Evaluation of solar fraction on north partition wall for various shapes of solarium by Auto-Cad

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Abstract

In the present paper, the distribution of solar energy inside the uneven span solarium has been determined in terms of solar fraction on north partition wall by using Auto-CAD 2000 for New Delhi (28.5° latitude). This enables the prediction of its performance for passive heating. The concept has been extended to other shapes of greenhouses for cultivation of flowers during off-season. The other shapes included for study are even span, modified arch, vinery and modified IARI. They have similar floor area and height. Analysis has been made with the help of a model based on Auto-CAD 2000 for a typical day of each month of the year. It has been observed that the solar fraction plays an important role at low altitude for thermal heating of either a building or a greenhouse during winter months. It mainly depends on the shape and size of greenhouse and time of the nth day of the year. Based on the analysis it can be concluded that the modified arch shape greenhouse is suitable for thermal cooling through out the year. Uneven span shape greenhouse is most suitable for thermal cooling of living space in winter and heating in summer, in comparison to other shapes.

Keywords: Solar fraction; Thermal heating; Shapes of greenhouse/solarium

1. Introduction

The use of transparent cover for thermal heating is one of the passive concepts (direct gain) used in design of a building [1,2]. The over heating of an environment inside building had been controlled by indirect thermal heating [3,4]. The combination of direct and indirect heating is generally known as solarium [5]. Various researchers have analyzed its performance for cold climatic conditions in India and abroad [6-9].

In order to predict the performance of solarium/greenhouse, it is necessary to know the distribution of solar energy inside on different walls and floor in terms of solar fraction [10,11]. Eisner et al. [12] have reviewed the work done in European countries for various shapes of greenhouses in terms of transmittance which depends on the rate of solar radiation available on the floor of greenhouse. This leads to determine the enclosed room air temperature inside the solarium/greenhouse which can be used either for thermal comfort of human being or for growth of plants.

The objective of the present paper is to evaluate the distribution of solar radiation in terms of solar fraction for the north opaque partition wall \( F_n \), for five shapes of solarium available in the literature [13]. The value of \( F_n \) was predicted with the help of an already validated model based on Auto-CAD 2000 for a typical day of each month of the year for a given solar azimuth and altitude angles [14]. The calculations were made for a typical day of each month of the year for 8:00 a.m., 10:00 a.m., 12:00 noon, 2:00 p.m. and 4:00 p.m. for New Delhi (latitude 28.5°). Based on the study it could be concluded that the \( F_n \) varies with the shape and size of the greenhouse and time of rath day of the year. Its value increases in winter and decreases in summer due low and high position of sun in the sky. Depending on the temperature requirement for thermal comfort, the shape and size of the solarium/greenhouse can be selected. It is found that modified arch shape solarium/greenhouse is most suited for thermal cooling of the living space through out the year while uneven span is suitable for heating of living space in winter and cooling in summer.

2. Working principle of solarium

Fig. 1 shows a cross sectional view of a passive thermal heating of a greenhouse cum a living space (solarium). There is a partition wall between greenhouse and the living
space. The partition can be opaque, semi transparent, transparent or partially transparent depending upon desired temperature inside the greenhouse and the living space. Solar radiation, after reflection from greenhouse cover is transmitted inside the greenhouse. It is important to know the distribution of solar radiation between floor and the partition north wall. The solar radiation falling on partition north wall may be reflected, conducted or transmitted depending upon the material of north partition wall. The thermal energy either transmitted or conducted into the living space can be utilized to heat the room air in the living space. The radiation falling on the floor of greenhouse and reflected radiation from north partition wall may be utilized to heat the greenhouse air temperature. Distribution of solar radiation on north partition wall and floor also depends upon the width and the height of the solarium. Fig. 2 indicate the sectional distribution of various predicted shapes of the greenhouse under study.

3. Theory

3.1. Definition of solar fraction ($F_n$)

Referring to Fig. 3, the solar fraction can be defined as the ratio of solar radiation falling on the opaque partition north wall of the solarium/greenhouse over the total incoming radiation. The expression of $F_n$ can be written as follows [11].

$$F_n = \frac{\text{ solar radiation available on north opaque wall inside the solarium for a given time}}{\text{ solar radiation measured on the north side and floor of the solarium at the same time}} \quad (1)$$

For example, the parallel rays entering inside the greenhouse at noon through sections ($j = 1-3$) of cover and the extended rays towards section ($j = 4$) have been shown in Fig. 3. According to definition of solar fractions ($F_{n,j}$) (Eq. (1)) for north side due to sections ($j = 1-3$) can be defined as:

$$F_{n1} = 0,$$

(since, no radiation falls on north wall from this section).

$$F_{n2} = \frac{\text{the length of the projected extended ray after the north wall}}{\text{the total length of the projected ray}} = \frac{ED'}{WE}$$

and,

$$F_{n3} = F_{n4} = F_{n5} = F_{n6} = 0,$$

(since, no radiation falls on north wall from these sections).

Solar fraction ($F_n$) will vary with the time of the day and it should be calculated for each section facing solar radiation for a given time of the day. Solar fraction ($F_n$) for north side
Fig. 2. Sectional distribution on predicted shapes of greenhouses (a) even span, (b) modified arch, (c) vinery, and (d) modified IARI (number indicates the section of the given greenhouse).

Fig. 3. Calculation of the solar fraction ($F_n$) of an even span greenhouse for north wall.
will be the average of solar fractions due to each section. This can be expressed as follows:

\[
F_n = \frac{F_{n1} + F_{n2} + F_{n3} + F_{n4} + F_{n5} + F_{n6}}{(F_{n1} + \ldots + F_{n6}) + (1 - F_{n1}) + (1 - F_{n2}) + (1 - F_{n3}) + \ldots + (1 - F_{n6})}
\]

or,

\[
F_n = i (F_{n1} + F_{n2} + F_{n3} + F_{n4} + F_{n5} + F_{n6})
\]

The above equation can be rewritten as follows:

\[
F_n = \frac{1}{6} \sum_{i=1}^{6} F_{ni}
\]

For evaluation of \( F_{nj} \) the values of declination (5), hour (co), solar altitude (a) and solar azimuth (y) angles are required.

### 3.2. Calculation of sun angles

Further, the required values of declination (5), hour (co), solar altitude (a) and solar azimuth (y) angles at different time for typical days of each months have been calculated by using the following expressions [15]:

\[
\sin \phi = \frac{180}{23.45 \sin \left( \frac{360(284 + n)}{365} \right)}
\]

\[
\omega = 15^\circ (t_{solar} - 12.0)
\]

\[
\sin a = \cos \phi \cos S \cos a + \sin S \sin \phi
\]

\[
a = \sin^{-1} \left( \cos q \cos 5 \cos co + \sin 8 \sin \phi \right)
\]

\[
\cos y = \frac{\sin a \sin cp - \sin 8}{\cos a \cos cp}
\]

or,

\[
y = \cos^{-1} \left[ \frac{\sin a \sin cp - \sin 8}{\cos a \cos cp} \right]
\]

A computer program has been made in FORTRAN-77 to calculate various angles. In the above formulae, \( n \) is the number of day of the year, \( cp \) is the latitude of the place. For calculations local time is taken as solar time. The values of these angles on typical day of December 2000 have been given in Table 1.

### 4. Methodology for computation of solar fraction using Auto-CAD 2000

In order to calculate solar fraction (\( F_n \)), the following steps have been taken:
Table 1
The angle of declination (δ), hour angle (θ), solar altitude (α) and solar azimuth angles (y) on typical days of month of the year at New Delhi

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Declination angle (δ) (°)</th>
<th>Hour angle (θ) (°)</th>
<th>Solar altitude angle (α) (°)</th>
<th>Solar azimuth angle (y) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-12-2000</td>
<td>8:00 a.m.</td>
<td>-23.45</td>
<td>-60.00</td>
<td>12.26</td>
<td>+54.39</td>
</tr>
<tr>
<td></td>
<td>10:00 a.m.</td>
<td>-23.45</td>
<td>-30.00</td>
<td>30.47</td>
<td>+32.16</td>
</tr>
<tr>
<td></td>
<td>12:00 noon</td>
<td>-23.45</td>
<td>0.0</td>
<td>37.96</td>
<td>-0.0</td>
</tr>
<tr>
<td></td>
<td>2:00 p.m.</td>
<td>-23.45</td>
<td>30.00</td>
<td>30.47</td>
<td>-32.16</td>
</tr>
<tr>
<td></td>
<td>4:00 p.m.</td>
<td>-23.45</td>
<td>60.00</td>
<td>12.26</td>
<td>-54.39</td>
</tr>
</tbody>
</table>

(b) Come to the front view of the model, for a given section (AB) and hour angle (θ), a line making an angle equal to the solar altitude angle (α) at the top of the model was drawn.

(c) Now, coming to the top view of the model, the same line was given an angle equal to solar azimuth angle with respect to the line due to south. The line, thus, represented the solar ray falling on section of the greenhouse.

Similarly, several rays parallel to the ray of (c) were drawn for each section of the greenhouse and extended towards the north side.

Fig. 4 shows the flow chart of the Auto-CAD 2000 model to calculate solar fraction at different time for a given shape (Fig. 2).

5. Results and discussion

The hourly variation of solar fraction ($F_n$) (Eq. (2)) for different months of the year has been shown in Fig. 5. This figure also shows the effect of different shapes of greenhouse (Figs. 1 and 2) on solar fraction. Fig. 6 shows the daily variation of $F_n$, with different shapes of greenhouses and the month of the year, at 8:00 a.m. It can be inferred from these figures that the value of solar fraction ($F_n$) is highest at 10:00 a.m. for all shapes and months of the year. The value of $F_n$ at 8:00 a.m. and 10:00 a.m. is numerically similar to the values at 4:00 and 2:00 p.m., respectively. Further, it can be concluded that the value of solar fraction ($F_n$) is minimum during the month of May to August (summer period) due to high altitude angle of sun (Fig. 6). However, the value of solar fraction is maximum during winter months (November to January) due to low altitude angle of sun. This is in accordance with the result reported earlier by Tiwari and coworkers [11,14].

It is important to note that the values of solar fraction ($F_n$) for uneven shape of greenhouse is higher during March to September (summer period) and becomes lower during October to March (winter period) in comparison to the values of $F_n$ for modified arch shape. Hence, the uneven span shape can be used either for heating or cooling of the greenhouse during winter or summer periods, respectively. It is important to note that the irregularities in the values of solar fraction for even span, uneven span and modified IARI shape during winter period (October to March) are due to small inclinations of sections of greenhouse cover and the low values of altitude angle of sun (Fig. 6).

The variations of daily average values of solar fractions ($F_n$) for a typical day of the month of the year have been shown in the Fig. 7. The value of monthly average of the
solar fraction at different time for different shapes has been shown in Fig. 8. From these figures it can be concluded that modified arch shape greenhouse can be used for thermal cooling throughout the year due to maximum value of solar fraction throughout the day. This is in accordance with the results reported earlier by Gupta and Tiwari [16].

Effect of width and height of solarium-cum-greenhouse on its solar fraction have been shown in Fig. 9. It is inferred...
that the daily average solar fraction decreases with the increase in the width of the greenhouse and vice versa with height, as expected. Further, the value of solar fraction in winter is significantly higher than in summer and hence it can be used for thermal cooling. The higher values of solar fraction during winter months is most suitable for thermal heating of attached living space (Fig. 1a). This can be achieved either by direct or indirect gain. The same design can be most suitable for thermal cooling for crop production due to higher thermal loss through north transparent cover.

6. Conclusion

Based on the above discussion it can be concluded that the value of $F_n$ is higher during winter months and lower during summer months. For a typical day the value of $F_n$ is found highest at 10:00 a.m. and lowest at 12 noon for all the shapes. Modified ach shape observed the highest $F_n$ value hence, suitable for thermal cooling throughout the year. From $F_n$ point of view, the uneven span shape is most suitable for thermal cooling and heating of the living space in summer and winter, respectively, comparing to other shapes. Further, the solar fraction on north wall ($F_n$) is reduced with increase in the width of solarium-cum-greenhouse and vice-versa with the height.
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References