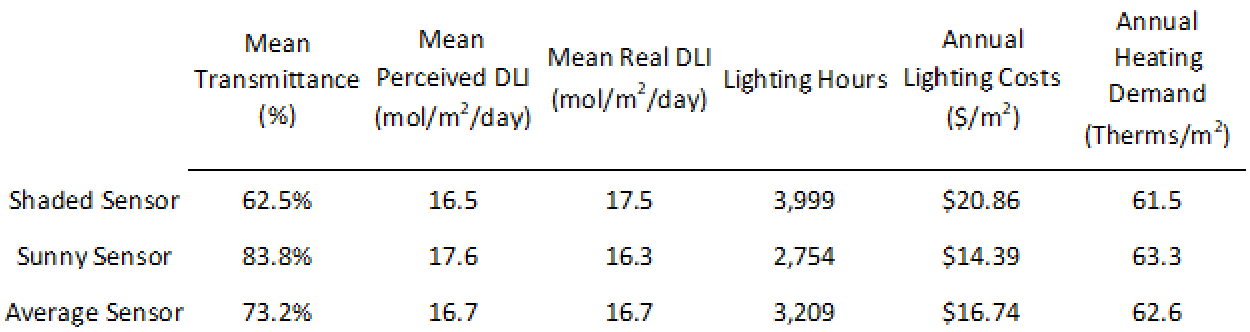


Figure 2. Daily Light Integral at Test Greenhouse for three scenarios: light sensor placed in a sunny spot, a shady spot, and an average spot. Note: the vertical axis is truncated to show differences more clearly

Table 1. Light and Shade System performance metrics for each scenario.



	Mean Transmittance (%)	Mean Perceived DLI (mol/m^2/day)	Mean Real DLI (mol/m^2/day)	Lighting Hours	Annual Lighting Costs (\$/m^2)	Annual Heating Demand (Therms/m^2)
Shaded Sensor	62.5%	16.5	17.5	3,999	\$20.86	61.5
Sunny Sensor	83.8%	17.6	16.3	2,754	\$14.39	63.3
Average Sensor	73.2%	16.7	16.7	3,209	\$16.74	62.6

opposed to the DLI as perceived by the control system, which reads data from the virtual light sensors. The average reading from all the virtual light sensors is considered the 'actual value' for the purposes of this comparison. As expected, the system receiving data from the sensor placed in a shady spot overshot the target (17 mol /m² /day) much of the time, and the reverse is true for the system with the sensor in a sunny spot. Overshooting the lighting target of 17 mol /m² /day for lettuce could result in a physiological disorder called tipburn [11] as well as cause unnecessary electricity costs for keeping supplemental lights on for longer than necessary. Undershooting the target DLI would result in lower crop productivity (longer crop cycles or lower harvested weight) than if the target integral had been achieved.

Table 1 contains summary information about the performance of the light/shade system controller in each scenario. As shown in Table 1, the location of the sensor can have a significant effect on the performance of the lighting control system and ultimately the cost of production. The three scenarios vary in performance for costs, hours, and control fidelity and show the importance of getting a representative light sensor reading in a greenhouse with uneven light distribution.

Summary

In this bulletin, light modeling was described briefly, and a case-study was presented using ray-tracing as a tool to model light uniformity in a greenhouse. This case-study compared the performance of an automated greenhouse light and shade control system under three scenarios given light sensor readings from different locations in the greenhouse. The final analysis shows that sensor placement is consequential for the performance of lighting control systems, and illustrates the importance of understanding distribution of light in production greenhouses. Choosing a bad sensor location or receiving misleading data from a malfunctioning sensor can greatly diminish performance of lighting control systems and reduce productivity and energy efficiency.

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