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# A Design Model of Transient Temperature Performance for a Green Greenhouse

*Michael R. Stiles, Ph.D. CEM*

## ABSTRACT

Synergistic Building Technologies (SBT) built and monitored a “green” solar greenhouse under the auspices of the Colorado Department of Agriculture in 2010. This greenhouse incorporates advanced methods of energy conservation in an application that traditionally uses only methods with very inexpensive capital expenditures. The SBT prototype accommodates year-round harvesting of summertime crops using sunlight as its sole heat source. A comparable planting regimen would be prohibitively fossil fuel-intensive using prevalent practices. This article presents a thermal circuit model of SBT’s design with an emphasis on winter energy performance. The model computes interior air and soil temperatures given the greenhouse’s size, composition, and location. A method is presented for reconciling the computed timing and amplitude of temperature transients with those measured in SBT’s prototype. The model thereby provides insight as to whether a proposed combination of insulation, thermal mass, and insolation will achieve specified conditions for plant growth. All modeled and measured results suggest that SBT’s greenhouse design offers an energy-efficient alternative to wintertime importation of fresh food in cold climates.

**Keywords:** Solar Greenhouse, year-around harvesting, winter energy performance

## INTRODUCTION

The Colorado Department of Agriculture’s Advancing Colorado’s Renewable Energy (ACRE) Program is a front-runner in the development

of next-generation technologies. Funded under this program, Synergistic Building Technologies designed, built, commissioned, and monitored an advanced greenhouse design at Cure Organic Farm in Boulder County (Kinney et al., 2011). The design features:

- Technology transfer of foundation perimeter insulation techniques that thermally couple the enclosed soil volume to deep-earth temperatures.
- Light shelves that enhance the collection of sunlight and allow for reduction of window areas.
- Automated insulating shutters that trap heat behind the windows when the sun isn't shining.
- Judicious inclusion of thermal mass to absorb solar heat gain and dampen temperature swings.
- A ducted moist air circulation system in the soil beneath plant roots.
- Substantially more wall and roof insulation than is usually specified for greenhouses.

This design incorporates principles proven to work on residential and commercial building stock that have never been applied to greenhouses. It works remarkably well, producing summer-time crops like tomatoes and eggplants throughout the winter. In Colorado, the only source of heating energy required by this greenhouse is sunlight. The design holds the potential for significantly expanding local crop production in the Frost Belt and reducing dependence on fossil fuel-based transportation of food (Kinney et al., 2011).

The details of construction and comparison with standard greenhouse designs are presented elsewhere (Kinney et al., 2011; Kinney and Stiles, 2012). This article addresses the development of simulations useful for predicting seasonal thermal performance as a function of building size, composition, and location. The simulations are reconciled against measurements taken at the demonstration site. Applications of the results are then discussed.

## DESCRIPTION OF MONITORED POINTS

Table 1 summarizes the measurement points for data used to compare with the results of the simulations. All temperature measurements

are taken in degrees Fahrenheit via thermocouples. For the soil measurements, the sensor ends of the thermocouples stick out of the sides of the plastic pipe. The insides of the pipes are filled with urethane foam to prevent convective loops.

## SELECTION OF A MODEL

An ideal model would include finite-element calculations of heat transfer (e.g., Beausoleil-Morrison and Mitalas, 1997). However, this approach was not adopted because of the time and resources needed to handle the number of different cases likely to be encountered in future design simulations.

A thermal circuit model was adopted to characterize the transient thermal response of the greenhouse (Hoffman and Feldman, 1981); this is similar to what is used in MATLAB Simulink building models (MathWorks 2012). Briefly, each section of the building's envelope is described by successive layers of construction materials. The thermo-physical properties of each section are compiled to arrive at a net value of conductance and of time constant.

Assuming linear superposition, the transient responses of the sections to the model's inputs are summed. Exterior temperature, insolation, and earth temperatures are the dynamic inputs. The model computes the average interior air temperature and the average ground temperature of the greenhouse. A flow chart of the process is shown in Figure 1. The calculations are listed in the Appendix.

## RECONCILING MODEL COMPUTATIONS WITH MEASURED DATA

The principal difficulties in translating on-site conditions into inputs for the model were associated with insolation and its interaction with the building. The light level measurements were photometric not radiometric and cannot be resolved into their components needed for the model (global horizontal irradiance, direct normal irradiance, ground-reflected irradiance, and two forms of cloud cover metrics). Optical/thermal surface absorptance values were not measured.

Table 1. Demonstration site monitoring points

Measurement	Sensor Placement	Sampling Interval
North wall mass temperature	Two sets of 5 sensors placed from 2" inside to just outside of 24" concrete blocks	Weekly
Indoor air temperature	5' above soil near middle of E wall	15 minutes
Outdoor air temperature	Shielded from sunlight and weather on the exterior north side	15 minutes
Enclosed soil temperature	Four stations of 2" PVC pipes fitted with 5 sensors to measure at depths of 0' - 4'; placed just inside the midpoints of the N,S,E,W walls	Weekly
Exterior soil temperature	Four stations of 2" PVC pipes fitted with 5 sensors to measure at depths of 0' - 4'; placed a few feet outside midpoints of N,S,E,W walls; additional array of 9 sensors at 1' intervals down heavily-bermed north wall	Weekly
Ambient light levels (lumens/ft <sup>2</sup> )	Externally at the middle window in the center of the south wall and internally five feet from the floor in the center of the east wall	15 minutes

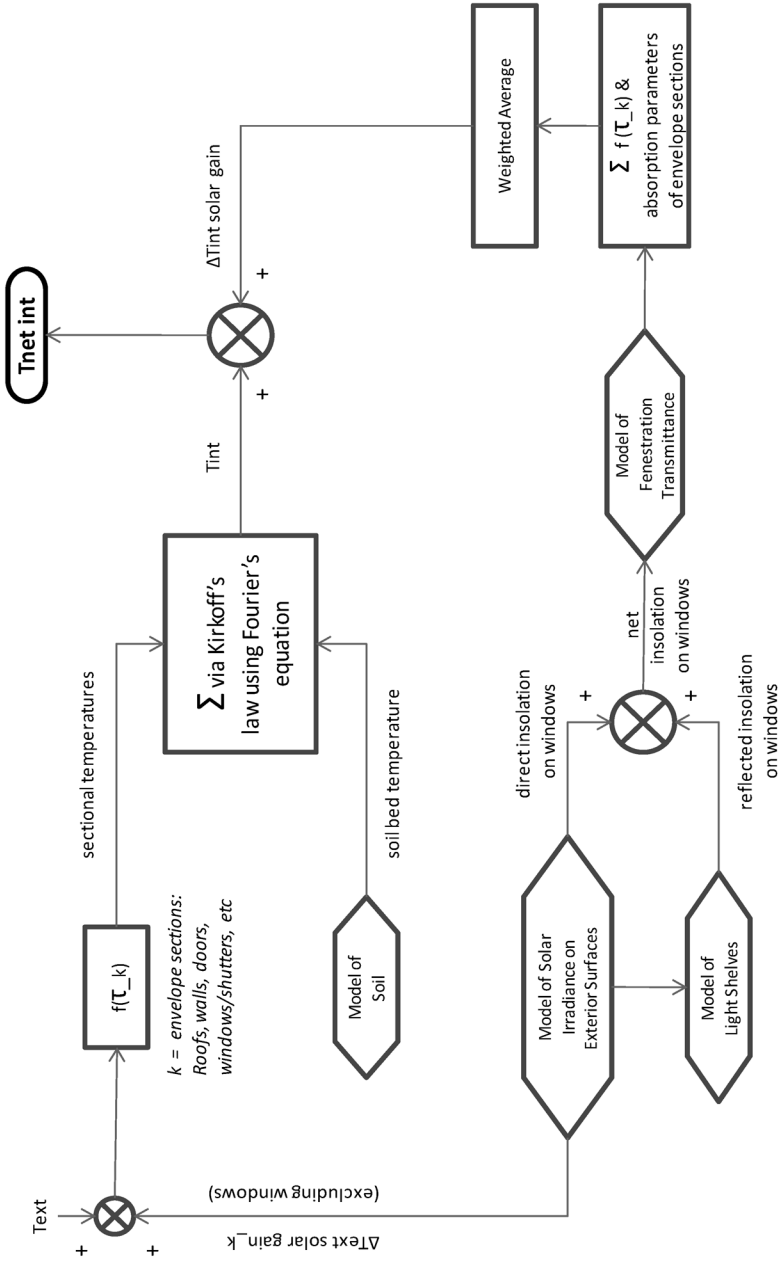


Figure 1. Simulation flow chart

LEGEND

- Text = exterior dry bulb ambient air temperature
- $\Delta\text{Text solar gain}_k$  = increment of exterior temperature of the kth envelope section due to insolation, excluding windows
- $f(\tau_k)$  = a function of the time constant ( $\tau$ ) of the thermal mass of each of the  $k$  envelope sections; “absorption parameters” are for calculation of interior solar heat gain of the section
- Tint = interior air temperature including gains through non-window areas of the envelope
- $\Delta\text{Tint solar gain}$  = total contribution of interior solar gains excluding storage mass contributions
- Tnet int = net interior air temperature; output of the model

These issues were addressed as follows:

- Instead of modeling instantaneous actual conditions, the simulations use Typical Meteorological Data that provide the necessary temperature and solar data on an hourly basis (TMY3, 1991).
- The solar absorptance values of the various surfaces were assigned typical values and adjusted until the computed interior air temperature approaches the measured value of 50°F on the coldest day.

The most informative part of the simulation is for the heating season—how warm will the greenhouse remain and thereby, what are the possibilities for crop production?

## REPRESENTATIVE RESULTS

### **Absorption of Interior Solar Heat Gain**

Figure 2 shows the recorded trends in indoor and outdoor air temperatures during the onset of cold weather. Relative light level is shown to represent solar availability. The graph starts with two mild days that are partly cloudy. The third and fourth days were successively colder and less sunny. The fifth and sixth days remained cold but were much sunnier.

The demonstration greenhouse's inside air temperature never goes below about 50°F under the conditions shown in Figure 2. Note the rapid recovery of interior air temperature on the last two days with the increased solar input.

The solar absorptance values of the simulation were tuned until calculated values matched the magnitude and timing of the demonstration greenhouse's temperatures. Figure 3 is a representative graph of the results.

Figure 3 shows six days of temperature calculations for the specified range of time in the TMY3 data set. The computed insolation incident on the windows is shown to indicate relative solar availability. The data are for an interval where mild temperatures accompanied by sunny skies transition to cloudy cold conditions.

The following similarities between Figures 2 and 3 were taken as evidence of adequate representation of observed trends by the simulation:

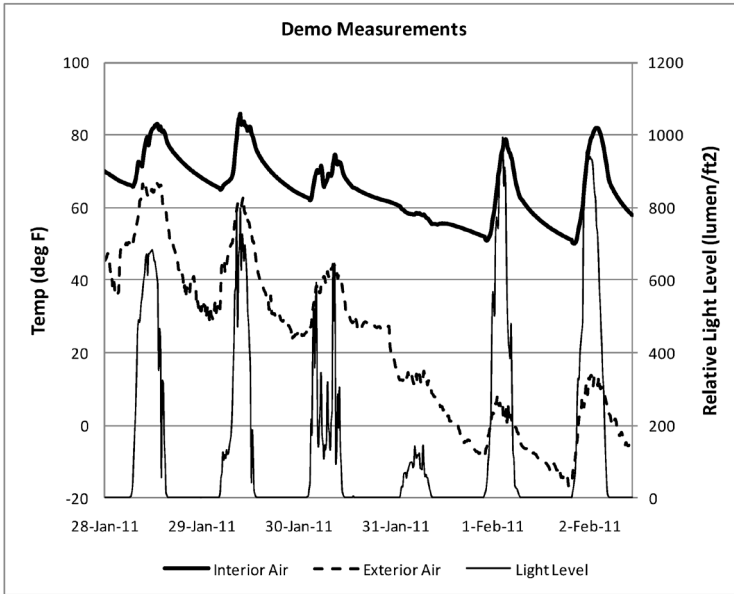


Figure 2. Measured greenhouse variables (courtesy of Synergistic Building Technologies)

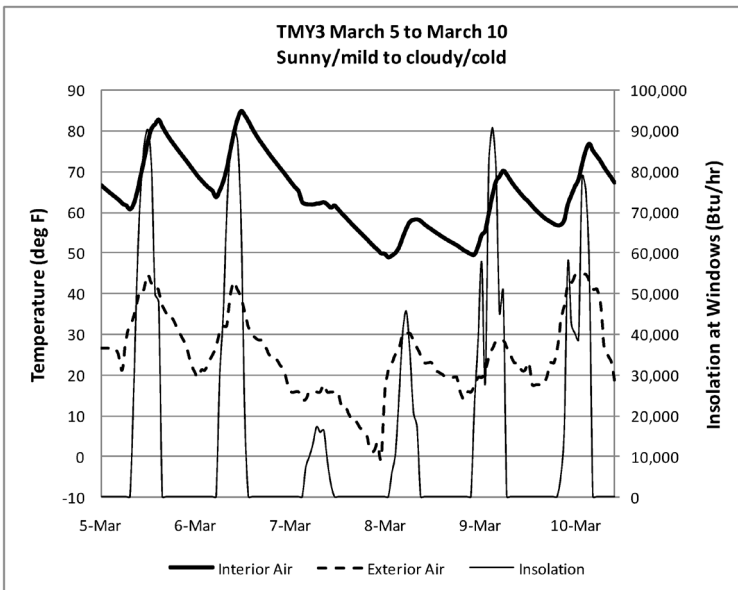


Figure 3. Simulated greenhouse variables

- All temperature profiles are sinusoidal in overall shape and have a diurnal period.
- Indoor air temperature decreases each night until insolation becomes available.
- Peak indoor air temperature lags behind peak outdoor air temperature (and peak insolation) by 3-6 hours.
- Even on cloudy days (fourth day in Figure 2, third day in Figure 3), the available daylight raises indoor air temperature slightly.
- Minimum indoor air temperature is about 50°F under very cold conditions.

### **Soil Temperature**

The average winter temperature of the enclosed soil volume of the demonstration greenhouse is reported to be in the low to mid-60s F (Kinney, 2011). This is the range returned by the simulations within 3-4 months of “starting” the greenhouse on January 1 of TMY3 conditions. Once the simulated ground temperatures evolved from their starting conditions they remained relatively stable for the remainder of the year and into the next. Slight increases and decreases about the mean, on the order of several degrees F, occur in the simulated average ground temperature over the course of a year. The trend is consistent both with ground temperature lag behind the seasonal variation of outdoor air temperature (Williams and Gold, 1976) and with the demonstration’s recorded data (Kinney, 2011). The simulations thus mimicked measured ground temperatures as well as interior air temperature.

### **CONCLUSIONS**

The timing and magnitude of the modeled thermal response matched measured data from SBT’s “green” greenhouse reasonably well. However, the model used typical yearly insolation data instead of actual site conditions. This will be a necessity whenever adequate onsite monitoring of the various forms of insolation is not available.

Insolation data from a nearby meteorological station may prove adequate if available. Another way of adapting on-site data might be to use a horizontal photometric sensor as a surrogate for a horizontal global irradiance station. It may be possible to create correlations between such onsite data and historical data from sources like NASA’s Climatology

Resource for Agroclimatology and the TMY data base.

Both the measured and modeled temperature trends indicate that SBT's greenhouse design provides an unprecedented winter growing environment using only sunlight as its heating source. The following work is underway to build on the results presented in this article:

- Worst case tuning—Substitute a cold cloudy day's worth of conditions for a specified number of days in the heating season to assess the impact on interior air temperature.
- Comparison of the seasonal performance of a given greenhouse's design across different geographic locations.
- Determination of how much thermal mass is required to maintain desired interior temperatures; this is underway for the second generation of SBT's greenhouse designs (Kinney and Stiles, 2012).
- Estimation of the auxiliary heating requirements to maintain a specified interior temperature of a greenhouse at a given location.

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## APPENDIX

### The Thermal Time Constant

A model was adopted for the transient thermal response of buildings (Hoffman and Feldman, 1981). It represents a building's envelope as a number of different thermal branches between the interior and exterior. Each branch is an area comprised of the same order, composition, and thickness of layers that determine its thermal time constant.

The computations of the model were composed to accommodate hourly binned Typical Meteorological Year (TMY3) data. Time interval  $\Delta t$  is the duration of an hourly bin. The temperature of the  $k$ th branch,  $T_k$ , at the end of the present time bin that starts at a time  $t_i$  with a value of  $T_k(t_i)$  and exterior temperature  $T_{ext\ i}$  is:

$$T_k = T_{ext\ i} + [T_k(t_i) - T_{ext\ i}] \exp\left(\frac{-\Delta t}{\tau_k}\right) \quad (A1)$$

where  $\tau_k$  is the time constant of the  $k$ th branch.

Initialization consists of setting  $T_k$  at time  $t = 0$  equal to exterior air temperature ( $T_{ext\ 0}$ ) for the first hour of the first day of the design year (January 1). Index  $i$  ranges from 1 to 8,760 for a year's worth of modeling.

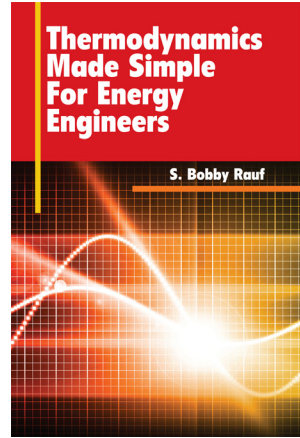
### Kirckoff's Law Using Fourier's Equation for Computation of Interior Air Temperature

The goal is to compute the value of the average interior dry bulb air temperature,  $T_{int}$ . In the absence of inputs other than  $T_{ext}$ , the thermal "current" exchanged between the  $k$ th building section and the interior of the whole building is  $(T_k - T_{int})/R_k$  where  $R_k$  is the thermal resistance of the innermost half of the innermost layer of the section. All such currents are assumed to be independent of one another.

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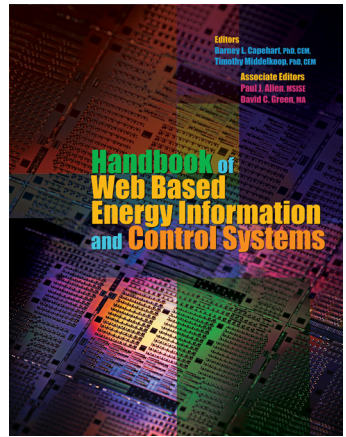
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Hoffman and Feldman (1981) invoke Kirchoff's current law: The sum of the thermal currents entering and leaving the common "node" at  $T_{int}$  must be equal to zero. Before quantifying that sum, note that the ratio of temperature to thermal resistance has units of (Btu/hr)/ft<sup>2</sup>. Total power through the k<sup>th</sup> section of building envelope is found by multiplying the quantity  $[(T_k - T_{int})/R_k]$  by its total interior surface area,  $A_k$  (ft<sup>2</sup>). The model stipulates that  $T_{int}$  must be the same for each term of this series, giving the final result for interior temperature of the whole building:

$$T_{int}(t) = \frac{\sum_k \frac{A_k}{R_k} T_k(t)}{\sum_k \frac{A_k}{R_k}} \quad (A2)$$

Additional factors besides  $T_{ext}$  contribute to interior air temperature. They are considered below.

### Calculation of Insolation on Exterior Surfaces

This calculation uses the conventions introduced in Stiles and Marzano (2010). The key features of these calculations are that they:

- Use TMY3 hourly data.
- Compute total insolation (Btu/hr/ft<sup>2</sup>) on a surface of a given orientation (direct beam, diffuse, ground-reflected).
- Assume that all wavelengths are converted to thermal energy at the greenhouse's surfaces.

The results consist of values for hourly incident insolation at walls and windows.

### Exterior Solar Gain

Hoffman and Feldman's (1981) model uses a variation of the concept of the "sol-air temperature" (ASHRAE Fundamentals, 2005). The increment of the k<sup>th</sup> surface's exterior temperature due to solar radiation is:

$$\Delta T_{ext\ solar\ gain\_k}(t) = \frac{\alpha_k I_{sk}(t)}{h_o} \quad (A3)$$

Where:

- $\alpha$  = absorptance of surface for solar radiation
- $I$  = total solar radiation incident on surface, Btu/hr ft<sup>2</sup>
- $h_o$  = coefficient of heat transfer by long-wave radiation and convection at outer surface; typical value = 3 Btu/hr ft<sup>2</sup> °F

$I_{sk}(t)$  is interpreted as the solar irradiance on the k<sup>th</sup> exterior surface for a given hourly time bin. The step function introduced in Eq. (A3) is thus one of a change from the absence of solar irradiance.

### Insolation through Windows; Insulating Shutters; Contribution of Light Shelves

Insolation to the interior through a window in Btu/hr, is taken as

$$I_{\text{flt}} * A * \text{SHGC} * \text{LF}$$

Where:

- $I_{\text{flt}}$  = irradiance on tilted surface (Stiles and Marzano, 2010);
- LF = "loss factor," taken as solar absorptance of the window = 0.85 per ASHRAE Fundamentals (2005) Ch. 31;
- A = area of window;
- SHGC = Solar Heat Gain Coefficient (from AHSRAE Fundamentals 2005 Ch 31 Fenestration Table 13).

For 1/4" clear single pane glass, the average SHGC over range of incidence angles is ~ 0.6; hemispherical diffuse value ~ 0.7; total SHGC for greenhouse calculations = 0.65.

Additional comments about the model are given next:

- This is a gross simplification of heat transfer through fenestration.
- The interior solar gain at any given hour is the sum of input through all windows.

**Table A1. Shutter Operation, Julian Dates**

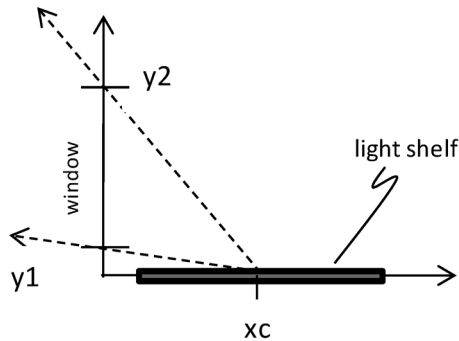
	From	To	Calendar Dates
Early Year	1	120	Jan 1 - Apr 30
Late Year	274	365	Oct 1 - Dec 31

**Table A2. Fenestration Closure Schedule  
(military time, inclusive hours)**

	From	To
a.m.	1:00	8:00
p.m.	18:00	24:00

- Automated window shutters diminish night-time envelope losses; when the shutters are closed, the simulation changes the R value of fenestration and sets the SHGC to 0.
- The fenestration shutter schedule is described by Tables A1 and A2.

Figure A-1 shows a model of the irradiance projected by a light shelf to a window. A light shelf is centered at a location  $x_c$ . In this perspective a window extends between the coordinates of  $y_1$  and  $y_2$ .



**Figure A-1. Geometry for light shelf optical model**

For the model illustrated in Figure A-1, the following assumptions apply:

- All forms of available irradiance are incident on the light shelf (direct beam, diffuse, ground-reflected, etc.); the same TMY3 data used for incident irradiance on windows and walls are used for light shelves.
- The light shelf reflects the incident irradiance isotropically, so that the reflected irradiance is distributed uniformly over a plane angle of  $\pi$  radians ( $180^\circ$ ).

- The fraction of reflected irradiance incident on the window occurs between the dashed arrows at  $y_1$  and  $y_2$  centered from the point  $x_c$ .

Let  $\alpha$  be the plane angle subtended by the window from the point  $x_c$ . By elementary trigonometry,

$$\alpha = \text{Tan}^{-1}(y_2/x_c) - \text{Tan}^{-1}(y_1/x_c) \quad (\text{A4})$$

The luminous power (in Btu/hr) incident on a window from the light shelf is then given by ( $\rho \Phi \alpha/\pi$ ), where

$$\begin{aligned} \rho &= \text{diffuse reflectivity} = 1 - \text{absorptance} \\ \Phi &= \text{irradiance (Btu/hr ft}^2\text{) incident on horizontal surface multiplied by the area of light shelf} \end{aligned}$$

The incident luminous power then passes through the window according to the conventions for non-reflected sunlight.

### Interior Solar Heat Gain and Interior Temperature

Let the asymptotic interior solar heat gain of the  $k$ th section of envelope be defined as:

$$\Delta T_{\text{int solar gain}_k} = \frac{\sum I_{\text{windows}} \times A_k / \sum A_k \times \text{solar absorptance}_k}{A_k / R_{\text{tot}_k}} \quad (\text{A5})$$

where the variables are as defined in previous sections. Using the same conventions as for Eq. (A1), The time-varying value for the  $k^{\text{th}}$  branch of envelope at the end of a given time bin is:

$$\begin{aligned} \Delta T_{\text{int}_k} &= \Delta T_{\text{int solar gain}_k} + \\ &[(\Delta T_{\text{int}_k} \text{ solar gain}_k(t_i) \\ &- \Delta T_{\text{int}_k} \text{ solar gain}_k) \times \exp(-\Delta t/\tau_k)] \end{aligned} \quad (\text{A6})$$

The total increment in interior air temperature is then taken as the sum of the  $\Delta T_{\text{int}_k}$ . However, a weighted average was necessary to compute this  $\Delta T_{\text{int}}$ . A small but low-mass structure like a door can have its temperature raised by ten degrees or more—but its

contribution to total interior air temperature cannot be ranked equally with larger more massive components. Accordingly, the net increase in interior air temperature due to the solar gains of the various building components is given by:

$$\Delta T_{int} = \sum_k \frac{\Delta T_{int\_int\ solar\ gain\_k}(t) \times A_k}{\sum A_k} \quad (A7)$$

### The Enclosed Foundation Soil Volume

The enclosed soil volume under consideration is the soil bounded by the floor of the greenhouse, the perimeter foundation insulation extending four feet deep, and a horizontal plane occurring 4 feet below the surface. The model of the enclosed soil volume has two independent components:

- Horizontal heat transfer through the vertical perimeter insulation that surrounds the soil.
- Vertical heat transfer through the horizontal footprint of the soil bed.

Horizontal heat transfer was modeled in the following way:

1. A single temperature was selected to be " $T_{ext}$ " at the midpoint of the perimeter insulation
2. This single temperature was found by taking the average of the periodic temperature distribution  $T_{g\_out}(y)$  from a depth of four feet to grade. The following function was adopted to represent that temperature distribution (Williams and Gold, 1976):

$$T_{g\_out}(y,p) = \bar{T} + A \exp\left(-y \sqrt{\frac{\pi}{\alpha p_o}}\right) \cos\left(\frac{2\pi p}{t_o} - y \sqrt{\frac{\pi}{\alpha p_o}}\right) \quad (A8)$$

Where:

$T_{g\_out}(y,p)$  = ground temperature as a function of depth below surface,  $y$ , and period,  $p$

$\bar{T}$  = average annual outdoor air temperature

$A$  = peak temp minus  $\bar{T}$  (=  $\bar{T}$  minus min temp); the annual "half temperature" excursion

$\alpha$  = soil thermal diffusivity term (K/Cv)

$p_o$  = term of period over the year (365 days)

$p$  = period (day) of the year (value ranges from 1-365)

The resulting averaged temperature term at a depth of 2 feet is given as the quantity  $T_{g\_out}(y = 2',p)$ .

3. Applying the conventions for the transient response of the perimeter insulation,

$$T_k = \text{perimeter insulation} = T_{g\_out}(y = 2',p) + [T_{k = \text{perimeter insulation}}(t_i) - T_{g\_out}(y = 2',p)] \exp\left(\frac{-\Delta t}{\tau_{k=\text{perimeter insulation}}}\right) \quad (\text{A9})$$

Vertical heat transfer assumed a thermal resistance ( $R_{soil}$ ) and capacitance ( $C_{soil}$ ) between the center of the enclosed soil volume and a constant "deep earth" temperature at a depth of 4 feet (valued at 60°F). The time constant of this branch of the foundation is then  $\tau_{soil} = R_{soil} C_{soil}$ .

These formulations allow for a calculation of the temperature at the center of the enclosed soil volume. Two additional parameters of area are required, let:

$A_{\text{perimeter}}$  = The face area of the foundation's perimeter insulation

$A_{\text{soil}}$  = The area of the enclosed soil volume, same as the footprint area of the greenhouse

Summing the thermal currents converging on the central node  $T_{soil}$

$$\frac{T_{k=\text{perimeter insulation}} - T_{soil}}{R_{k=\text{perimeter insulation}}} A_{\text{perimeter}} + \frac{T_{g\_out}(y=4') - T_{soil}}{R_{soil}} A_{soil} - C_{soil} \frac{dT_{soil}}{dt} A_{soil} = 0 \quad (\text{A10})$$

The result is then:

$$T_{soil} = \frac{1}{\kappa 1} \left[ \kappa 2(t) + (\kappa 1 T_{soil}(t_i) - \kappa 2(t)) \exp\left(\frac{-\kappa 1 \Delta t}{\tau_{soil}}\right) \right] \quad (\text{A11})$$

Where:

$$\kappa_1 = 1 + \frac{A_{\text{perimeter}}/A_{\text{soil}}}{R_{\kappa=\text{perimeter}}/R_{\text{soil}}} \quad (\text{A12})$$

$$\kappa_2(t) = \frac{A_{\text{perimeter}}/A_{\text{soil}}}{R_{\kappa=\text{perimeter}}/R_{\text{soil}}} T_{\kappa=\text{perimeter insulation}}(t) + T_{g\_out}(y=4')$$

and where  $\kappa_2(t)$  denotes the present time bin's value of  $\kappa_2$ ,  $T_{\text{soil}}(t_i)$  is the value at the start of the present time bin, and  $T_{\text{soil}}$  is the result at the end of the present time bin.

### The Greenhouse's Design Parameters

The values of the thermo-physical parameters outlined above are summarized for the various sections of the greenhouse in Table A-3 on the following page. L. Kinney's publications listed in the references provide details of building section compositions and construction techniques.

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### ABOUT THE AUTHOR

**Michael R. Stiles** is a senior energy specialist with MCW Custom Energy Solution Ltd. MCW executes, guarantees, and monitors energy performance projects for a wide range of clients. Dr. Stiles has over 20 years experience in energy analysis and technology development, holds three US patents, and is currently engaged with MCW on projects in the US, Canada, and the UK. He enjoys creating open-source applications in a number of different fields ranging from solar energy to building modeling. As of the writing of this article, MCW is developing a strategic alliance with Synergistic Building Technologies to act as third-party monitoring evaluator for SBT's technology transfer initiatives. Dr. Stiles is available at [mstiles@mcw.com](mailto:mstiles@mcw.com).

**Table A-3. The simulation set for SBT's Boulder County Demonstration Greenhouse**

Section	Area ( $A_k$ , $\text{ft}^2$ )	$R_k$ (hr $\text{ft}^2$ $^\circ\text{F}/\text{Btu}$ )	Time Constant (hrs)	Interior Solar Absorptance	Exterior Solar Absorptance
E wall	214.75	0.929	42.25	0.2	0.2
E door	56	0.929	2.10	0.2	0.2
Self-sealing vents	33.75	5.980	0.60	0	0
W wall	246.75	0.929	42.25	0.2	0.2
W door	24	0.929	2.10	0.2	0.2
N storage mass	500	0.960	88.56	0.2	N/A
N wall (lower)	400	1.640	1605.35	N/A	0.5
N wall (top)	100	1.640	2474.42	N/A	0.2
N roof	784	0.929	18.46	0.2	0.9
S roof	294	0.929	92.30	0.2	0.2
S non glazed	210.7	0.929	52.25	0.2	0.2
Upper Fenestration: Open (uninsulated)	288	1.180	0.34	N/A	N/A
Upper Fenestration: Closed (insulated)	288	5.980	1.05	N/A	N/A
Lower Fenes Pocket Area: Open (uninsulated)	198	0.929	26.87	0.2	0.9
Lower Fenes Pocket Area: Closed (Insulated)	198	0.929	44.68	0.2	0.9
Lower Fenes Glass: Open (uninsulated)	186	1.680	3.14	N/A	N/A
Lower Fenes Glass: Closed (insulated)	186	5.980	3.96	N/A	N/A
Lower Fenes Light Shelf	196	N/A	N/A	N/A	0.2
Foundation Perimeter	560	0.960	1198.97	N/A	N/A
Enclosed Soil Volume	1000	1.410	70.51	0.4	N/A