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A theoretical approach of developing a thermal model for greenhouse

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ABSTRACT : The thermal behaviour of a greenhouse in any climatic condition can be studied by developing analytically a suitable thermal model with the help of which the inside environmental conditions can be predicted corresponding to the outside atmospheric situation. Based on the predicted inside conditions, heating and cooling requirements for a particular crop can be decided to maintain suitable environment for the growth of the crop. The various controlling parameters *i.e.*, solar radiation, ambient air temperature, transmittance of greenhouse cover, ventilation, relative humidity etc. are generally taken into consideration for studying the thermal behaviour of the naturally ventilated greenhouse. For quantitative analysis of the thermal model, numerical calculations can be done to predict the effects of the above controlling parameters on the thermal behaviour of the greenhouse. The developing model can be validated for studying its accuracy and applicability under various situations. Various controlling parameters can accordingly be adjusted suitable for the better growth of a plant inside the greenhouse after studying the thermal bahaviour of greenhouse through the developing model.

KEY WORDS : Thermal modeling, Solar energy, Greenhouse

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Greenhouses are available in various shapes and sizes suitable for different climatic zones. A greenhouse is an expensive option for rural farmers in India. Selecting a greenhouse that will perform most efficiently depends on many factors. Essentially a well designed greenhouse should be able to maintain a required environment inside a greenhouse enclosure for healthy growth of plants for maximum yield. The control of various environmental parameters like solar radiation, air temperature, transmittance of greenhouse cover, ventilation, relative humidity inside the greenhouse, suitable for favourable growth of plant can be studied mathematically by developing a suitable thermal model, which is required to optimize those parameters involved in either heating or cooling of greenhouse. A suitable thermal model can also be used to optimize greenhouse air temperature (one of the important constituents of the environment inside the greenhouse) for higher yield of a plant inside greenhouse for a given climatic condition (Singh and Tiwari, 2000). The objective of designing a greenhouse is to maximize yield from a plant by providing suitable environmental conditions. Thermal modeling requires basic energy balance equations for different components of greenhouse system for a given climate (solar radiation, ambient air temperature, relative humidity, wind velocity etc.) and design (volume, shape, height, orientation, latitude etc.) parameters. Basic knowledge of heat and mass transfer is also of great importance in deriving energy balance equation for heating and cooling operations of a greenhouse under given climatic conditions (Nelson, 1985). The transfer of heat energy occurs as a result of driving force called temperature difference and mass transfer which take place in the form of evaporative heat transfer.

To facilitate the modeling procedure, a greenhouse is considered to be composed of a number of separate but interactive components (Sharma, 1998). These are greenhouse cover, the floor, the growing medium, enclosed air and the plant. The crop productivity depends on the proper environment and more specifically on the thermal performance of the system. The thermal performance of a greenhouse can be studied with the help of a mathematical model with suitable assumptions. Energy balance equations are derived to formulate the model, which permits the prediction of environmental conditions in a greenhouse from outside atmospheric conditions (Das, 2010).

In this study, an attempt has been made to develop a suitable mathematical model based on energy balance equations for each component of the greenhouse. The mathematical model so developed can be validated by the recorded experimental findings for its applicability in enhancing production and productivity of a crop in a given climatic condition with the objective of predicting environmental parameters like temperature, humidity and light intensity inside a greenhouse.

Modeling:

The process of breaking something complex down into simpler elements and subjecting them to scrutiny is called analysis. In engineering, systems are broken down into subsystems and subsystems into components. Everything is broken down until it becomes simple enough to be understood and to be converted into mathematical expressions that describe its properties, behaviour or function. The process of describing something physical by mathematical formulae is called analytical or mathematical modeling. Hence, modeling is the representation of a system, process or phenomenon occurring in real world situation and is expressed in mathematical form. The advantage of a model is two-fold:

– By studying the model, it is possible to figure out how to change, improve and optimize the design.

– The performance and behaviour of a design under a great variety of operational and environmental conditions can be predicted analytically long before the design is actually constructed and taken into service.

METHODOLOGY

Experimental site :

A semi circular shaped greenhouse (Fig. A) covering the floor space of 4 m x 12 m (48 sq m) oriented in East-West direction was used for developing the thermal model. The greenhouse was covered with ultra violet (UV) low density polyethylene (LDPE) film of 200 micron thickness. The greenhouse was covered with a netlon make shade net of 50 per cent as a shading device as and when required. The experimental greenhouse is located in the nursery site of the Department of Horticulture, Orissa University of Agriculture and Technology, Bhubaneswar and experimental observations were taken during the year 2009-10. The place is situated at $20^0 15'$N latitude and $85^0 52'$E longitude with an elevation of 25.9 m above the mean sea level and nearly 64 km west of the Bay of Bengal and coming under the warm and humid climatic condition. The mean air temperature varies from 25 to 37.17 ^{0}C in summer, 24.53 to 32.72 ^{0}C in rainy and 14.88 to 28.33 ^{0}C in winter seasons. The photograph of experimental greenhouse is shown in Fig. B.

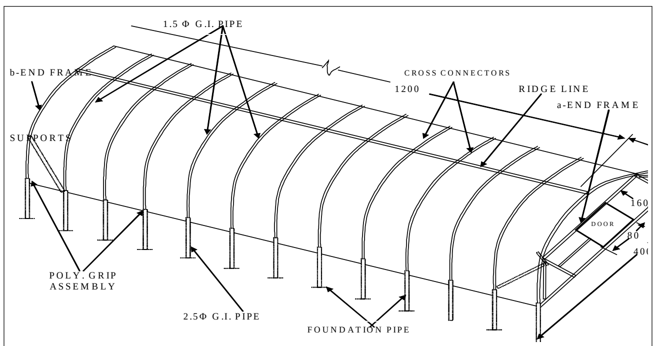

Fig. A: Semi cylindrical greenhouse

Fig. B : Experimental greenhouse

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Energy balance equation for a greenhouse:

The energy balance equations for various components of greenhouse with energy flow processes (Fig. 1) can be written on the basis of following assumptions:

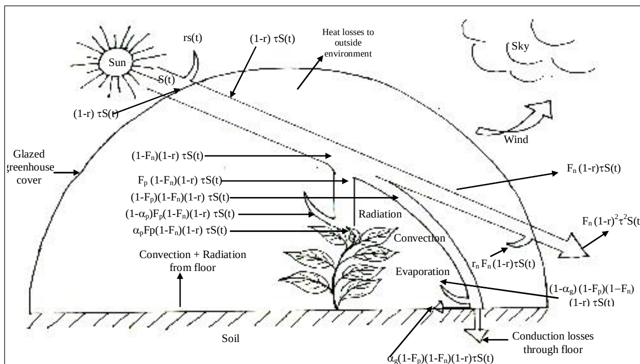

Fig. 1 : Cross sectional view of a greenhouse with energy flow at different components

– Analysis is based on quasi-steady state condition.

– Storage capacity of greenhouse cover materials is neglected.

– Absorptivity and heat capacity of air is neglected.

– Heat flow in the ground is one dimensional.

– Thermal properties of plants in the greenhouse are nearly same as those of water.

– There is no radiative heat exchange between the walls and roofs of greenhouse due to negligible temperature differences.

The energy balances for various components like plant mass, floor and air of greenhouse can be written as follows:

Greenhouse plant mass:

Rate of thermal energy absorbed by plant mass in the greenhouse	=	**Rate of thermal energy stored in the plant mass**	+	**Rate of thermal energy transferred from plants to greenhouse air**

Greenhouse floor:

Rate of thermal energy absorbed by the greenhouse floor	=	**Rate of thermal energy transferred from ground surface to greenhouse air**	+	**Rate of thermal energy conducted into the greenhouse floor**

Rate of thermal energy conducted into the ground is equal to the rate of overall heat transfer from floor to the higher depth of ground.

Rate of thermal energy retained in greenhouse air after absorption by	+	**Rate of thermal energy retained in greenhouse air after absorption in**	+	**Rate of thermal energy retained in greenhouse air after reflected from**				
+	**Rate of thermal energy transferred from plants to greenhouse air**	+	**Rate of thermal energy transferred from floor to greenhouse air**	=	**Rate of overall heat loss between greenhouse air and ambient air**	+	**Rate of thermal energy lost due to ventilation**	

Greenhouse enclosed air:

The above energy balances can be solved mathematically for determining the temperature of greenhouse air and plants (Das, 2010).

Computational procedure and input parameters:

The mathematical model formulated above can be solved with the help of the computer program. Numerical calculations can be made corresponding to the hourly variations of solar radiation and ambient air temperature for typical days of clear sunny days. Solar radiation falling on different walls and roofs of the greenhouse can be calculated with the help of Liu and Jordan formula by using the beam and diffuse components of solar radiation incident on the horizontal surface. The input parameters and design parameters can be used for experimental validation. Hourly variations of air and plant temperatures for greenhouse enclosure both during day time and night time can be recorded during experimentation. While studying the effects of parameters like infiltration/ventilation, relative humidity, heat capacity of plants, transmissivity of greenhouse cover, absorptivity of plant, plant area on the temperatures of air and plants inside the greenhouse, the single parameter is changed and others are kept constant. For analysis of thermal environment of greenhouse, quasi-steady state method is used. In order to verify the accuracy of the model, the predicted values of temperatures of air and plants inside greenhouse are validated against the experimental results for typical sunny days. The closeness of predicted and experimental values can be studied with the help of coefficient of correlation (r) and root mean square of per cent deviation (e).

Conclusion:

Thermal modeling of a controlled environment greenhouse is required to optimize the various parameters involved in either heating or cooling of greenhouse. The modeling can also be used to optimize greenhouse air temperature (one of the important constituents of the environment inside greenhouse) for maximum production of a crop from greenhouse for a given thermal capacity. Thermal modeling requires basic energy balance equation for different components of greenhouse system for a given climatic (solar radiation, ambient air temperature, relative humidity, wind velocity etc.) and design (volume, shape, height, orientation, latitude etc.) parameters. The thermal model can become a useful tool for designing a greenhouse and predicting its environmental parameters suitable for a plant in any climatic condition.

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