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Passive Thermal Heating of a Controlled Environment Greenhouse: A Periodic Analysis

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Abstract: *In this paper the passive heating concept is used in the greenhouses of different shapes for various climatic conditions of India. A numerical analysis has been carried out using Matlab and Borland C++ corresponding to the climatic conditions of five different climatic zones of India. A total of three types of greenhouse (even span, uneven span and modified model of the Indian agriculture research institute, Delhi (IARI)) with the same cross section (6 m × 4 m×3m) for different climatic zones of India using passive mode in the greenhouse heating. It has been inferred that the uneven span greenhouse is most suitable from heating point of view and the places wherecooling is required evenspan greenhouse is prefered.*

Keywords: *Greenhouse; phase change material; solar energy; thermal modelling; water storage*.

1. Introduction

As is known, greenhouses are designed to provide suitable environment for the intensive production of various crops by controlling solar radiation, temperature, humidity and carbon dioxide levels within them. The availability of solar radiation and its daily and yearly distribution has a significant influence on the productivity and quality of plant growth and also on comfort living with solarium-cum-greenhouse [1]. The greenhouse air temperature mainly depends on the distribution of solar radiation after transmission through the greenhouse cover which in turn depends on the shape and size of the greenhouse, motion of the sun and weather conditions [2]. Design of a greenhouse, its orientation and type of its glazing will affect the amount of light transmitted into the structure [3]. The design and selection of a controlled environment greenhouse can be determined on the basis of the zonal climatic conditions of a country; assuming that the country is divided in different climatic zones. India has been classified in six climatic zones on the basis of rainfall, relative humidity, ambient air temperature and solar insolation. These zones are: hot and dry (Jodhpur), warm and humid (Mumbai, Chennai), moderate (Bangalore), cold and cloudy (Srinagar), cold and sunny (Leh) and composite (New Delhi); [4].

The heating of a greenhouse can be achieved either by passive or active mode. The temperature inside the greenhouse can be increased or decreased with the heating and cooling of the greenhouse air. Heating of greenhouses is one of the most important activities during winter season and it is an essential requirement for proper growth and development of the winter crops [5]. Passive mode uses the sun’s rays to heat a surface inside the greenhouse directly, storing the heat in a mass of concrete, rock, or water [6]. Anew concept was investigated and started in 2004: the Passive Greenhouse [7]. This term originate from *Passive House*, which means a building with a reduced ecological footprint. Although this might open some controversies, we decided to consider the term passive in the sense of free of conventional energy, relying exclusively on sustainable energy. The objective of the present paper is to evaluate the distribution of solar radiation (considering area of a section), for three different shapes of the greenhouse with the same floor area (6 m × 4 m) and the same central height (3 m). Analysis has been carried out for different climatic zones of India using passive mode in the greenhouse heating. It has been inferred that the uneven span greenhouse is most suitable from heating point of view for cold climatic zone like Srinagar in India.

2. METHODOLOGY

The methodology followed for the analysis is presented in this section. Longitudes and latitudes of the places selected, shapes of greenhouses and methods for calculation of solar altitude, solar azimuth angles and solar radiations on each section of the greenhouse have been incorporated.

2.1. Place

Five locations depending upon the importance of the location from agricultural point of view were selected for the present study. These are given in Table 1.

2.2. Shapes of Greenhouse

In the present study three shapes, as shown in Figure 1, have been considered. These are: even, uneven, and modified IARI, their orientation is always taken in the east–west direction [8].

Table1. *Locations of the places selected for the present study*

Sr. No.	Place	Longitude (deg)	Latitude (deg)
1.	Delhi	77.20	28.58
2.	Srinagar	74.83	34.08
3.	Jodhpur	73.02	26.30
4.	Kolkata	88.33	22.53
5.	Chennai	80.18	13.00

2.3. Calculation of Angles and Solar Radiation on Each Section of the Greenhouse

The required values of the declination angle (δ), hour angle (ω), solar altitude (α) and solar azimuth (γ) at different time of the day for a typical day in winter month were calculated using Matlab and Borland C++. The total solar radiation incident on a surface consists of beam solar radiation, diffuse solar radiation and solar radiation reflected from the ground and the surroundings. A computer programme has been made in Borland C++ to calculate the various angles. For calculations, local time is taken as solar time (ST).

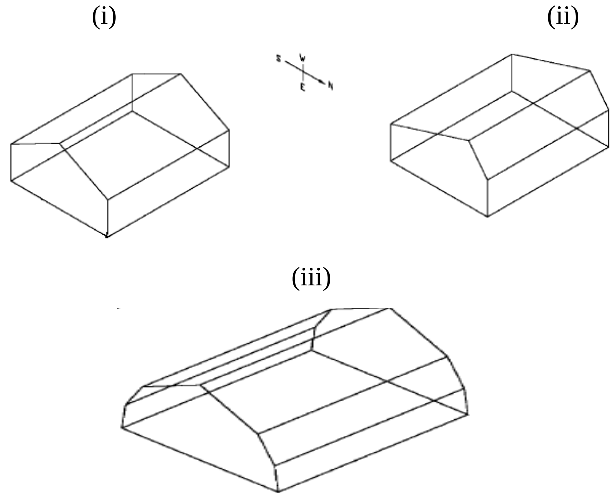

Fig1. *Sectional distribution of different shapes of greenhouse (i) Evenspan (ii) Uneven span (iii) Modified IARI*

3. THE PASSIVE GREENHOUSE STRUCTURE

A Passive Greenhouses is independent of any conventional energy like gas, hot water, electricity, etc. The concept is just like the Solar Passive Greenhouse, which uses only solar radiation and natural ventilation [9] . If provided with renewable energy sources as geo-thermal water, wind, photovoltaic, etc. a Solar Passive Greenhouse becomes a Passive Greenhouse. The shape of the greenhouse depends on the location and weather condition of a specific location. Passive Greenhouses could be concentrated into remote locations, out of other immediate interest. In harsh weather conditions these type of passive methods are not as such successful onlt then we can use the other conventional methods to heat up a greenhouse. Since such extreme weather periods are rather seldom, this is a good method to reduce the investment costs, avoiding the overdimensioning of the other energy sources. Figure 2 shows a cross-sectional view of passive thermal heating of an even span greenhouse.

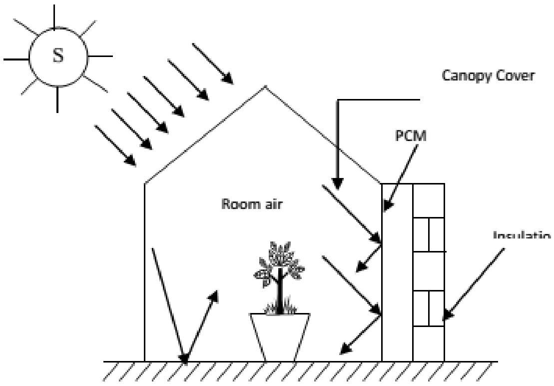

Fig2. *Schematic view of greenhouse with insulated PCM north wall*

Thermal load levelling, TLL = $\frac{Q_{\max} - Q_{\min}}{Q_{\max} + Q_{\min}}$, gives estimate for the fluctuation in temperature inside the greenhouse. Q_{max} and Q_{min} are maximum and minimum flux available inside room through roof. T_0 is the reference temperature (^{0}C), T_r is the room temperature (^{0}C). Substituting the value of Q in the above equation, the expression for TLL becomes,

$$TLL = \frac{M_a C_a (T_r - T_0) - M_a C_a (T_r - T_0)}{M_a C_a (T_r - T_0) + M_a C_a (T_r - T_0)} = \frac{T_{r,\max} - T_{r,\min}}{T_{r,\max} + T_{r,\min}}.$$

4. Result and Discussions

Computations for the passive mode of heating have been made to find the best-suited shape and methods of heating the greenhouses for different climatic zones of India. The heating mode which we are using is the PCM north wall. The hourly variation of plant (T_p) and room (T_r) temperature for even span, uneven span and modified IARI shapes of the greenhouse with PCM north wall for a very cold climate of Srinagar are shown in Figures 3 and 4 respectively. Ambient air (T_a) temperature is also plotted in both the figures. It is evident from Figure 3 and 4 that uneven span greenhouse with PCM north wall gives the highest hourly variation of plant and room temperature for Srinagar. A significant rise in the plant temperature, in comparison to the ambient air temperature, occurs for all the three shapes due to the PCM north wall. It is due to minimum heat loss from the north wall / roof of the greenhouse. Also, as expected the plant temperature (T_p) is higher than room temperature during sunny hours, because the plant receives direct as well indirect thermal energy. The result is reverse during the night.

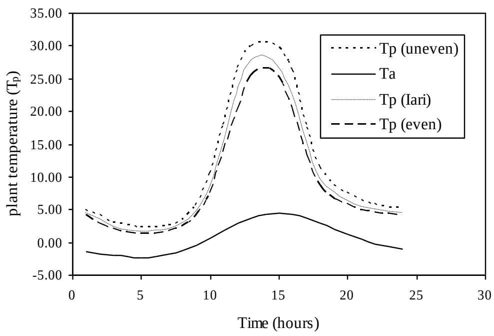

Fig3. *Hourly variation of plant temperature (Tp) and ambient temperature (Ta) in different shapes (even, uneven, and IARI) of greenhouse with PCM North wall for Srinagar climatic conditions.*

The maximum and minimum room air temperatures evaluated for different climatic conditions were used to calculate the thermal load leveling (TLL) using its expression. From these figures it is inferred that the TLL is maximum for Srinagar climatic conditions for all shapes of greenhouse. Further it was noted that the TLL for New Delhi and Jodhpur are nearly the same. This indicates that the active thermal heating by the present method is the most suitable for Srinagar in comparison to Kolkata, Delhi, Jodhpur and Chennai. Since places having climatic conditions like Srinagar require heating for most of the year, the uneven span shape of the greenhouse should be chosen from the heating point of view.

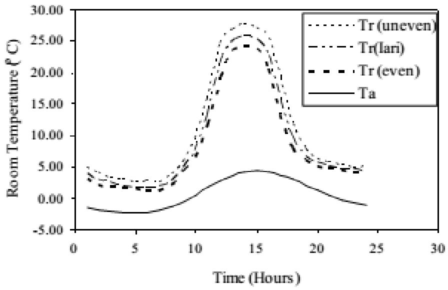

Fig4. *Hourly variation of room air temperature (T_r) and ambient temperature (T_a) in different shapes (even, uneven, and IARI) of greenhouse with PCM North wall for Srinagar climatic conditions*

5. CONCLUSIONS

For different climatic zones of India, the heating requirement varies with the shape of greenhouse. A particular shape may be recommended by knowing the climatic conditions of a zone. For the cold and cloudy zone, like in Srinagar, where heating is the requirement, an uneven span shape greenhouse using passive mode of heating, i.e. the greenhouse with PCM north wall will be suitable. The study has shown that for others zones, like New Delhi, Chennai, Jodhpur and Kolkata where cooling is the requirement, even span shape of the greenhouse is preferred.

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