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*Full Length Research Paper*

# Thermal modeling and performance evaluation of arch shape greenhouse for nursery raising

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**This paper presents mathematical model for predicting thermal environment inside the arch shape greenhouse. Predicted thermal environment inside the greenhouse helped to select the crop nursery for growing inside the greenhouse. Actual thermal environment inside the greenhouse compared with predicted thermal environment. Experimental and predicted values of greenhouse temperature were almost same with variation of 2 to 3$^{o}$C.**

**Key words:** Arch shape greenhouse, mathematical model.

## INTRODUCTION

Open field agricultural practices have no control on the environment parameters such as sunlight, air composition and temperature that affect the plant growth. Hence a large number of winter vegetables, flowers and other horticultural crops and their nursery can not be grown locally during summer and have to be transported from distant places, same is true for summer crop during winter. Control of environment inside the greenhouse depends on outer environment. Plants hormonal activity depends on microclimatic environment inside the greenhouse. Hence before going to take nursery inside the greenhouse, more precise performance prediction of greenhouse environment to meet the physiological requirements for growth and development of plants (Georgios, 2001), systematic model is needed. The model should also take care of plant transpiration, evaporation from soil along with other heat transfer processes. It should also take care of effect of inside microclimate, ventilation and infiltration with ambient air while predicting inside climate (Wang et al, 2000).

For successful plantation programme, cuttings/seed must be raised first in nursery. Production of healthy seedlings is important where the planting stock is raised seed or cuttings and maintain for about some months (Thakur et al, 1993). Cultivation of nursery also improves the overall growth of plant substantially in terms of height and leaves as compare to outside condition, thus clear saving of 15 days in raising the nursery under green-house (Sethi et al, 2002). A study is therefore undertaken to find out the suitability of greenhouse by predicting the environment inside the greenhouse for nursery raising, where overall year round growth of seedling is very important.

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### MATERIALS AND METHODS

#### Description of arch shape greenhouse

A modified arch shape greenhouse was selected for cultivation of nursery as modified arch greenhouse performed better where cooling is required (Amita and Tiwari, 2002). An arch shaped greenhouse was designed covering a soil area of 13.4 x 6.00 m that is, 80 square meters as shown in Figure 1. Orientation is in East-West direction. The greenhouse was covered by ultra violet stabilized low-density ethylene sheet of 200-micron thickness.

#### Energy transfer mechanism

By considering the number of complexities of the heat and mass transfer mechanisms occurring in greenhouse (Garg, 1987) and

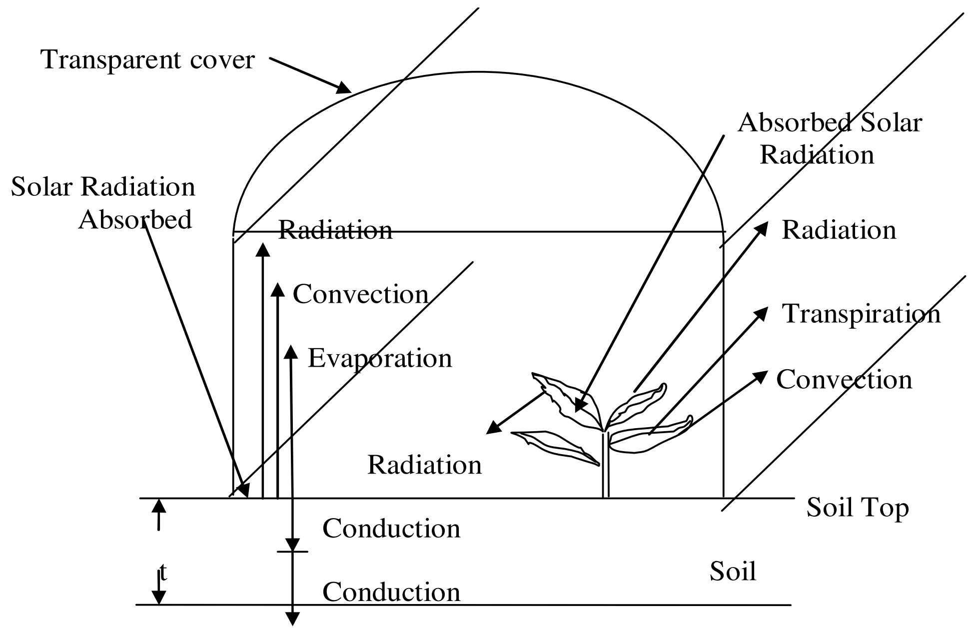


**Figure. 1** Energy transfer mechanism in greenhouse

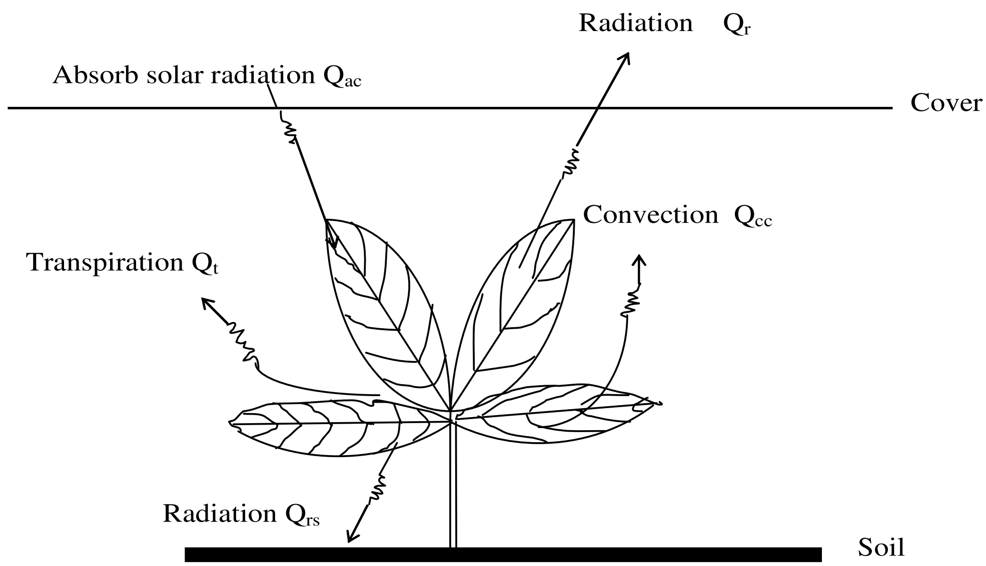


**Figure 2**. Energy transfer mechanism for plant

(Kaushick, 1988) (Figure 1), modeling the greenhouse as a single component is too cumbersome. Therefore, it could more rational approach to divide a greenhouse into separate components and model them independently. In view of above consideration, energy balance equations developed separately for the plant (Figure 2), Soil (Figure 3), greenhouse air and cover. The complete analysis has been described in the following sub-sections (Cooper and Fuller, 1983) by considering following assumptions.

(1) Greenhouse was oriented in E- W direction.
(2) No coefficient has been included to account for shading due to the structural members.
(3) The moisture was freely available at the surface of the soil for evaporation.
(4) The temperature of the top surface layer of the soil assumed to respond instantaneously to energy transfer mechanism. Edge loses were considered to be negligible compared with, those through the base of the soil.
(5)The temperature of inlet air through fan-pad at a pad assumed as dew point temperature. (6)The greenhouse air was well mixed at all times so that no temperature or moisture gradient existed in the air.
(7) The greenhouse is long enough in one direction to permit one-dimensional analysis of heat transfer.
(8) The greenhouse cover was thin enough so that heat transfer through it was essentially one-dimensional.

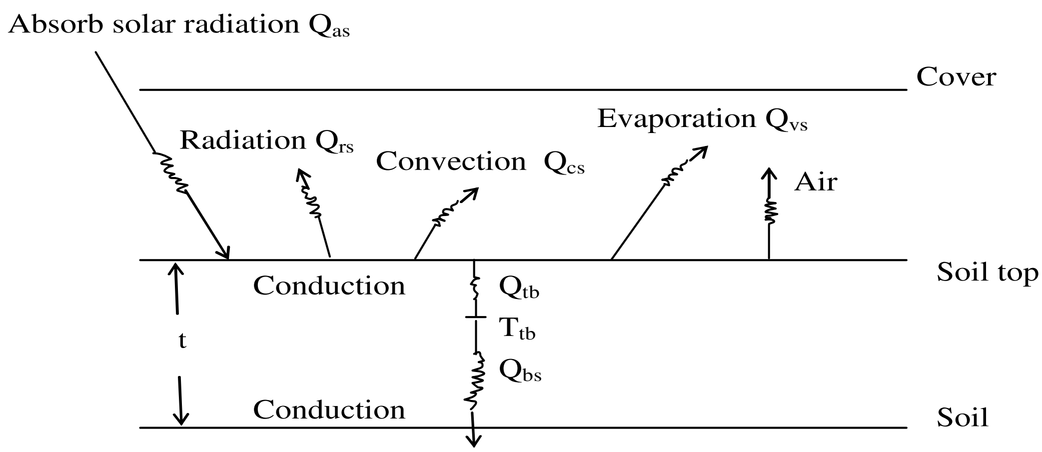


**Figure 3**. Energy transfer mechanism for soil

9) Heat 1oss from the soil to the ground was considered in a steady state.
(10) Thermal properties of materials of construction are time independent. The energy balance equations for the greenhouse soil, plant, greenhouse air and cover are discussed in following subsections.

**Under steady state conditions**

**Cover**

$Q_{aco} + Q_c + Q_{cps} + Q_{rpco} + Q_{rsco} = Q_{cco} + Q_{rcosky}$

**Greenhouse air**

$Q_{cpi} + Q_{cp} + Q_{cs} = Q_i + Q_{ve} + Q_h$

**Plant**

$Q_{ap} = Q_{pc} + Q_t + Q_{rs} + Q_{rpsky}$

**Soil**

$Q_{as} = Q_{cs} + Q_{vs} + Q_{rs} + Q_{tb}$

**Energy balance analysis**

The factor influencing the temperature and relative humidity of air inside greenhouse includes solar radiation, ambient temperature, plant respiration, photosynthesis, photo transpiration, thermal exchange between the greenhouse and its surrounding, conduction through greenhouse soil, ventilation, infiltration etc. On account of number and complexity of heat and mass transfer mechanism occurring within the greenhouse, mathematical models have been developed to predict the hourly variation in greenhouse environment i.e. temperature of cover, enclosed air, plants and soil surface and relative humidity of enclosed air for operating condition. The energy balance equations for using finite difference technique and result solved different components of the system were obtained by using computer programme prepared in FORTRAN -77 and Microsoft Office Excel. Solarimeter and data logger for comparison with model observations also took inside and outside the greenhouse actual experimental observation of solar radiation and ambient temperature.

**Cover**

The energy received by the cover is the amount of solar radiation absorbed by the cover, convection heat transfer between cover and greenhouse air, energy transferred due to condensation. The cover received heat by radiation heat transfer between cover and soil and cover and plant. The energy lost by the cover was due to the convection and radiation heat transfer between cover and ambient. The energy balance equation at cover can be written as.
Energy stored by the cover = Energy received by cover-Energy lost by cover.

$$M_{co}\ C_{co}\ dT_{co}/\ dt = I_{co}\ A_{co}\ \alpha_{co} + A_{co}h_{coa}(T_{gh} - T_{co}) + A_{co}(h_{coa}/1005)h_{sg}(W_{gh}-W_{co}) + A_p\ h_{rpco}\ (T_p - T_{co}) + A_{st}\ h_{rsco}\ (T_{st} - T_{co}) - A_{co}h_{coo}(T_{co} - T_a) + A_{co}\ h_{rcosky}\ (T_{co} - T_{sky}) \quad \text{--- (1)}$$

**Greenhouse air**

The energy received by greenhouse air is because of the heat transfer between cover, plant and soil due to convection and radiation. Heat lost by the greenhouse air is the energy lost through infiltration, ventilation and cooling devices. The energy balance equation for greenhouse air can be written as.

Energy stored in the greenhouse air = Energy received by greenhouse air-Energy lost by the greenhouse air

$$M_{gh}C_{gh}\ dT_{gh}/dt = h_{coa}\ A_{co}\ (T_{co} - T_{gh}) + h_{pa}\ A_p\ L_i(T_p-T_{gh}) + h_{sa}\ A_s\ (T_{st}-T_{gh}) - LVC_{pc}\ \rho_a\ (T_{gh} - T_a) - m_v\ C_{pa}\ (T_{gh}-T_a) - m_h\ C_{pa}\ (T_{gh}-T_h) \quad \text{---(2)}$$

**Plant**

Energy received by the plant is the amount of solar radiation absorbed by the plant. Energy lost by the plant is the heat transfer by convection from plant to greenhouse air and transpiration between plant and greenhouse air. Energy was also lost by radiation from plant to soil and plant to sky. The energy balance equation at plant can be expressed as:

Energy stored by the plant = Energy received by the plant-Energy lost by the plant

$$M_p C_p dT_p / dt = I_p \alpha_p A_p - h_{pa} A_p L_i (T_p - T_{gh}) - k_t L_i A_p (W_p - W_{gh}) h_{sg} - h_{rps} A_p (T_p - T_{st}) - h_{rpsky} A_p (T_p - T_{sky}) \quad \text{---(3)}$$

**Soil**

Energy received by the soil is the amount of solar radiation absorbed by the soil. The energy lost from the soil include the heat transfer due to convection soil from soil to the greenhouse air, due to evaporation from soil to greenhouse air, radiation heat transfer from soil to greenhouse air and conduction heat transfer between soil and sink. The energy balance equation at soil can be written as.

$$M_s C_s dT_s / dt = \alpha_s I s A_s - h_{sa} A_s (T_{st} - T_{gh}) - h_{ds} h_{sg} (W_{st} - W_{gh}) A_s - h_{rsc} A_s (T_{st} - T_p) - \frac{kA_s}{t} (T_{st} - T_{sb}) \quad \text{---(4)}$$

**Humidity ratio**

For determining $W_{co}$, $W_p$, $W_{st}$ ,$W_{gh}$ saturation conditions can be assumed at the cover, leaf and soil surfaces. From psychrometric relations various humidity terms can be written as follows.

$$W_{co} = 0.622 \times \frac{P_{sco}}{P - P_{sco}} \quad \text{--- (5)}$$

$$W_p = 0.622 \times \frac{P_{sp}}{P - P_{sp}} \quad \text{--- (6)}$$

$$W_{st} = 0.622 \times \frac{P_{sst}}{P - P_{sst}} \quad \text{---(7)}$$

The mass balance equation for the greenhouse air could be written as:

$$W_{gh} = 0.622 \times \phi \times \frac{P_{sgh}}{P - P_{sgh}} \quad \text{---(8)}$$

Where $\phi$ is the relative humidity inside the greenhouse.

The comparisons of different expressions developed by various researchers for calculating saturation vapour pressure corresponding to different temperatures were made with the steam table (Tiwari and Goyal 1998).

According to this expression, vapour pressure at saturation at cover, plant, soil and greenhouse air temperature could be given by

$$P_{sco} = 6894.76 \exp \left[51.59 - \frac{6834.3}{T_{co} + 273.15} - 5.17 \ln(T_{co} + 273.15)\right] \quad \text{---(9)}$$

$$P_{sp} = 6894.76 \exp \left[51.59 - \frac{6834.3}{T_{sp} + 273.15} - 5.17 \ln(T_{sp} + 273.15)\right] \quad \text{---(10)}$$

$$P_{sst} = 6894.76 \exp \left[51.59 - \frac{6834.3}{T_{st} + 273.15} - 5.17 \ln(T_{st} + 273.15)\right] \quad \text{---(11)}$$

$$P_{sgh} = 6894.76 \exp \left[51.59 - \frac{6834.3}{T_{gh} + 273.15} - 5.17 \ln(T_{gh} + 273.15)\right] \quad \text{---(12)}$$

The actual vapour pressure in the greenhouse was determined by HORTITRANS model (Jolliet, 1994).

$$P_{gh} = \frac{\upsilon a I + h_t P_{sgh} + h_v P_{so}}{h_t + h_c + h_v}$$

The relative humidity inside the greenhouse can be determined by

$$\phi = \frac{P_{gh}}{P_{sgh}} \text{ X } 100$$

$$a = c_1 \ln(1 + c_2 L_i^{c_3})$$

$$h_t = c_4 L_i (1 - c_5 e^{(-I/c_6)})$$

$$h_v = \rho_a C_{pa} \frac{q}{A}$$

**Finite difference method**

The expression for cover temperature can be written as

$$T_{co} = \frac{1}{D_4} [T_{st} A_4 + T_{gh} B_4 + T_p C_4 + E_4 + A_{co}(h_{coa}/1005) h_{sg} (W_{gh} - W_{co})] \quad \text{---(13)}$$

Where,
$A_4 = A_{st} h_{rsco}$
$B_4 = A_{co} h_{coa}$
$C_4 = A_p h_{rpco}$
$D_4 = A_{co} h_{coa} + A_c h_{rcco} + A_p h_{rpco} + A_{co} h_{coo} + A_{co} h_{rcosky}$
$E_4 = I_{co} A_{co} \alpha_{co} + T_a A_{co} h_{coo} + T_{sky} A_{co} h_{rcosky}$

The expression for greenhouse air temperature can be written as

$$T_{gh} = \frac{1}{B_3} [T_{st} A_3 + T_c C_3 + T_{co} D_3 + E_3] \quad \text{--- (14)}$$

Where,
$A_3 = h_{sa} A_s$
$B_3 = h_{coa} A_{co} + h_{pa} A_p L_i + h_{sa} A_s + LVC_{pc} \rho_a + m_v C_{pa} + m_h C_{pa}$
$C_3 = h_{pa} A_p L_i$
$D_3 = h_{coa} A_{co}$
$E_3 = T_a (LVC_{pc} \rho_a + m_v C_{pa}) + T_h (m_h C_{pa})$

The expression for greenhouse plant temperature can be written as

$$T_p = \frac{1}{C_2} [T_{st} A_2 + T_{gh} B_2 + E_2 - k_t L_i A_p (W_p - W_{gh}) h_{sg}] \quad \text{---(15)}$$

Where,
$A_2 = h_{rps} A_p$
$B_2 = h_{pa} A_p L_i$
$C_2 = h_{pa} A_p L_i + h_{rps} A_p + h_{rpsky} A_p$
$E_2 = I_p \alpha_p A_p + h_{rpsky} A_p T_{sky}$

Equation could be simplified for soil temperature as

$$T_{st} = \frac{1}{A_1} [ T_{gh} B_1 + T_p C_1 + E_1 - h_{ds} h_{sg} (W_{st} - W_{gh}) A_s] \qquad \text{---(16)}$$

Where

$A_1 = h_{sa} A_s + h_{rsp} A_s + \frac{kA_s}{t}$
$B_1 = h_{sa} A_s$
$C_1 = h_{rsc} A_s$
$E_1 = \alpha_s Is A_s - \frac{kA_s}{t} T_{sb}$

**Heat and mass transfer coefficients**

The convective heat transfer coefficient between ($h_{cogh}$) cover and greenhouse air, ($h_{sgh}$) ground and greenhouse air, ($h_{pgh}$) plant and greenhouse air, ($h_{coa}$) cover and ambient air. The radiative heat transfer coefficient between ($h_{rpco}$) plant and cover, ($h_{rsco}$) ground and cover, ($h_{rcosky}$) cover and sky, ($h_{rps}$) ground and plant. The mass transfer coefficient ($h_{ds}$) is obtained by using Lewis relation (Cooper and Fuller, 1983) and given in following section.

Natural convective heat transfer between cover and ambient

$h_{coa} = 2.8 + 3.8 W$

Forced heat transfer between Cover, Ground, plant and greenhouse air

$h_{cogh/pgh/sgh} = k Nu/R$

Where,
K = Constant
$Nu = 0.664 Re^{0.5} Pr^{0.3}$
$Re = \rho VR/\mu$

Various radiative heat transfer coefficient (Swinbank, 1963) and (Kothari et al., 2006) are given as follows.

**Cover and sky**

$$h_{rcosky} = \frac{\sigma (T_{co}^2 + T_{sky}^2)(T_{co} + T_{sky})}{\frac{1}{\varepsilon_{co}} - 1}$$

Where,
$T_{sky} = 0.0552(Ta)^{1.5}$

**Plant and cover**

$$h_{rpco} = \frac{\sigma (T_p^2 + T_{co}^2)(T_p + T_{co})}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{co}} - 1}$$

**Soil and cover**

$$h_{rsco} = \frac{\sigma (T_{st}^2 + T_{co}^2)(T_{st} + T_{co})}{\frac{1}{\varepsilon_s} + \frac{1}{\varepsilon_{co}} - 1}$$

**Plant and sky**

$$h_{rpsky} = \frac{\sigma (T_p^2 + T_{sky}^2)(T_p + T_{sky})}{\frac{1}{\varepsilon_p} - 1}$$

**Plant and soil**

$$h_{rps} = \frac{\sigma (T_p^2 + T_{st}^2)(T_p + T_{st})}{\frac{1}{\varepsilon_c} + \frac{1}{\varepsilon_{st}} - 1}$$

**Soil and plant**

$$h_{rsc} = \frac{\sigma (T_{st}^2 + T_c^2)(T_{st} + T_c)}{\frac{1}{\varepsilon_{st}} + \frac{1}{\varepsilon_c} - 1}$$

**Mass transfer coefficient**

The mass transfer coefficient, $h_{ds}$ is obtained by using the Lewis relation.

$$h_{ds} = \frac{heat \text{ transfer coefficient}}{\text{specific heat of air}} \cong \frac{h_{sa}}{1005}$$

An approximate value for the latent heat of vaporisation $h_{fg}$ can be obtained from the expression [7] obtained by curve fit to data from standard tables and can be expressed as:

$h_{sg} = 3161.36 - 2.406 T_{st}$

**Input parameters**

The hourly ambient temperatures, solar radiation (Mani and Rangarajan, 1981) and humidity for typical winter day for December and summer day for May for Udaipur were considered for numerical calculations.

Temperatures of greenhouse soil, plant, air and cover can be calculated with the help of equations 5 to 16, specification and properties use in Table 1, at any time under steady state conditions.

## RESULTS AND DISCUSSION

### Effect of radiation on greenhouse air temperature

The results showing the increase in greenhouse air temperature over ambient temperature corresponding to different solar radiation have been presented in this sec-

**Table 1.** Specification and properties used for modeling.

| Parameter | Values | Unit |
|---|---|---|
| Length of greenhouse (L) | 13.4 | meter |
| Thickness of polythene | 200 | micron |
| Absorptivity of cover ($\alpha_{co}$) | 0.25 | Dimensionless |
| Transmitivity of cover ($\tau_{co}$) | 0.75 | Dimensionless |
| Density of polythene ($\rho_{pe}$) | 1150 | Kg/m$^3$ |
| Specific heat of cover ($C_{co}$) | 2302 | J/Kg $^0$C |
| Emissivity of cover ($\varepsilon_{co}$) | 0.9 | Dimensionless |
| Specific heat of air (Ca) | 1005 | J/Kg $^0$C |
| Thermal conductivity of air (Ka) | 0.028 | W/m$^2$ $^0$C |
| Density of air ($\rho_a$) | 1.2 | Kg/m$^3$ |
| Specific heat of plant ($C_p$) | 3190 | J/Kg $^0$C |
| Emissivity of plant ($\varepsilon_p$) | 0.5 | Dimensionless |
| Specific heat of soil (Cs) | 2300 | J/Kg $^0$C |
| Density of soil ($\rho_s$) | 1250 | Kg/m$^3$ |
| Absorptivity of soil ($\alpha_s$) | 0.80 | Dimensionless |
| Emissivity of soil ($\varepsilon_s$) | 0.05 | Dimensionless |
| Wind velocity (W) | 5 | Km/h |
| Area of ventilation ($A_{vent}$) | 0.09 | m$^2$ |
| Stefan-Boltsman constant ($\sigma$) | 5.67 x 10$^{-8}$ | W/m$^2$ K$^4$ |
| Prandtl Number (Pr) | 0.7 | Dimensionless |
| Atmospheric pressure ($P_{atm}$) | 101.325 | Kg/m$^2$ |

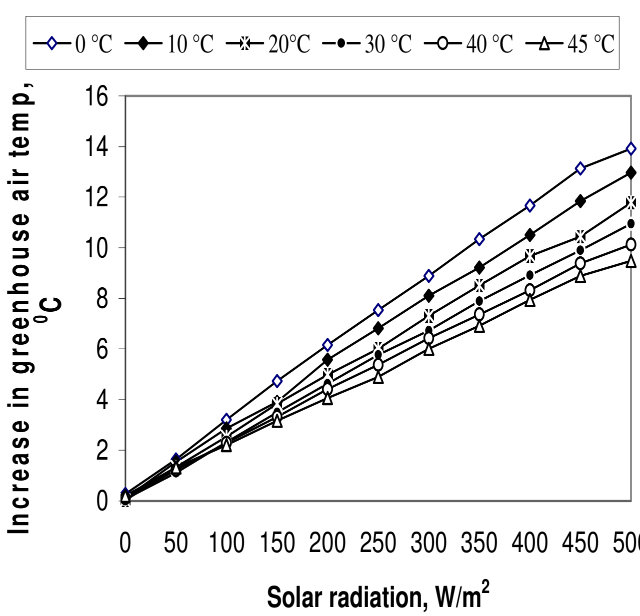


**Figure 4.** Increase in greenhouse air temperature with solar radiation.

tion. The calculations was carried out for different values of ambient temperature viz. 0, 10, 20, 30, 40 and 45$^o$C.

The increase in greenhouse air temperature over ambient temperature corresponding to solar radiation transmitted was calculated and plotted for different values of ambient temperature in Figure 4. It is clear that the greenhouse temperature was highly influenced by the solar radiation. The increase in greenhouse temperature over ambient temperature was more with increase in radiation. This increase in temperature was more if the ambient temperature was less and the increase was less if ambient temperature was more. During no radiation period the increase in greenhouse temperature over ambient temperature was negligible. The maximum increase in greenhouse air temperature was 13.92$^o$C for a solar radiation of 500 W/m$^2$ with 0$^o$C ambient temperature (Kothari et al, 2006). Above results indicates that under cold and sunny climate we could cultivate those crops inside the greenhouse which cannot be grown outside the greenhouse at low temperature.

## Effect of ambient temperature on greenhouse air temperature

The results showing the increase in greenhouse air temperature over ambient temperature corresponding to different ambient temperatures have been presented in this section. The calculations was carried out for different values of solar radiation viz. 0, 100, 200, 300, 400 and 500 W/m$^2$.

In Figure 5 the increase in greenhouse air temperature over ambient temperature corresponding to ambient temperature was plotted for different values of solar radiation. It is clear that for most of solar radiation values of solar radiation the increase in greenhouse air temperature over ambient temperature decreases with the increase in ambient temperature.

## Prediction of microclimate inside the greenhouse for Udaipur condition

The hourly values of greenhouse temperatures were calculated by finite difference method. The microclimate inside the greenhouse was predicted for the climatic data of Udaipur. For this, whole year was assumed to be represented by 12 monthly average days for which the hourly data of solar radiation and ambient air temperatures were taken from the actual reading for performance of greenhouse.

The hourly values of soil temperature, plant temperature, greenhouse air temperature and cover temperatures calculated by finite difference method for typical days of different months for Udaipur climate. The hourly values indicate that there was an appreciable increase in greenhouse soil and plant temperature as compared to

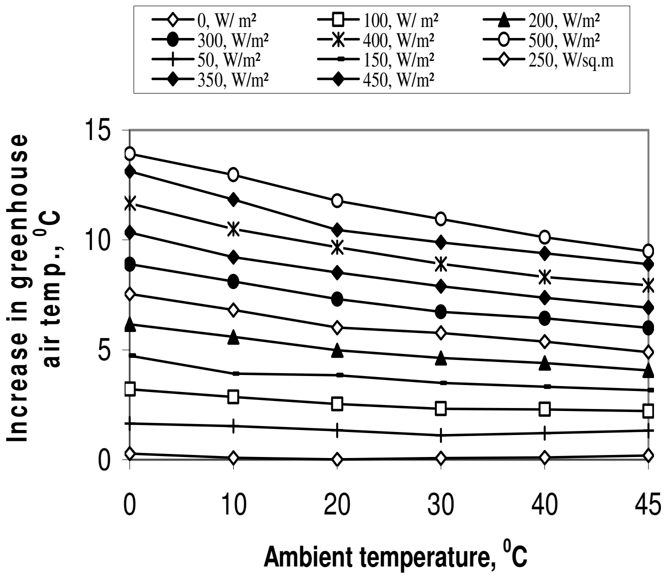


**Figure 5.** Increase in greenhouse air temperature with ambient temperature.

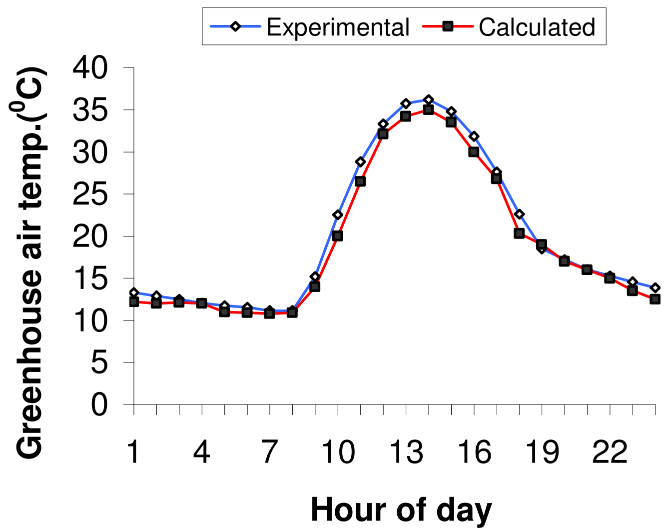


**Figure 6.** Comparison of theoretical and experimental values of greenhouse air temperature for the month of December at Udaipur.

outside condition in winter. The increase in greenhouse air temperature above ambient temperature is up to 15°C more over ambient temperature during sunshine hours. Cover temperature, Soil temperature, plant temperature and greenhouse temperature shown in Table 2. It is evident that there was an appreciable increase in greenhouse temperature during daytime as compared to ambient temperature. The increase in greenhouse air temperature above ambient temperature varies approximately from 4 to 15°C corresponding to low and high values of solar radiation respectively.

Based on these results it could be concluded that temperature conditions inside the greenhouse could be improved and it is possible to propagate the nursery inside the greenhouse, which could not be grown under low temperature condition outside the greenhouse.

## Comparison with experimental observation

Values of greenhouse air temperature on typical day for the month of December 2006 were measured at an experimental site. The measured values of solar radiation and ambient temperature were used as input data in computer programme developed for calculating hourly values of greenhouse temperature by finite difference method. The calculated values of the hourly greenhouse air temperature along with experimental results have been presented in Figure 6 for the month of December. Experimental and calculated values of greenhouse temperature were almost same with variation of 2 to 3°C (Kothari et al., 2006). It may be inferred from these results that the theoretical values were in reasonably good agreement with the experimental results. Therefore, the mathematical model could be used to predict temperature conditions inside the greenhouse for a variety of climatic parameters.

## Conclusions

- Condition with highest solar radiation with lowest ambient temperatures, raise in greenhouse air temperature is higher than the condition with lowest solar radiation with highest ambient temperatures.
- The parametric study reveals that maximum increase in greenhouse air temperature was 13.92°C for solar radiations of 500 $W/m^2$ and 0°C ambient temperatures.
- Experimental and predicted values of greenhouse temperature were almost same with variation of 2 to 3°C.
- The mathematical model could be used to predict temperature conditions inside the greenhouse for a variety of climatic parameters.

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**Table 2.** Hourly variation in greenhouse cover, floor, crop and greenhouse temperatures for the month of March at Udaipur.

| Hour of the day | Ambient Temperature ($^0$C) | Solar radiation W/m$^2$ | Cover Temperature ($^0$C) | Floor Temperature ($^0$C) | Crop Temperature ( $^0$C) | Greenhouse Temperature ( $^0$C) |
|---|---|---|---|---|---|---|
| 1 | 15.5 | 0 | 20.4 | 20.65 | 20.53 | 20.53 |
| 2 | 14.9 | 0 | 20.7 | 20.94 | 20.82 | 20.8 |
| 3 | 14.4 | 0 | 20.11 | 20.35 | 20.23 | 20.21 |
| 4 | 13.7 | 0 | 19.61 | 19.86 | 19.73 | 19.7 |
| 5 | 13.3 | 0 | 18.92 | 19.17 | 19.04 | 19.02 |
| 6 | 12.8 | 1 | 18.52 | 18.78 | 18.65 | 18.63 |
| 7 | 17 | 65 | 18.06 | 18.34 | 18.2 | 18.29 |
| 8 | 18 | 259 | 19.47 | 21.15 | 20.36 | 20.57 |
| 9 | 20.3 | 473 | 24.89 | 29.64 | 27.43 | 27.55 |
| 10 | 22.8 | 653 | 31.76 | 39.04 | 35.63 | 35.58 |
| 11 | 24.9 | 778 | 37.02 | 45.96 | 41.74 | 41.58 |
| 12 | 26.3 | 842 | 40.74 | 50.58 | 45.9 | 45.66 |
| 13 | 27.2 | 844 | 42.72 | 52.85 | 48.01 | 47.72 |
| 14 | 33.2 | 769 | 43.21 | 53.08 | 48.36 | 48.02 |
| 15 | 28.1 | 635 | 42.24 | 51.2 | 46.92 | 46.58 |
| 16 | 27.9 | 458 | 40.1 | 47.59 | 44.03 | 43.68 |
| 17 | 27.6 | 249 | 36.74 | 42.2 | 39.62 | 39.31 |
| 18 | 26.4 | 64 | 33.01 | 36.05 | 34.62 | 34.39 |
| 19 | 24.5 | 1 | 29.35 | 30.46 | 29.95 | 29.8 |
| 20 | 22.9 | 0 | 26.49 | 26.74 | 26.63 | 26.56 |
| 21 | 21.8 | 0 | 24.87 | 25.1 | 24.99 | 24.94 |
| 22 | 21 | 0 | 23.78 | 24.01 | 23.9 | 23.86 |
| 23 | 20.2 | 0 | 22.98 | 23.22 | 23.1 | 23.07 |
| 24 | 18.4 | 0 | 22.19 | 22.42 | 22.31 | 22.23 |

**Abbreviations:** A -Area, m2; As, Aco, Ap - soil, cover and plant area; C - Specific heat, J/kg 0C; C1-C6 Coefficient of equation; Cpa Cpp - Specific heats of greenhouse air and plant; h - Heat transfer coefficient, W/m2$^0$C; hdshe - Mass transfer coefficient for floor; hrpco, hrsco, hrcosky - Radiative heat transfer between plant to cover, soil to cover and cover to sky; hrpsky - Radiative heat transfer between plant and sky; hpa, hcoa, hcoo – Convective heat transfer coefficients between crop and greenhouse air, cover and greenhouse air, cover and ambient; has - Convective heat transfer between floor and greenhouse air; hsg - Latent heat of evaporation, kJ/kg; ht - Coefficient of heat transfer for transpiration; hv - Coefficient of heat transfer for ventilation; Is, Ip, Ico - Solar radiation on soil, plant and cover; k - Thermal conductivity of floor; L - Length of greenhouse; Li -Leaf area index; mh-Mass flow rate out of cooling/ dehumidifying device; mv - Mass flow rate due to natural or forced venting with ambient air; Nu - Nusalt Number; P - Vapour pressure of outside air; Pgh -Vapour pressure inside greenhouse; Psco, Pdst, Psc -Saturation vapour pressure at cover, floor and crop temperature; Qap, Qaco, Qas -Energy absorbed by crop, cover and floor from solar radiation; Qbs-Energy transferred by conduction; Qc -Energy transfer by condensation; Qcp, Qcs, Qcps - Energy transfer by convection between plant, soil and Plant and soil; Qcco, Qccs - Energy transfer by convection between cover and cover and soil ; Qh, Qi-Energy transfer due to cooling device and infiltration; Qpci, Qpc, Qps -Energy transfer by convection between plant and infiltration, plant and soil and greenhouse air; Qr, Qrs- Energy transfer by radiation between plant and ambient and between soil and plant; Qrpco, Qrsco-Energy transfer by radiation between plant and cover and between soil and cover; Qrcosky, Qrpsky -Energy transfer by radiation between cover and skay and plant and sky; Qt; Energy transfer by plant transpiration; Qtb - Energy transfer by conduction between top surface layer and main mass of soil; Qve - Energy transfer due to ventilation with ambient air; Qvs-

Energy transfer due to evaporation from soil ; r – Radius; Re - Reynolds Number; Tp - Plant temperature; t - Thickness of soil; Ttb, Tst - Temperature of toplayer of soil and temperature of top layer and soil sink; Ta, Tp, Tco - Ambient, plant and cover temperature; Tsb, Tst, Tgh -Soil sink, soil and greenhouse temperature; v - Psychrometric constant; V- Wind velocity; w - Fraction of floor with free water available for evaporation; Wp, Wco - Absolute humidity ratio of plant and cover; wdi - Diffuse radiation on greenhouse floor; Wst, Wgh - Saturated air at plant, cover, soil and greenhouse air temperature; αp , αco, αs - Plant, cover and floor absorbance; εp, , εst - Plant and floor emittance.

**REFERENCES**

Amita G, Tiwari GN (2002). Performance Evaluation of Greenhouse for Different Climatic Zones of India. J. Solar Energy Soc. India 12(1): 45-57.

Cooper PI, Fuller RJ (1983). A Transient Model of the Interaction Between Crop, Environment and Greenhouse Structure for Predicting Crop Yield and Energy Consumption'. J. Agric Eng Res. 28: 401-417.

Garg HP (1987). Advances in solar Energy Technology Vol. 3: Heating, Agricultural and Photovoltac Application of Solar Energy'. D Reidel Publishing Co, Holland.

Georgios K. Spanomitsion (2001). Temperature Control and Energy Conservation in a plastic greenhouse. J. Agric Eng. Res. 80(3): 251-259.

Jolliet O (1994). A Model for Predicting and Optimizing Humidity and Transpiration in Greenhouse, J. Agric Eng. Res. 57: 23-37.

Kaushick SC (1988). Thermal Control in Solar Passive Building'. Geo-Environ Academic Press, IBT Publisher, New Delhi.

Kothari S, Kaushick SC, Mathur AN (2006). Greenhouse Technology for Protected Cultivation a Text Book, Khana Publication, Udaipur.

Mani A, Rangarajan S (1981). Solar radiation Over India. Allied Publisher, New Delhi.

Sethi VP, Tarsem lal, Gupta YP, Hans VS (2002). Effect of Greenhouse Environment on the Germination and Growth of Plants, Agric. Eng. Today, 26 (1-2): 24-29.

Swinbank WC (1963). Longwave Radiation from Clear Skies, Qurt. J. Roy Metrorol Soc. 89: 539.

Thakur ML, Thakur RK (1993). Forest protection in arid zones, problem and research priorities. In aforestation of arid lands (Edited by Dwivedi AP, Gupta GN). Scientific Publisher, Jodhpur, pp. 511-521.

Tiwari GN, Goyal RK (1998). Greenhouse Technology, Narosa Publishing House New Delhi, India.

Wang S, Boulard T (2000). Predicting the microclimate in Naturally ventilated plastic House in a meditarranean climate. J. Agric. Eng. Res. 75(1): 27-38.