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# Tuning eQUEST for Plastic Shell Greenhouses with Dirt Floors

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**Abstract:** As growers expand year-round crop production in cold climates, considerable attention is being directed towards the energy performance of plastic shell greenhouses where crops grow in the native soil. A fundamental aspect of these structures is their temperature response in the absence of HVAC equipment. A review of the technical literature shows an absence of studies that reconcile thermal modeling of plastic greenhouses with actual field performance. Modeling studies typically emphasize parameters concerned only with the energy-saving performance of isolated components or systems like electric lighting or thermal curtains. The more fundamental parameters are unstated and presumably assume the default settings of the simulation tool. This paper investigates the implications of these modeling practices with respect to the passive temperature response of these structures. A set of criteria for reconciling modeled passive temperature response with field data-based performance has been developed previously for this type of greenhouse. Using the industry-standard simulation tool eQUEST as an example, we show that default parameters for the shell and for ground coupling do not reproduce key features of actual temperature response of these structures to ambient conditions. This paper reports work-arounds and parameter-tunings for eQUEST that produced a simulation that met the reconciliation criteria. These results call into question the suitability of present modeling approaches for baselining this type of greenhouse in simulations of active HVAC. Recommendations include revisiting the source files of published past simulations and directing the attention of industry stakeholders to these issues.

**Keywords:** Building Energy Modeling, Plastic Greenhouses, eQUEST, Baseline Conditions, Utility Company Incentives

## 1. Introduction

This paper addresses the passive temperature response of plastic shell greenhouses with crops planted in the native soil. The passive interior temperature of a greenhouse is its response to ambient conditions in the absence of mechanical heating, ventilation, and cooling (HVAC) equipment.

Passive temperature response is the baseline for calculations of energy requirements for active HVAC. The objective is to bring the interior conditions of a greenhouse from what they would be under ambient conditions to desired setpoints under regulated conditions.

As growers increasingly produce crops year-round in cold climates, considerable attention is being directed towards the energy performance of plastic shell greenhouses. The authors have participated in recent New York State programs for these greenhouses ranging from utility company agricultural rebates [1], to impacts on carbon emissions and electrification initiatives [2], to applications in the state's recently legalized cannabis cultivation industry [3].

A review of the technical literature shows an absence of studies that relate baseline thermal modeling of plastic greenhouses to actual field performance. Modeling studies typically report parameters concerned only with the energy-saving performance of isolated components or systems [4, 5]. Baseline performance is not discussed and presumably follows from unstated default parameter settings of a given simulation tool.

This paper investigates these omissions and focuses on the industry-standard building energy simulation tool eQUEST [6]. A set of criteria for reconciling modeled passive temperature response with field data-based performance has been developed previously for this type of greenhouse [7, 8]. These criteria provide qualitative and quantitative guidelines for checking modeled results.

The paper begins by describing the reconciliation criteria. This is followed by a consideration of the relevant eQUEST parameters for meeting the criteria for a representative plastic shell greenhouse with a dirt floor. The paper then presents eQUEST screen shots for establishing these parameters and presents selected outputs from the simulation. The paper concludes with a discussion of the implications of the results and recommendations for future work.

## 2. Model Reconciliation Criteria

These criteria originated in a study of energy efficient greenhouses sponsored by the Colorado Department of Agriculture [7] and were subsequently developed into a model of energy performance [8]. The study collected field data for a 2,000 square foot dirt-floored plastic shell greenhouse ("hoop house") that served as a control for a more energy efficient structure.

In the absence of insolation, the interior passive temperature of a hoop house approaches outdoor air temperature. However, a least-squares linear regression of indoor versus outdoor temperature for night-time data returned a slope of 0.614 indoor:outdoor temperature, an intercept of 9.94°F, and $R^2 = 0.88$ [8].

The intercept of about 10°F suggests that the soil enclosed by the hoop house stores some heat even in the winter. However, the moderate thermal mass is unable to prevent large diurnal temperature fluctuations. On sunny winter days when outdoor temperature exceeds about 30°F, hoop houses need to be ventilated to prevent excessive heating.

The thermal mass of the enclosed soil is also responsible for a slight lag of interior temperature with respect to peak insolation [8]. Cross-correlation analysis [9] showed an average lag time of 2.75 hours.

Many of these features of plastic greenhouse temperature response are familiar to growers in cold climates and are reported by numerous anecdotal sources [10]. Six criteria that simulations of hoop house passive temperature response should meet are [8]:

1) Temperature profiles are sinusoidal in overall shape and have a diurnal period.
2) Indoor air temperature decreases each night until insolation becomes available.
3) Indoor air temperature approaches outdoor air temperature during the night.
4) Even on cloudy days the available daylight raises indoor air temperature slightly.
5) Maximum winter passive indoor air temperature should be around 100°F +/- about 10°F.
6) Peak daytime indoor air temperature lags behind peak insolation by an interval of 2-3 hours, as confirmed by a cross correlogram.

## 3. A Test Case for eQUEST

Insufficient data was collected during the cited Colorado study to model the hoop house [7]. A model was thus developed for a representative test case for comparison against the reconciliation criteria.

The remainder of the paper assumes that the reader is familiar with eQUEST or at least the basics of its operation. The default settings for the various parameters are not reported here for sake of brevity and can be accessed for Version 3.65.7175 [6].

An eQUEST simulation was developed for a structure with the following features:

1) A "Gothic Arch" style hoop house with a dirt floor; this is a common commercially-available hoop house that can be furnished with its own utility service and operate year-round.
2) 30' x 84' with its long axis oriented East/West.
3) Plastic (polyethylene) film sides and light-colored corrugated metal end walls.
4) Gross annual average infiltration rate of 1 air change per hour (ACH).
5) TMY3 data was for Utica NY, the site of a recent project for the authors.
6) Because the structure is mostly transparent, Global Horizontal Irradiance (GHI) was used as the primary parameter for representing insolation.

## 4. Parameter Tuning to Meet the Reconciliation Criteria

eQUEST's sketch of the structure is shown in Figure 1. One of the software's limitations is its inability to effectively reproduce the curvilinear gabled sections of a Gothic Arch greenhouse. The work-around was to approximate the gables as a series of horizontal strips.

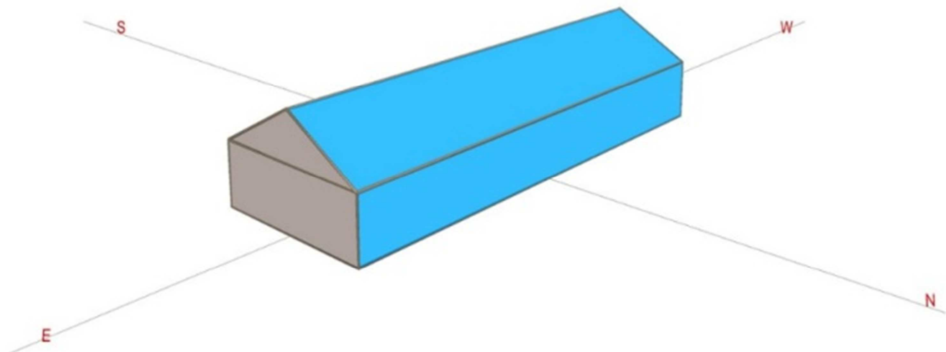


***Figure 1.*** *eQUEST's sketch of the test case greenhouse.*

The next series of figures are screen shots of inputs for the various parameters that achieved the reconciliation criteria.

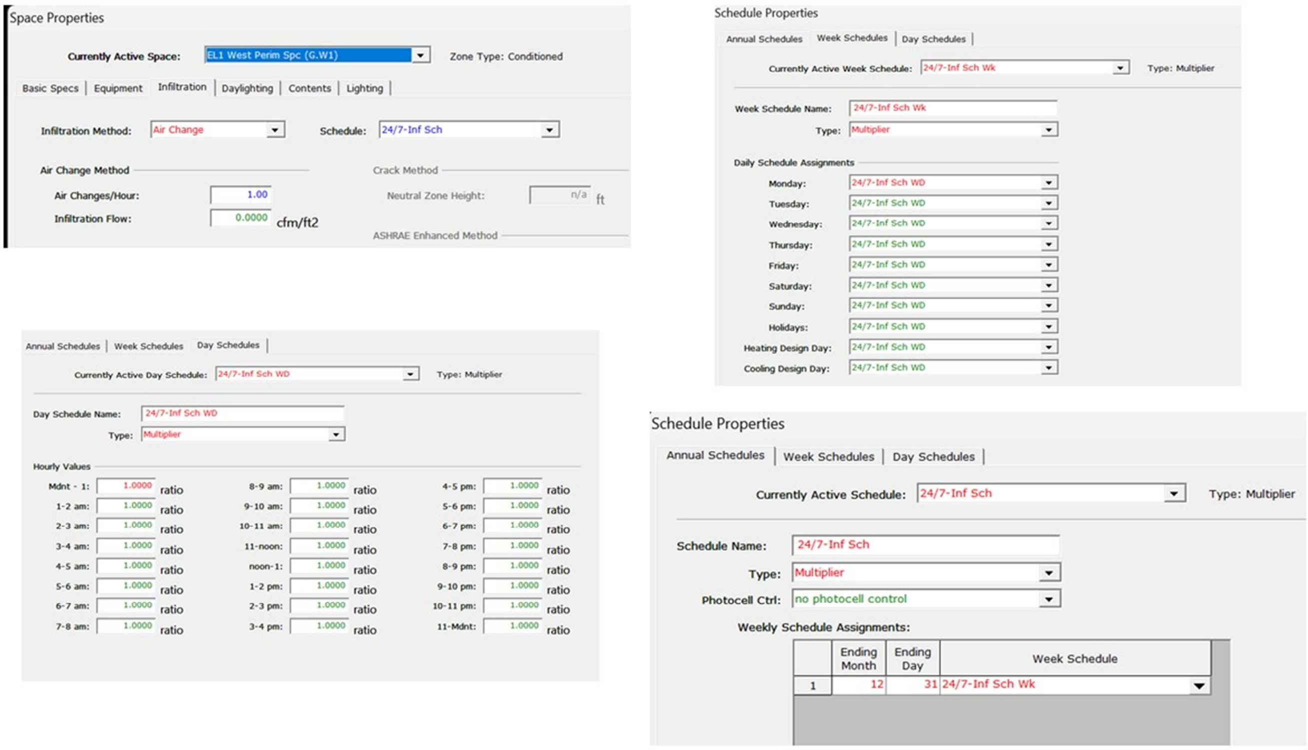


***Figure 2.*** *Screens for stipulating air changes per hour.*

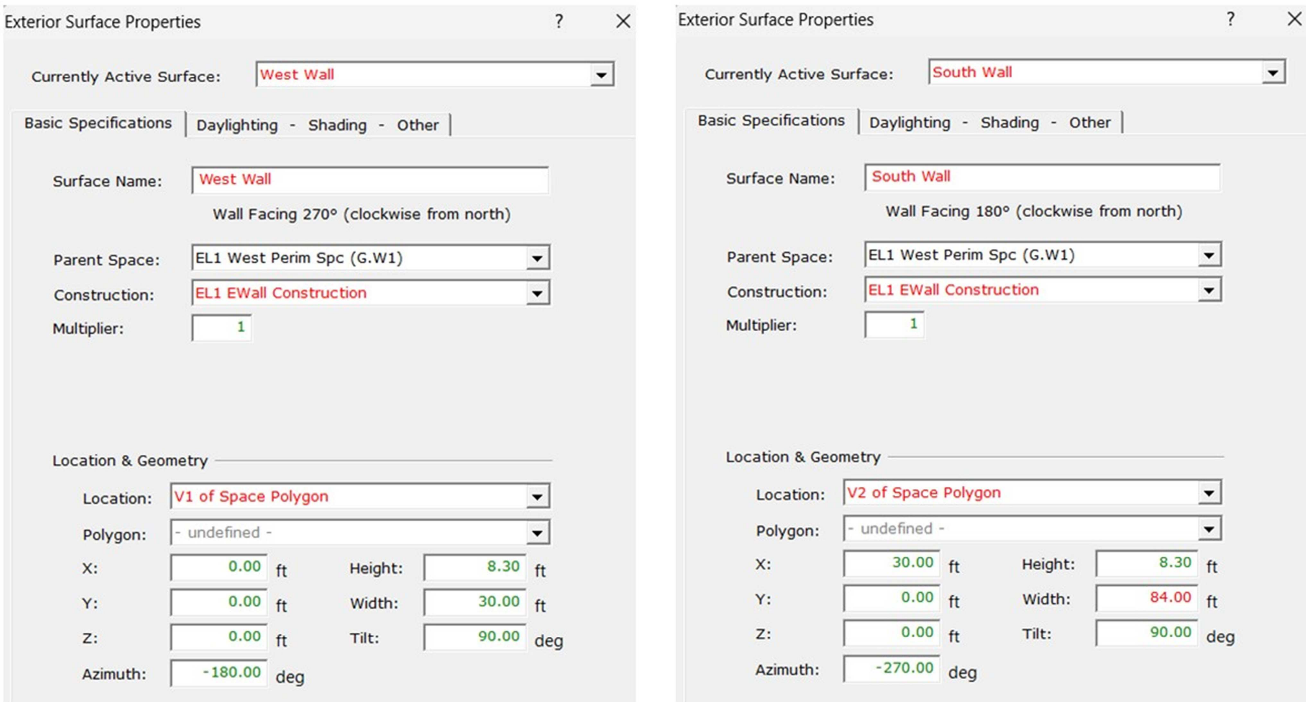


***Figure 3.*** *Exterior surface properties. The east wall is the same as the west wall (the end caps of the greenhouse). The north wall is the same as for the south wall, however they are mostly "windows" (see Figure 5).*

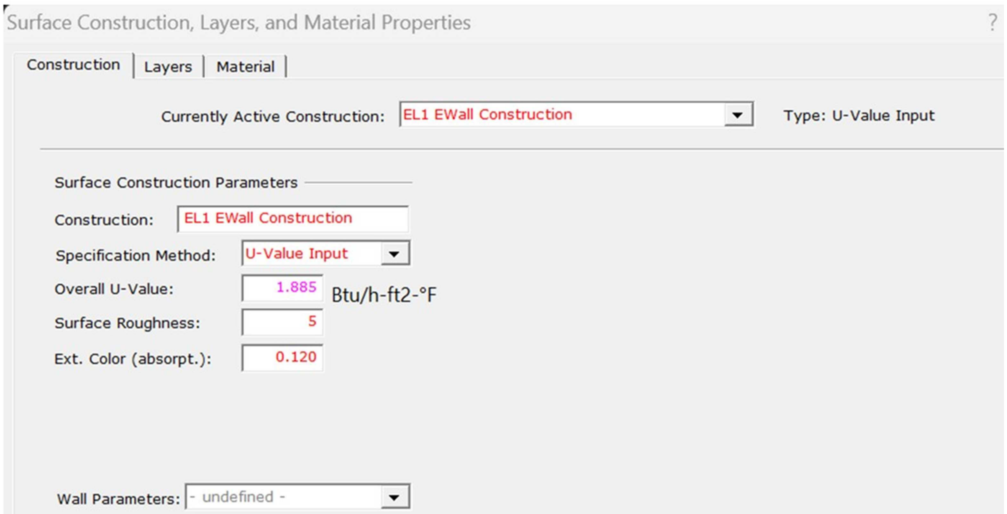


***Figure 4.*** *Shell layer properties.*

The following additional complications and their work-arounds were found for the shell layer properties of Figure 4:

1) eQUEST's "layers" menu does not include options for walls that are very conductive. To accommodate subsequent calculations, a single U-value ("Overall U-Value") must be input to represent the corrugated metal walls.
2) U-value input needed adjustment until its value in the "LV-D Report" (see below) matched the desired U-value. This adjustment is needed due to the way eQUEST internally accounts for solar gain and for exterior air film coefficient.

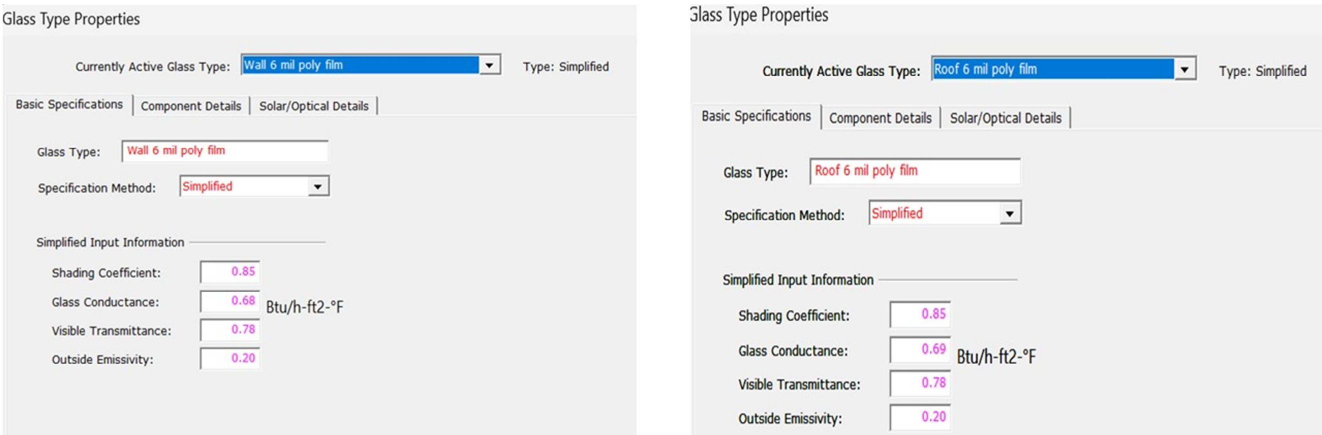


***Figure 5.*** *Shell screens for the window sections of the north and south walls. The shading coefficient and visible transmittance are typical of 6 millimeter thick polyethylene film. The U-value input needed adjustment until its value in the LV-D Report matched the desired U-value as eQUEST accounted for exterior air film coefficient. Left: First trial inputs. Right: Final entries to achieve the desired LV-D Report U-value.*

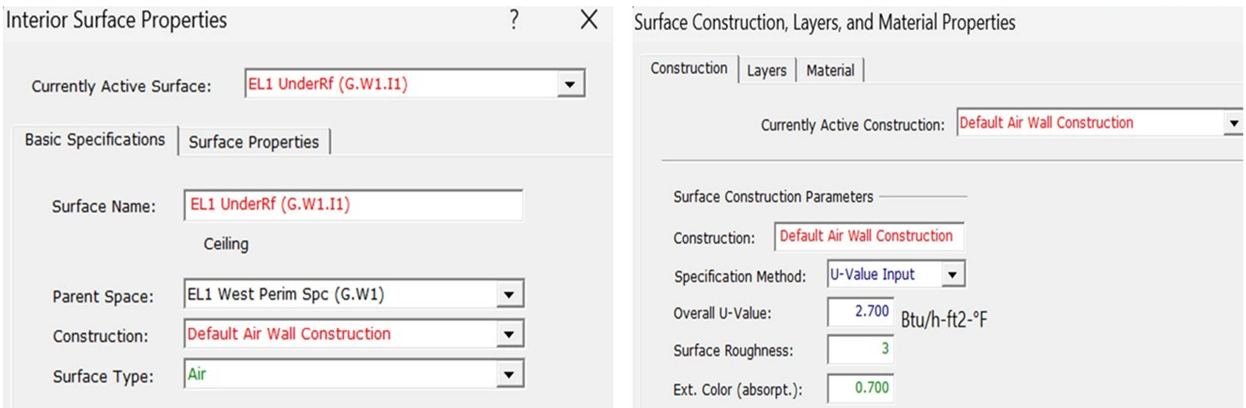


***Figure 6.*** *eQUEST assumed an "attic floor" between the rectangular volume of the greenhouse and the gabled space above it. The inputs shown eliminated the "attic floor" resulting in a single zone for the simulation.*

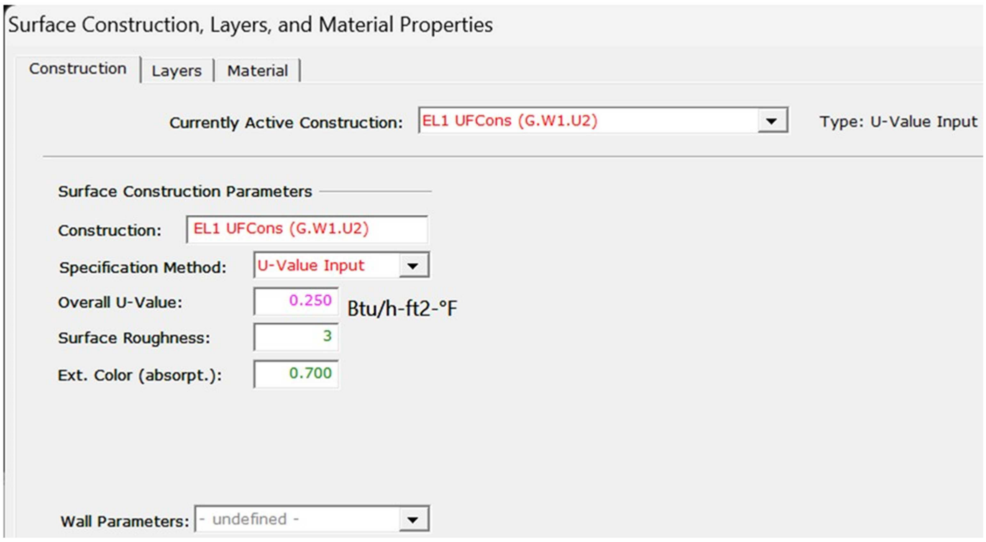


***Figure 7.*** *Screen for basic earth contact properties, using a specified input for U-value. This approach bypasses eQUEST's default "material" earth thermal resistance assumptions for subsequent calculations to which the user has no access.*

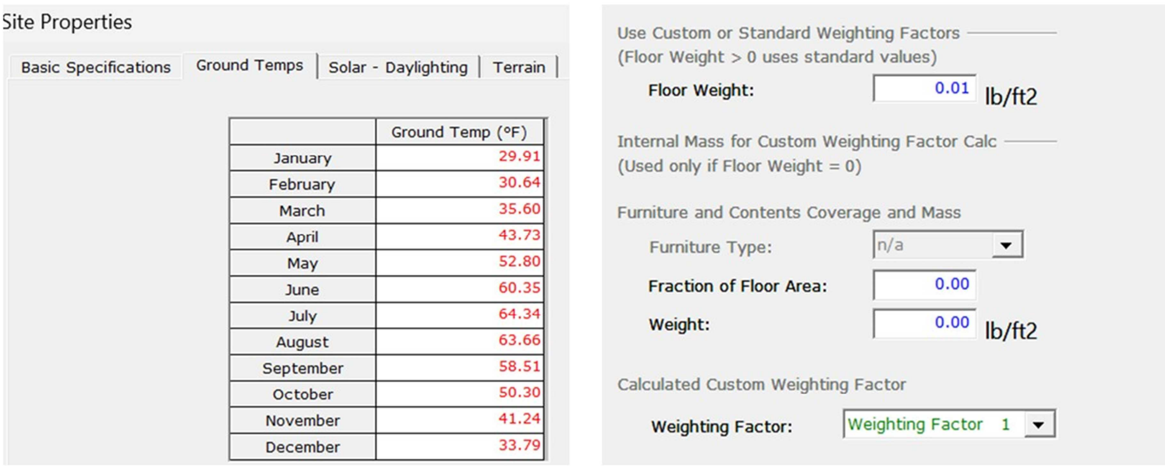


***Figure 8.*** *Other ground/floor inputs that required work-arounds. Left: Manual inputs for monthly ground temperature at a depth of 2' below grade, based on soil properties and other analysis used for previously published thermal models of plastic greenhouses [8, 11, 12]. Right: Work-arounds to bypass eQUEST's assumptions about thermal mass due to furniture and other non-greenhouse accoutrements.*

REPORT- LV-D Details of Exterior Surfaces WEATHER FILE- UTICA ONEIDA COUN NY

NUMBER OF EXTERIOR SURFACES 8
(U-VALUE INCLUDES OUTSIDE FILM; WINDOW INCLUDES FRAME AND CURB, IF DEFINED)

| SURFACE | - - - W I N D O W S - - - U-VALUE (BTU/HR-SQFT-F) | AREA (SQFT) | - - - - W A L L - - - - U-VALUE (BTU/HR-SQFT-F) | AREA (SQFT) | -W A L L + W I N D O W S- U-VALUE (BTU/HR-SQFT-F) | AREA (SQFT) | AZIMUTH |
|---|---|---|---|---|---|---|---|
| North Wall<br>in space: EL1 West Perim Spc (G.W1) | 0.568 | 669.60 | 1.075 | 27.60 | 0.588 | 697.20 | NORTH |
| East Wall<br>in space: EL1 West Perim Spc (G.W1) | 0.000 | 0.00 | 1.075 | 249.00 | 1.075 | 249.00 | EAST |
| East Gable<br>in space: EL1 Under Roof (G.2) | 0.000 | 0.00 | 1.075 | 94.50 | 1.075 | 94.50 | EAST |
| South Wall<br>in space: EL1 West Perim Spc (G.W1) | 0.568 | 669.60 | 1.075 | 27.60 | 0.588 | 697.20 | SOUTH |
| West Gable<br>in space: EL1 Under Roof (G.2) | 0.000 | 0.00 | 1.075 | 94.50 | 1.075 | 94.50 | WEST |
| West Wall<br>in space: EL1 West Perim Spc (G.W1) | 0.000 | 0.00 | 1.075 | 249.00 | 1.075 | 249.00 | WEST |
| South Roof<br>in space: EL1 Under Roof (G.2) | 0.588 | 1330.83 | 1.075 | 35.85 | 0.601 | 1366.68 | ROOF |
| North Roof<br>in space: EL1 Under Roof (G.2) | 0.588 | 1330.83 | 1.075 | 35.85 | 0.601 | 1366.68 | ROOF |
| EL1 Flr (G.W1.U1)<br>in space: EL1 West Perim Spc (G.W1) | 0.000 | 0.00 | 0.250 | 2520.00 | 0.250 | 2520.00 | UNDERGRND |

***Figure 9.*** *The LV-D Report that eQUEST generated after it ran the simulation.*

## 5. Results

Hourly eQUEST outputs are graphed in Figure 10 to illustrate their adherence to the first four reconciliation criteria. With regard to the fifth criterion, peak interior temperature from December through February was 99.2°F. Correlogram analysis revealed distinct peaks at multiples of 3 hour delays – which aligns with the sixth criterion.

By way of contrast, the greenhouse interior temperature profile resulting from default parameter values ("un-reconciled") is also plotted in Figure 10. The passive temperature response is markedly damped in terms of both daytime and nighttime temperature excursions.

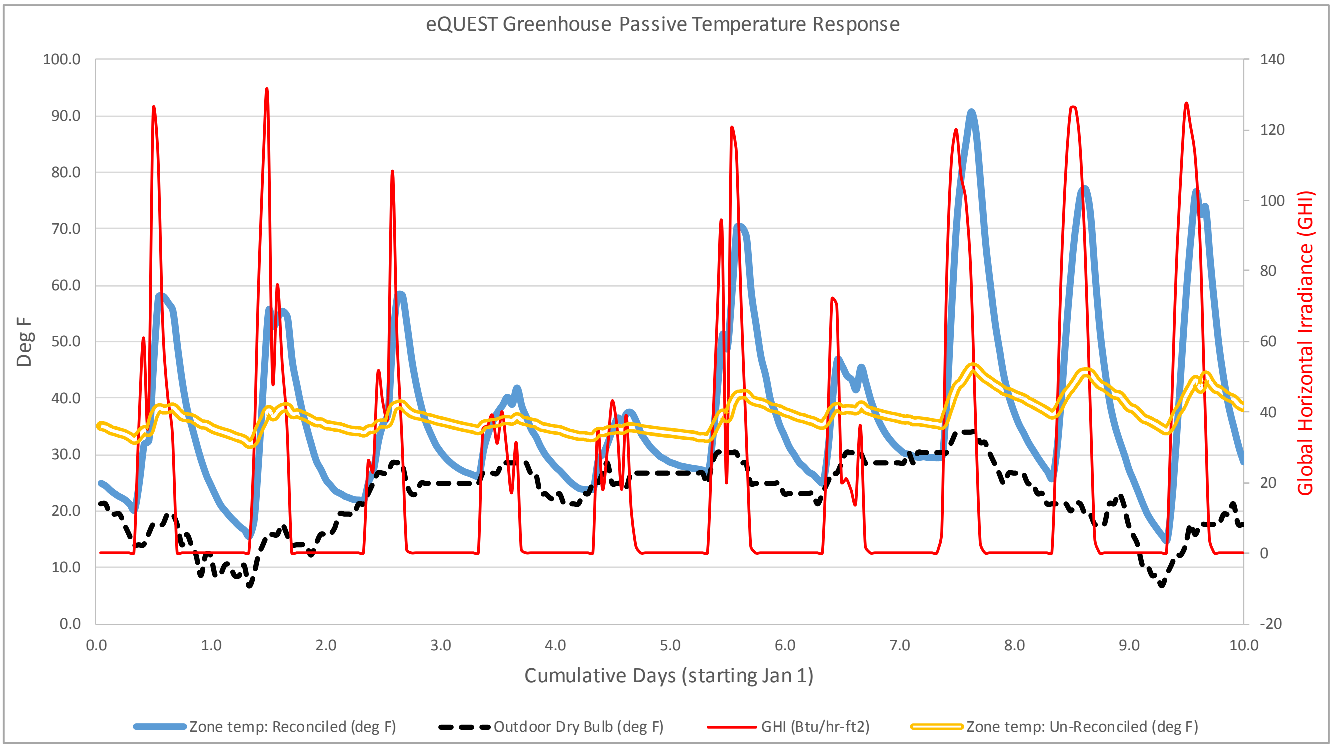


***Figure 10.*** *Time series plots of key eQUEST results, first 10 days of the TMY3 year. See text for details.*

## 6. Discussion

With proper parameter tuning, eQUEST successfully modeled the passive temperature response of a representative case of a 2500 square foot plastic shell greenhouse with a dirt floor. Default settings returned results that underestimated both maximum and minimum temperature excursions.

eQUEST calculations of building loads based on the default settings would underestimate the energy requirements for both cooling/ventilation and for heating. There may be additional issues introduced by eQUEST's defaults and assumptions for active HVAC calculations that have yet to be explored.

These findings raise new questions about previous studies using energy simulations for these simple greenhouses. Estimated energy savings for commercial products like thermal curtains [4, 5, 13-15] would be unreliable if baseline conditions were not adequately modeled.

Recommendations based on these findings include:

1. Re-visiting the source files of previous eQUEST studies with an eye towards evaluating their alignment with the reconciliation criteria.
2. Detailed reporting of simulation parameters used to establish baseline conditions in future publications, and verification that results meet minimal reconciliation/performance criteria.
3. Developing and implementing field studies to validate industry-standard simulation tools for hoop houses.
4. Refining the reconciliation criteria presented in this paper as a function of climate zone and physical attributes like size, shell materials, and other features of hoop houses.
5. Disseminating results among stakeholders including utility company program developers, manufacturers of energy-related products and systems for greenhouses, and strategic planners in relevant agricultural sectors.

## 7. Conclusions

1. Investigators who modeled plastic greenhouses with dirt floors have previously lacked criteria for comparing modeled results with actual field performance.
2. The paper presented reconciliation criteria for modeled passive temperature response at ambient conditions based on published field studies.

3. Modeled passive temperature response establishes a model's baseline for the greenhouse.
4. In the absence of criteria for checking this fundamental aspect of the baseline, the model's default settings may not be reliable for realistically establishing baselines for heating and cooling loads.
5. The paper demonstrated this to be the case for a representative simulation of a plastic greenhouse using an industry-standard tool (eQUEST): The default model would have markedly underestimated active heating and cooling requirements.
6. This calls savings calculations into question for energy conservation measures developed under these circumstances; stakeholders like utility incentive programs should become aware of this.
7. The authors found work-arounds and parameter tunings for eQUEST that aligned modeled results with the reconciliation criteria.
8. Based on these findings, there are significant opportunities both for re-visiting previous studies of this class of greenhouse and for improving simulations going forward.

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