DETERMINING THE OPTIMUM ORIENTATION OF A GREENHOUSE ON THE BASIS OF THE TOTAL SOLAR RADIATION AVAILABILITY

by

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Original scientific paper
UDC: 551.5811:697.7
DOI: 10.2298/TSCI100220057D

This paper presents an approach to determining the optimum orientation of a greenhouse for year round applications for different climatic conditions. The most commonly used uneven-span single shape of greenhouse in east-west and north-south orientation have been selected for comparison. Total solar radiation input to each wall, included surfaces and roofs, is computed for both solar greenhouse orientation and compared for each month of the year at different latitudes at the northern hemisphere. Experimental validation is carried out for the measured global solar radiation data for horizontal surface and south wall at (44° N and 20° E), Belgrade, Serbia. The predicted and measured values are in close agreement. Results shows that east-west orientation of uneven-span solar greenhouse is the best suited during each months for all analyzed latitudes.

Key words: *solar greenhous, orientation, solar energy*

Introduction

The main purpose of a greenhouse is to provide an environment conducive to plant production on a year-round basis or to extend the growing season. The environment inside a greenhouse is dependant on many factors including the time of year, the amount and duration of natural sunlight, the relative humidity, the size and type of equipment, and structure and the type of plants growing in the house. Total solar radiation received by a greenhouse at a particular time and locations depends upon its shape as well as orientation, which ultimately determines the inside air temperature. Air temperature is one of the most dominant parameters affecting the plant growth. It is already established that inside air temperature of a passive greenhouse directly depends upon the ambient air temperature, the solar radiation intensity, the overall heat transfer coefficient, the cover material, and the wind velocity [1].

Various researchers have used different greenhouse shapes at different latitudes for raising off-season vegetables and ornamental plants around the world. These greenhouses are either constructed along east-west (EW) or north-south (NS) orientation (longer axis). It is observed that the most commonly used single span shapes of greenhouses for the agriculture

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applications are even-span, uneven-span, vinery, modified arch, and quonset type. Sethi [2] compared different shapes of greenhouses in order to select the most suitable shape and shows that uneven-span shape greenhouse receives the maximum solar radiation during all months of the year for different climatic zones. Tavares *et al.* [3] discussed the specific climate problems of the utilizations of greenhouses in Portugal, during winter and summer days and show the necessity of having a tool capable of predicting the thermal behavior of a greenhouse under specific exterior conditions. Beshada *et al*. [4] analyzed the performance of a solar energy greenhouse, oriented due south to absorb maximum solar energy, and had a north wall to store solar energy at daytime, which has been efficiently used in China to grow vegetables and flowers during the wintertime, under cold weather conditions. Kumari *et al*. [5] determined the performance of different shapes of greenhouses, with equal floor area as well as the central height, for five different climatic zones of India. Impron *et al*. [6] developed a greenhouse climatic model to optimize cover properties and ventilation rates for the tropical lowlands of Indonesia. Pieters *et al.* [7] developed three-dimensional numerical model for the simulation of the solar radiation transmittance and distribution in any single or multi-span greenhouse with vertical walls and flat roof planes. Saravia *et al*. [8] discussed greenhouse solar heating in the Argentinean north-west in order to increase the average night temperature and avoid freezing problems inside greenhouses, for local meteorological conditions. Lawrence *et al.* [9] discussed thermal modeling of a greenhouse, and the effect of the various components of the system (heat capacity of plants, orientation, *etc*.) as well as climatic parameters (solar insolation, ambient air temperature and ventilation due to wind, *etc*.) has been analyzed. Hasson [10] studied measurement of solar energy parameters and the heating requirement of a double plastic cover greenhouse during the growing season.

The selection of optimum orientation of a greenhouse can cause some reduction in the heating loads of the installed systems thereby saving a lot of cost. In this paper, an attempt has been made to select the orientation of greenhouse on the basis of total solar radiation availability for different latitudes in the northern hemisphere.

Total solar radiation availability on greenhouse cover

A double layer polyethylene greenhouse, uneven-span shape, is selected for this study in EW and NS orientation (fig. 1). Uneven-span shape greenhouse receives the maximum solar radiation during each month of the year at all latitudes, and air temperature remains the highest inside an uneven-span shape as compared to other shapes during different months of the year [11]. Length, width, and height of greenhouse are 12 m, 4 m, and 3 m. Greenhouse is divided into various sections along EW and NS orientation. The details of each section are shown in tab. 1.

Hourly solar radiation incident on an inclined surface of a greenhouse depends upon the time of the day, *i. e.* the sunset hour angle ω_s, n^{th} day of the year (starts from January 1^{st}), *i. e.* declination angle δ, the latitude of the site ϕ, and angle β of the surface with horizontal. The required values of these parameters have been computed from the available global solar radiation data measured on a horizontal surface [12].

The extraterrestrial solar radiation on a horizontal surface is a function only of a horizontal surface latitude and independent of other location parameters. Extraterrestrial radiation on a horizontal surface I_0, can be computed for latitudes in the range +60 to –60 on the day of year n:

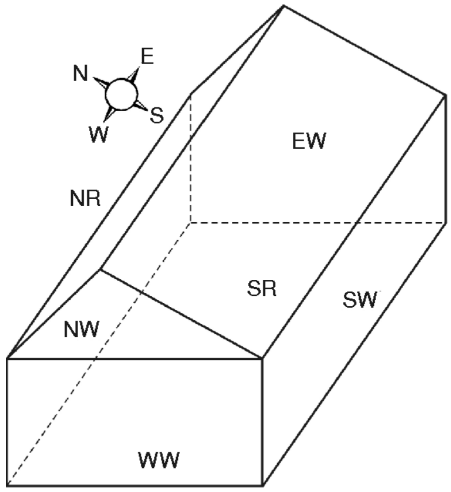

Figure 1. Selected greenhouse shape in EW orientation

Table 1. Sectional details of selected geometry greenhouses

EW orientation	β [°C]	A [m^2]
SW	90	24
SR	18.5	37.9
NW	90	24
NR	135	16.8
EW	90	10
WW	90	10
NS orientation	β [°C]	A [m^2]
EW	90	24
ER	18.5	37.9
WW	90	24
WR	45	16.8
NW	90	10
SW	90	10
Section details: SW – south wall, SR – south roof, NW – north wall, NR – north roof, EW – east wall, WW – west wall, ER – east roof, WR – west roof;		

$$I_0 = \frac{24 \cdot 3600 \cdot G_{SC}}{\pi} \left(1 + 0.033 \cos \frac{360 n}{365}\right) \cdot \left(\cos\varphi \cos\delta \sin\omega_s + \frac{\pi\omega_s}{180} \sin\varphi \sin\delta\right) \tag{1}$$

where G_{SC} is the solar constant equal to 1367 W/m^2 [13].

Adopting the isotropic diffuse model, the solar radiation on a tilted surface can be calculated on an hourly basis based on the following well-known eq. (2). The first term on the right-hand side of eq. (2) represents solar radiation coming directly from the Sun, the second term represents the contribution of monthly average diffuse radiation, and the last term represents reflection of radiation on the ground in front of the collector.

$$I_T = I_b R_b + I_d \left(\frac{1 + \cos\beta}{2}\right) + I \rho_g \left(\frac{1 - \cos\beta}{2}\right) \tag{2}$$

where I_T is the hourly total radiation on a tilted surface, I_b – the hourly beam radiation, the geometric factor R_b is the ratio of beam radiation on the tilted surface to that on a horizontal surface at any given time, I_d – the hourly diffuse radiation, I – the hourly total radiation on a horizontal surface, and ρ_g – the ground reflectance factor. For surface facing directly towards the equator in the northern hemisphere, R_b is given by the equation:

$$R_b = \frac{\cos(\phi - \beta)\cos\delta \cos\omega + \sin(\phi - \beta)\sin\delta}{\cos\phi \cos\delta \cos\omega + \sin\phi \sin\delta} \tag{3}$$

The hourly total solar radiation S_t incident on different inclined and vertical surface of the greenhouse is total sum of solar radiation falling on different surfaces (each wall and roof) of the greenhouse. Total solar radiation falling on tilted surface of the greenhouse has been computed on an hourly basis for all the sections of each shape of the greenhouse in both EW and NS orientations, using the above equations and data from tab. 1. Total solar radiation available on the greenhouse cover is thus given by:

$$S_t = \sum_{i=1}^{6} A_i I_i \tag{4}$$

where A_i and I_i are the surface area of the i^{th} section and total solar radiation available on i^{th} section *i. e.* For EW orientation the hourly total solar radiation is given by:

$$S_t = A_{SW} I_{SW} + A_{SR} I_{SR} + A_{NW} I_{NW} + A_{NR} I_{NR} + A_{EW} I_{EW} + A_{WW} I_{WW} \tag{5}$$

The hourly total solar radiation on greenhouse cover surfaces is calculated for a typical summer and winter day. The hourly variation of total solar intensity on different walls and roofs in E-W orientation greenhouse at 44° N latitude, for a typical summer day (17-07-05) is shown at fig. 2, and for a typical winter day (17-01-05) at fig. 3.

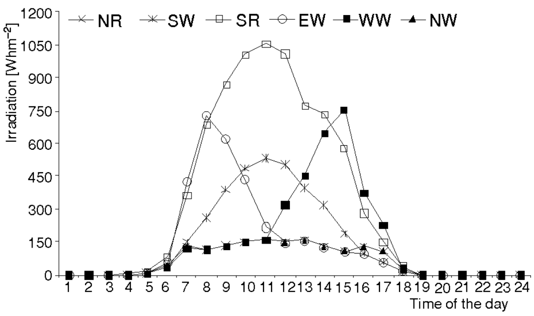

Figure 2. Hourly variation of the total solar intensity on different walls and roofs in EW orientation greenhouse for a typical summer day (17-07-05) at 44° N

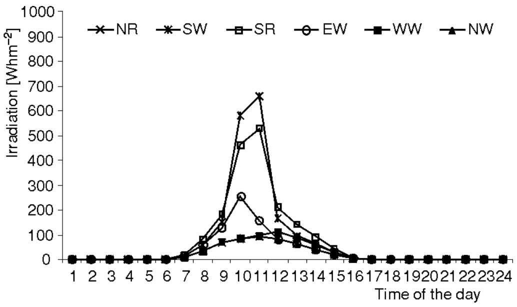

Figure 3. Hourly variation of the total solar intensity on different walls and roofs in EW orientation greenhouse for a typical winter day (17-01-05) at 44° N

The hourly total solar radiation incident on different inclined and vertical surface of the greenhouse for the same greenhouse in N-S orientation is also calculated and substituted in the model. The obtained values have been compared for each month (typical days of each month) in order to determine the more suitable orientation of the selected greenhouse.

Experimental validation

Experimental validation is carried out for measured solar radiation data at (44°47' N, 20°32' E) Belgrade, Serbia [14]. Measured daily average global solar radiation data on the horizontal surface as well as measured daily average global solar radiation on the south wall are compared with theoretically computed data on the same surfaces (fig. 4 and 5). It is observed that both the set of values are closely matched indicating that the developed model is validated.

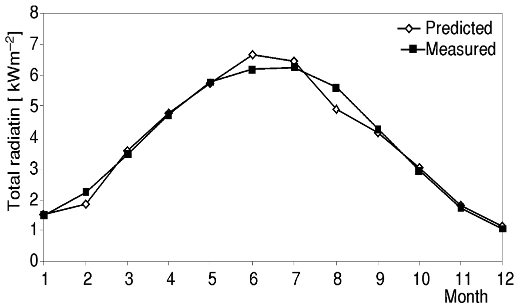

Figure 4. Predicted and measured monthly average daily global solar radiation on horizontal surface

Results and discussion

A comparison of total solar radiation availability on the selected typical day of each month of the year in EW and NS orientation is shown in figs. 6-9, at different latitudes.

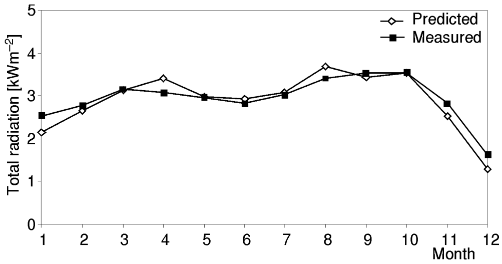

Figure 5. Predicted and measured monthly average daily total solar radiation on south wall

At 24° N latitude, NS orientation receives more solar radiation during all months of the year as compared to EW orientation, because in summer eastern and western section in NS orientation receive more radiation as compared to northern and southern section in EW orientation. The difference is small in winter months than in summer months. At this latitude ambient air temperatures are high throughout the year and EW orientation which receives less solar radiation is more suited, as its application would be held lower inside air temperature during the year.

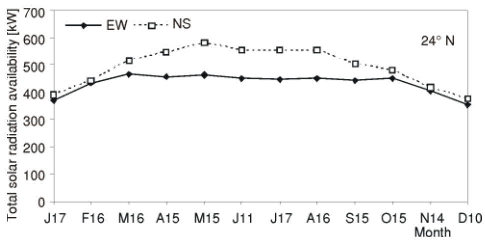

Figure 6. A comparison of annual variation in total solar radiation availability for greenhouse in EW and NS orientation at 24° N latitude

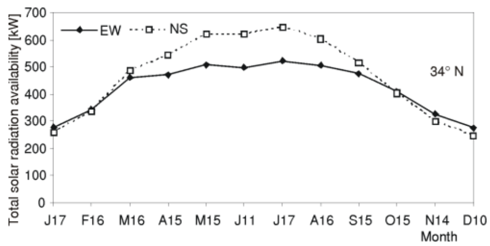

Figure 7. A comparison of annual variation in total solar radiation availability for greenhouse in EW and NS orientation at 34° N latitude

At 34° N latitude, NS orientation of greenhouse receives less solar radiation in winter months (7.7% less in January) but more in summer months (24% more in July) as compared to EW orientation. This is because in winter the eastern and western side sections in NS orientation receive less radiation as compared to northern and southern side sections in EW orientation. However in summer months, eastern and western side sections in NS orientation receive more solar radiation as compared to the eastern and western side sections in NS orientation. It can be concluded that EW orientation should be preferred as it would provide more radiation in winter and less in summer.

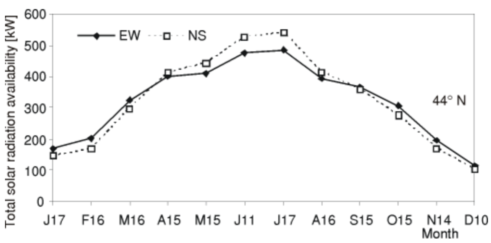

Figure 8. A comparison of annual variation in total solar radiation availability for greenhouse in EW and NS orientation at 44° N latitude

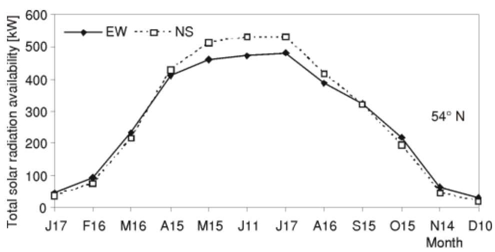

Figure 9. A comparison of annual variation in total solar radiation availability for greenhouse in EW and NS orientation at 54° N latitude

At 44° N and 54° N latitude, NS orientation of greenhouse receives much less solar radiation in winter months (less in January: 14.2% at 44° N, and 14.6% at 54° N) but more in summer months (more in July: 11.8% at 44° N, and 9.9% at 54° N) as compared to EW orientation. In can be concluded that NS orientation receives more radiation in summer, but significantly less in winter month, as compare to EW orientation. EW orientation should be preferred as it would provide and maintain higher inside air temperatures during winter months, because winters are severe and longer at these latitudes.

Conclusion

A model was developed for analyzing the orientation of greenhouse which use is most suitable for all year round applications. At 24° N, EW orientation *should be preffered as it receives less solar radiation is summer with small differences in receive solar radiation in winter months.* With increase of the latitude angle, the difference in the radiation received during winter month increase as compared to lower altitude. As winters are severe and longer at higher altitude angle, EW orientation should be also preferred, as it would provide more radiation in winter and less in summer.

Nomenclature

A – surface, [m^2]
G_{SC} – solar constant, (= 1367 W/m^2)
I – hourly total radiation on a horizontal surface, [kWhm^{-2}]
I_b – hourly beam radiation, [kWhm^{-2}]
I_d – hourly diffuse radiation, [kWhm^{-2}]
I_T – hourly total radiation on a tilted surface, [kWhm^{-2}]
I_0 – daily extraterrestrial solar radiation on a horizontal surface, [kWhm^{-2}]
n – number of the day of the year starting from the first of January, [–]
R_b – the ratio of beam radiation on the tilted surface to that on a horizontal surface, [–]
S_t – total solar radiation available on the – greenhouse cover, [kWh]

Greek letters

β – angle of the surface with horizontal, [°]
δ – solar declination, [°]
ρ_q – round reflectance factor [–]
ϕ – latitude of site, [°]
ω_s – the sunset hour angle, [°]

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Paper submitted: February 20, 2010
Paper revised: March 17, 2010
Paper accepted: July 18, 2010