Temperature Profile Study of Selected Natural Ventilated Greenhouses and Development of Temperature Prediction Models

ABSTRACT:

In India because of the least expensive cooling method of greenhouse, natural ventilated types of greenhouses are considered to be the most acceptable structures for growing of vegetable and flower crops. In natural ventilated greenhouse, the inside air temperature is affected by its geometrical dimensions, span, orientation, ventilation rate etc. In the present study, efforts have been made to study the diurnal variation of inside air temperature during January to April months for three different types of natural ventilated greenhouses constructed at Junagadh Agricultural University campus From the study it was found that for Type-I, Type-II and Type-III greenhouses, inside air temperature was varied from 13.52^{0}C to 35.13^{0}C, 11.54^{0}C to 36.87^{0}C and 12.43^{0}C to 31.59^{0}C respectively for January month 14.88^{0}C to 38.87^{0}C, 16.31^{0}C to 35.90^{0}C, 13.21^{0}C to 33.40^{0}C for February month, 16.83^0 C to 27.97^{0}C, 24.4 to 46.62^{0}C, 20.44^{0}C to 46.62^{0}C, 20.57^{0}C to 41.35^{0}C for March month respectively. In April month it was found to be 22.31^{0}C to 48.80^{0}C, 22.17^{0}C to 43.40^{0}C for type-II and type-III in April month respectively. The variation in average ventilation rate per minute from January to April

months were observed to be 1.7 to 1.9, 2.0 to 2.3 and 2.1 to 2.5 respectively for type-I, II and III. The mathematical models developed for soil bed and pot cultivation conditions using the energy balance equations and comparison of predicted temperature values with measured data has shown good fitting to the pattern of diurnal variation of weekly average temperatures for all the three types of greenhouses. The maximum fitting efficiency of the models was found as 94%, 77% and 98% for type-I, II and III respectively.

INTRODUCTION

The primary purpose of greenhouse ventilation is to prevent excessive rise of temperature and humidity and in some cases, it is applied to prevent CO_2 depletion due to the crop photosynthesis and non adequate air exchange between the greenhouse and the environment. At the same time, ventilation can also reduce the concentration of pollutant gases (e.g., toxic gases generated by incomplete combustion in a heating system). Furthermore, ventilation is important since it generates air movement within the greenhouse and thus reduces the boundary layer thickness near the leaves. This improves sensible and latent heat transfers from the crop to the greenhouse air and enhances CO_2 transfer to the leaves. The least expensive method used in greenhouse to prevent excessive temperatures is natural cooling which is more popular at the places having moderate climate. The main advantages of natural ventilation are that it does not require investment for ventilation and electrical equipments and their maintenance. No problems created by “brown-outs” or “black-outs”, caused by storms or insufficient generation capabilities. Also as the cost of energy and likelihood of power failures increase, the natural ventilation systems become more desirable. But at places having temperate climate, as the temperature in summer is very high, the inside temperature of greenhouse cannot be controlled only by natural ventilations. Also care must be taken while selecting site for naturally ventilated green house keeping in mind the direction and velocity of the wind. One of the major assets of a good grower is the ability to maintain an "optimum" growing temperature. The

The advantages of simulation techniques in greenhouse environment prediction is three folds (i) It is more flexible and versatile to researchers in constructing a fairly realistic model of the temperature response for raising nurseries and simulating the response of the system. (ii) It requires less field data regarding physical characteristics of the system and response of the system can be analyzed by changing any coefficients. (iii) It enables the decision maker to examine the consequences of various scenarios of an existing system or new system without actually building it. So, for installation of greenhouse it becomes very necessary to know the different climatic conditions. Otherwise after installation it may not be possible to maintain desired inside temperature. So, a model is desired that can give us an exact prediction for the installation of greenhouse for different climatic conditions under natural ventilation. With help of this model just by giving the values of different climatic parameters of that place we can know the inside conditions of greenhouse.

The cooling performance of the natural ventilated greenhouse is mainly affected by the greenhouse geometrical dimensions, vent's windward area, span and orientation of greenhouse etc. In the present study, efforts were made to analyze the effect of natural ventilation on inside air temperature during winter and summer season i.e. January to April months for three selected naturally ventilated greenhouses and to develop mathematical models for prediction of inside temperature to help investigators to examine the variation in inside temperature for different location without actually building such types of greenhouses.

Objectives:

1. To study the temperature profile for natural ventilated greenhouses

2. To evaluate diurnal variation in inside air temperature .

3. To study the different three greenhouse structure for inside air temperature

4. To predict inside air temperature with temperature prediction modelin

THEORATICAL ANALYSIS

1. DEVELOPMENT OF MATHEMATICAL MODELS:

The energy and mass balance equations and computer programme presented in annexure of the previous year's annual report were modified and written for different components of the greenhouses in natural ventilated condition viz; (a) Greenhouse cover (b) Greenhouse air (c) Plant canopy (d) Growing media (e) Floor surface layer and (f) Subsequent soil layers considering the following assumptions. The heat transfer in the analysis is assumed to be unsteady state. The mathematical models were developed by incorporating various input data in equations and inside environmental parameters for different sets of condition were generated. The theoretical results were plotted against experimental results for validation of the model. The input parameters considered for development of the models are presented in Table-4.1.

Assumptions:

1. Heat flow is one dimensional
2. The effect of shading due to structural members is negligible
3. Moisture is freely available at various surfaces for evaporation
4. Edge losses of greenhouse are negligible
5. 30 per cent plant leaf area and 70 per cent floor area receive only diffuse radiation and remaining direct radiation

6. During night the transpiration coefficient is assumed to be reduced to 10% of the normal sunshine hours value

2 ENERGY BALANCE EQUATIONS FOR DIFFERENT SETS OF CONDITIONS:

2.1 Plants Grown In Soil Beds (Type-II & Type-III)

Cover : $M_{co} C_{co} dT_{co}/dt = \alpha_{co} G A_{co} + A_{co} (h_{cogh}/C_{gh}) (W_{gh} - W_{co}) \lambda_{co} + A_{co} h_{cogh} (T_{gh} - T_{co}) + A_p h_{r,pco} (T_p - T_{co}) + A_s h_{r,cos} (T_{s(1)} - T_{co}) - A_{co} h_{coa} (T_{co} - T_a) - A_{co} h_{r,cosky} (T_{co} - T_{sky})$ (4.1)

Greenhouse air: $M_{gh} C_{gh} dT_{gh}/dt = A_{co} h_{cogh} (T_{co} - T_{gh}) + A_s h_{sgh} (T_{s(1)} - T_{gh}) + A_p Li\ h_{pgh}(T_p - T_{gh}) + A_p Li\ f \lambda_{gh} (W_{sp} - W_{gh}) + A_s (h_{sgh}/c_{gh}) (w_{s(1)} - W_{gh}) \lambda_s - H_{nv}$ (4.2)

Plant Canopy : $M_p C_p dT_p/dt = \alpha_p G_p A_p - A_p Li\ h_{pgh} (T_p - T_{gh}) - A_p Li\ f (W_{sp} - W_{gh}) \lambda_p - A_p h_{rsp} (T_p - T_s) - A_p h_{r,pco} (T_p - T_{co})$ (4.3)

Soil Surface layer : $M_s C_s (1-\varepsilon_s) dT_{s(1)}/dt + A_s K_s dT_{s(1)}/dh = \alpha_s G_s A_s - A_s h_{sgh} (T_{s(1)} - T_{gh}) - A_s h_{r,ps} (T_{s(1)} - T_p) - A_s h_{rcos} (T_{s(1)} - T_{co})$ (4.4)

Subsequent soil layers (j=2,n)

$M_s C_s (1-\varepsilon_s) dT_{s(j)}/dt = A_s K_s dT_{s(j)}/dh$ (4.5)

Relative Humidity of Greenhouse Air

$\Phi = W_{gh} P_{atm} / [(0.622 + W_{gh}) P_{s,gh}]$ (4.6)

The absolute humidity of greenhouse air in above equation was computed as

$M_{gh} W_{gh} /dt = A_p Li\ f (W_{sp} - W_{gh}) + A_{co} (h_{cogh}/C_{gh}) (W_{sco} - W_{gh}) + A_{s(1)} (h_{s(1)gh}/C_{gh}) (W_{s(1)} - W_{gh}) - E_{nv}$ (4.7)

2.2 PLANTS GROWN IN POTS USING GROWING MEDIA (TYPE-I)

For Cover : $M_{co} C_{co} dT_{co}/dt = \alpha_{co} G A_{co} + A_{co} (h_{cogh}/C_{gh}) (W_{gh} - W_{co}) \lambda_{co} + A_{co} h_{cogh} (T_{gh} - T_{co}) + A_p h_{r,pco} (T_p - T_{co}) + A_s h_{r,cos} (T_{s(1)} - T_{co}) - A_{co} h_{coa} (T_{co} - T_a) - A_{co} h_{r,cosky} (T_{co} - T_{sky})$ (4.8)

For Greenhouse air : $M_{gh} C_{gh} dT_{gh}/dt = A_{co} h_{cogh} (T_{co} - T_{gh}) + A_s h_{sgh} (T_{s(1)} - T_{gh}) + A_p Li h_{pgh}(T_p - T_{gh}) + A_p Li f \lambda_{gh} (W_{sp} - W_{gh}) + A_{gm} h_{gmgh} (T_{gm} - T_{gh}) + A_{gm} (hg_{mgh}/C_{gh}) (W_{sgm} - W_{gh}) \lambda_{gm} - H_{nv}$ (4.9)

Plant Canopy: $M_p C_p dT_p/dt = \alpha_p G_p A_p - A_p Li h_{pgh} (T_p-T_{gh}) - A_p Li f (W_{sp} - W_{gh}) \lambda_p - A_p h_{rsp} (T_p-T_s) - A_p h_{r,pco} (T_p-T_{co}) - A_p h_{r,pgm} (T_p - T_{gm})$ (4.10)

Growing Media : $M_{gm} C_{gm} (1-\varepsilon_{gm}) dT_{gm}/dt = \alpha_{gm} G_{gm} A_{gm} - A_{gm} h_{gmgh} (T_{gm}-T_{gh}) - A_{gm} (W_{sgm} - W_{gh}) \lambda_{gm} + A_{gm} h_{r,gmp} (T_p - T_{gm}) - A_{gm} h_{r,gmco} (T_{gm} -T_{co})$ (4.11)

Floor Surface layer : $M_s C_s (1-\varepsilon_s) dT_{s(1)}/dt + A_s K_s dT_{s(1)} /dh = \alpha_s G_s A_s - A_s h_{sgh} (T_{s(1)}-T_{gh}) - A_s h_{r,ps} (T_{s(1)} - T_p) - A_s h_{rcos} (T_{s(1)} -T_{co})$ (4.12)

Subsequent soil layers (j=2,n)

$M_s C_s (1-\varepsilon_s) dT_{s(j)}/dt = A_s K_s dT_{s(j)} /dh$ (4.13)

Relative Humidity of Greenhouse Air

$\Phi = W_{gh} P_{atm} / [(0.622 + W_{gh}) P_{s,gh}]$ (4.14)

The absolute humidity of greenhouse air in above equation was computed as

$M_{gh} W_{gh} / dt = A_p Li f (W_{sp} - W_{gh}) + A_{co} (h_{cogh}/C_{gh}) (W_{sco} - W_{gh}) + A_{gm} (h_{gmgh}/C_{gh})(W_{sgm} - W_{gh}) - E_{nv}$ (4.15)

In above equations, the heat loss (H_{nv}) and mass loss (E_{nv}) were calculated as

$$H_{nv} = Q\,\rho_a\,(t_{gh} - t_a) \quad \text{and} \quad E_{nv} = Q\,\rho_a\,(W_{gh} - W_a) \qquad (4.16)$$

The absolute humidity for saturation condition at cover, plant canopy, growing media and floor was computed as

$$W_{s,co} = 0.622\, P_{s,co}\,(P_{s,p},\, P_{s,s}) / (P_{atm} - (P_{s,co}\, P_{s,p},\, P_{s,s}) \qquad (4.18)$$

$$W_{s,gm} = 0.622 / (P_{atm} - P_{s,gm}) \text{ (Only for Type I greenhouse)} \qquad (4.19)$$

In above equations, the saturated vapour pressure at different components of greenhouse system was calculated as

$$P_{s,co} = 6894.76 \exp[54.63 - (12301.69/ T_{R,co}) - 5.17 \ln (T_{R,co})] \qquad (4.20)$$

$$P_{s,gh} = 6894.76 \exp[54.63 - (12301.69/ T_{R,gh}) - 5.17 \ln (T_{R,gh})] \qquad (4.21)$$

$$P_{s,p} = 6894.76 \exp[54.63 - (12301.69/ T_{R,p}) - 5.17 \ln (T_{R,p})] \qquad (4.22)$$

$$P_{s,gm} = 6894.76 \exp[54.63 - (12301.69/ T_{R,gm}) - 5.17 \ln (T_{R,gm})] \text{ (for only type-I)} \qquad (4.23)$$

$$P_{s,s} = 6894.76 \exp[54.63 - (12301.69/ T_{R,s}) - 5.17 \ln (T_{R,s})] \qquad (4.24)$$

In above equations, the heat of vaporization at cover, plant canopy, greenhouse air, growing media and floor temperature can be expressed as

$$\lambda_{co}/ \lambda_{gh} / \lambda_p/ \lambda_{gm}/ \lambda_s = 2500.78 - 2.3601\, T_{co} / T_{gh}/T_p/ T_{gm}/ T_s \qquad (4.25)$$

Computer programme was prepared in FORTRAN by using finite difference technique using energy balance equations considering finite difference technique.

2.3 MODEL EFFICIENCY: The efficiency of a model can be found by the following equation:

$$\frac{(X - \bar{X})^2 - (X - Y)^2}{(X - \bar{X})^2}$$

Where,
η = Model efficiency
x = Observed data_
x̄ = Mean of observed data Y = Predicted data

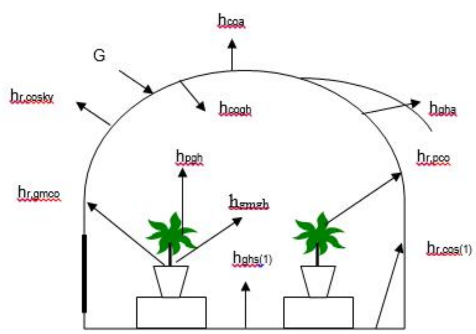

Fig. 1 The schematic veiw of various coefficients of heat transfer occurring at different components of the type-i greenhouse (plants grown in pot using growing media)

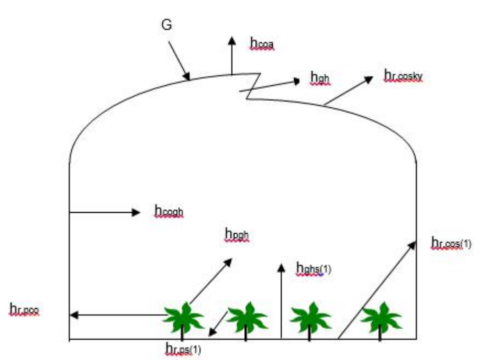

Fig. 2 The schematic view of various coefficients of heat transfer occurring at different components of the type-ii & type-iii (plants grown in soil bed)

METHODOLOGY

1. EXPERIMENTAL GREENHOUSE:

Type I: GI pipe framed gothic arc 70' x 30' x 18'(ridge height) greenhouse covered with 200 µ UVS yellowish anti dust, anti sulphur and anti condensation PE sheet. Two 48" size propeller type SS fans were installed at E side and 4" thick 6' x 30' size cooling pad was installed at west side. Devices /systems like co-axial fans, fogging, greenhouse benches and pots were also installed in the greenhouse. All cooling systems was connected with temperature-humidity sensor based locally designed and programmed PLC to control inside environment and save energy. Five mechanized push-up type vents each of 10' x 6' were designed and constructed at gutter height on southern side by using a common shaft operated by 0.25 hp gear motor with gears & square tooth rods arrangement and to control opening limit by the push-up tooth rods two limit switches are provided. Whereas, on opposite wall a manual curtain roll-up mechanism is provided. 50% light reduction black & white shading net was provided at eve height.

Type II: The experimental greenhouse of 70ft (L) x 30ft (W) x 21ft (H) gothic arc design covered with 200 micron thick UV stabilized yellowish plastic film. The greenhouse is equipped with ridge vent and all four side roll-up vents operated by 0.2 hp DC motors. The ridge vent of the size 231 ft^2 ($21.3m^2$) is along the length of greenhouse. Along the periphery side walls of the greenhouse at 4 ft high curtain type ventilators are provided that covers the1/4th floor area of the span. The full opening area of the side vents is 653 ft^2 ($61m^2$). All the ventilators were operated using motorized mechanism. The insect net is provided inside both the vents. 50% light reducing shade screen (net) at gutter height is provided to

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reduce the light level and thereby inside air temperature. The shade net opening and closing is done by using rack and pinion mechanism operated by 0.2 hp DC motor. The foggers are provided for cooling during extreme adverse condition.

TYPE-I GREEN HOUSES PHOTOS:

TYPE-II GREEN HOUSE PHOTOS:-


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Type III: The experimental greenhouse is 180ft (L) x 85ft (W) x 21 ft (H) gothic arc design. It is a multi span aero dynamic structure type of greenhouse with 6 spans in which each span is of 26ft x 80ft (8m x 24.5m) covered with 200 micron thick transparent diffuse light transmittance type UV stabilized LDPE sheet. The greenhouse consists of manually operated roller pipe arrangement for roll-up type vents in all four sides and open ridge vents. The size of ridge vents is 1292 ft^2 ($120m^2$). The full opening area of the side vents is 2067 ft^2 (192 m^2). The insect net is provided on vents and 50% light reducing shade screen (net) at gutter height is provided to reduce the light level and thereby inside air temperature. The shade net opening and closing is done by using rope and pulley mechanism operated manually. The foggers are provided for cooling during extreme adverse condition. Raised soil beds were used for crop cultivation in this type of greenhouse.

TYPE-III GREEN HOUSE PHOTO:

2. OPERATION OF GREENHOUSE TEMPRATURE CONTROL SYSTEM:

In type-I greenhouse, during the month of January the greenhouse was operated on ft^2 ($21.3m^2$) is along the length of greenhouse. Along the periphery side walls of the greenhouse at 4 ft high curtain type ventilators are provided that covers the1/4th floor area of the span. The full opening area of the side vents is 653 ft^2 ($61m^2$). All the ventilators were operated using motorized mechanism. The insect net is provided inside both the vents. 50% light reducing shade screen (net) at gutter height is provided to reduce the light level and thereby inside air temperature. The shade net opening and closing is done by using rack and pinion mechanism operated by 0.2 hp DC motor. The foggers are provided for cooling during extreme adverse condition. fully natural ventilation condition. Both the vents, i.e. gutter and side vents were kept fully open during whole period. This condition continued till half of the February. The treatment for without ventilation condition was kept during third week of February. So both vents were fully close for whole period. The treatment for shading with full opening of vents and half vents was given during 1st week of March.

In type-II greenhouse, for controlling the inside environment the regular practice was that during January to April the side vents were kept full open from morning 8:00 a.m. till evening 6:00 p.m. The side vents were kept closed from 6:00 p.m. to 8:00 a.m. in the morning. The ridge vents were also operated in the same manner as the side vents.

The side vents of Type-III greenhouse were also operated similarly as of type-II for controlling the inside environment. The ridge vents were kept open throughout 24 hours. The shading was done in this greenhouse from 10:00 a.m. to 6:00 p.m. and fogging was done for cooling during extreme adverse condition before flowering stage

3. MEASURMENT OF ENVIRONMENT PARAMETERS:

The environmental parameters like temperature, relative humidity, solar radiation and wind velocity for the duration January-08 to April -08 were obtained and measured. The hourly ambient environmental parameters like temperature, relative humidity, solar radiation and wind velocity for the duration January-08 to April -08 were obtained from Automatic Weather Station (AWS) installed at J.A.U., Junagadh. The daily measured data are converted to weekly and monthly basis.

RESULTS AND DISCUSSION:

1. AMBIRNT ENVIRONMENTAL DATA:

The diurnal variation in solar radiation, wind velocity, ambient temperature and relative humidity January' 2008 to April' 2008 were measured at Automatic Weather Station (AWS), Agronomy Instructional Farm, Junagadh Agricultural University, Junagadh. The data are presented in Table-2 were analyzed to obtain weekly and monthly average hourly data to use them in development of models.

2. GREENHOUSE ENVIRONMENT:

2.1 INSIDE AIR TEMPRATURE

The monthly average hourly temperatures (T_{gh}) for Type-I, Type-II and Type-III greenhouses during the study period were varied from 13.52^{0}C to 35.13^{0}C, 11.54^{0}C to 36-87^{0}C, 12.43^{0}C to 31.59^{0}C respectively for January month. 14.88^{0}C to 38.87^{0}C, 16.31^{0}C to 35.90^{0}C, 13.21^{0}C to 33.40^{0}C for February month, 16.83^{0}C to 27.97^{0}C, 20.44^{0}C to 46.62^{0}C, 20.44^{0}C to 46.62^{0}C, 20.57^{0}C to 41.35^{0}C for March month and NA, 22.31^{0}C to 48.80^{0}C, 22.17^{0}C to 43.40^{0}C respectively for April month. From data it can be seen that during January and February month the maximum Tgh was found lower in type-III as compared to other two types, may be because of larger expose area to the ambient and having larger greenhouse volume. During the month of March in type-I fan-pad cooling was started from 3rd week caused low value of Tgh maximum. In the month of April data were not recorded for this greenhouse as Fan-Pad cooling . Comparing the results of type-II and type-III for the month of March and April , it can be seen that Tgh is about 5^{0}C lower in type-III as compared to type-II.

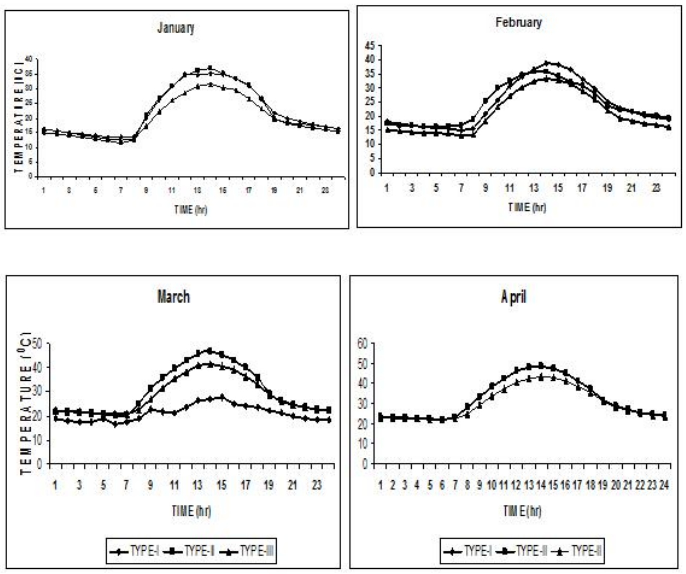


Fig.3 Diurnal variation of monthly average t_{gh} for different types of greenhouses

2.2. WEEKLY AVERAGE GREENHOUSE AIR TEMPRATURE (T_{gh})

January: During 1st to 4th week of January month in type-I greenhouse the T_{gh} was varied from 12.51^{0}C to 44.20^{0}C, 13.98^{0}C to 40.79^{0}C, 13.03^{0}C to 36.73^{0}C and 14.91^{0}C to 31.86^{0}C respectively during sunshine hours and from 11.84^0 C to 22.26^0 C, 13.65^0 C to 22.25^0 C, 12.96^0 C to 20.64^0 C and 14.49^0 C to 22.26 ^{0} C during off sunshine hours. During 4th week, fan and pad system was operated for last four days during 1:00 p.m. to 3:00p.m., which caused fall in T_{gh}. Similarly for type-II the above temperatures during 2nd to 4th week were observed to be 12.97^0 C to 40.07^0 C, 11.87^0 C to 34.41^0 C and 12.39^0 C to 36.13 ^{0} C whereas during off sunshine hours these were found to be 13.65^0 C to 22.25^0 C, 10.69^0 C to 18.16^0 C and 10.97^0 C to 18.91^0 C respectively. For type-III the Tgh during sunshine hours for respective weeks was varied from 13.73^0 C to 35.07^0 C, 12.16^0 C to 29.20^0 C and 12.16^0 C to 30.49^0 C respectively and from 11.87^0 C to 22.24^0 C, 13.44^0 C to 22.24^0 C, 13.44^0 C to 22.24^0 C and 13.44^0 C to 22.24^0 C respectively during off sunshine hours (Fig.4)

February: The diurnal variation in weekly average T_{gh} with ventilation for February month data are plotted in Fig. 5. It can be seen that during 1st to 4th week T_{gh} was varied from 12.60 ^{0} C to 32.45^0 C, 14.48^0 C to 37.29^0 C, 17.05^0 C to 43.65^0 C and 18.02^0 C to 42.84^0 C respectively during sunshine hours and 12.17^{o}C to 20.66^{o}C, 14.14 ^{o}C to 23.63^{o}C, 16.12^{o}C to 28.89^{o}C and 17.34^{o}C to 28.24^{o}C respectively during off sunshine hours . Data on variation in T_{gh} in Type-II (1st to 3rd week) and type-III (1 st to 4th week) for February month presented in above figure shows that during 1st, 2nd, and 3rd week T_{gh} was varied from 10.00^0 C to 33.16^0 C, 11.00^0 C to 37.06^0 C and 12.91^0 C to 42.61^0 C respectively whereas for type-III it was varied from 10.93^0 C to 28.73^0 C, 12.39^0 C to 32.24^0 C, from 13.41^0 C to 37.39^0 C and 15.10^0 C to 37.26^0 C respectively.

March: In type-I greenhouse from Fig. 6, it can be seen that during 1st week of March month, the weekly average hourly T_{gh} during sunshine and off sunshine hours was varied from 20.03^0 C to 42.40^0 C and from 18.56^0 C to 29.17^0 C respectively. During 2nd week it was varied from 20.38^0 C to 36.36^0 C and from 18.97^0 C to 26.08^0 C respectively. During 3rd week, from 22.83^0 C to 33.63^0 C and from 20.03^{0}C to 29.21^{0}C respectively and in 4th week from 16.26^0 C to 25.45^0 C and from 14.02^0 C to 18.45^0 C respectively. From 7th March onwards the greenhouse was operated on fan pad system and that causes reduction in T_{gh} which can be seen in the figure.

For type-II, during 3rd week of March month, the average air temperature was varied from 19.60^0 C to 47.33^0 C during sunshine hours and from 19.88^0 C to 26.80^0 C during off-sunshine hours and in 4th week, the T_{gh} varied from 21.28^0 C to 45.90^0 C during sunshine hours and from 21.02^0 C to 25.83^0 C during off-sunshine hours. In type-III greenhouse, during 1st week of March month, during sunshine and off sunshine the average air temperature was varied from 16.63^0 C to 38.77^0 C and from 17.29^0 C to 23.59^0 C respectively. Similarly during 2nd week it was varied from 19.61^0 C to 40.40^0 C and from 19.55^0 C to 26.50^0 C respectively and during 3rd week T_{gh} was varied from 19.89^0 C to 42.25^0 C during sunshine hours and from 19.84^0 C to 26.83^0 C during off-sunshine hours and during 4th week of it was varied from 21.06^0 C to 40.70^0 C and from 21.03^0 C to 25.66^0 C respectively. From figure it can be observed that the temperature in 1st week is lower than the other weeks.

April: In the month of April T_{gh} for In type-II and type-III was recorded while for type-I it was not recorded as type-I greenhouse was operated on fan-pad cooling and not natural ventilation. The results on variation in T_{gh} for these two types of greenhouse are given in Fig. 7. The figure shows that the for type-II greenhouse the maximum T_{gh} during 1st to 4th week was observed to be 41.51^0 C, 48.99^0C, 49.36^0C and 54.45^0C respectively and minimum 21.20^0 C , 21.89^0 C , 22.13^0 C and 23.84^0 C respectively. For type-III the above temperature during 1st to 4th week were observed to be 39.27^0 C, 43.37^0 C, 45.04^0 C and $45.05\ ^0$ C respectively and minimum 21.07^0 C, 21.93^0 C , 21.70^0 C and 23.81^0 C respectively. Thus for type-II 2.24^oC to 9.40^oC higher temp was observed as compared to Type-III this was due to the larger volume of the greenhouse as well as shading was provided during peak sunshine hours in type-III greenhouse.

2.3 INSIDE RELATIVE HUMIDITY:

The diurnal variation in relative humidity during the study period was measured in different types of greenhouses and weekly and monthly averages were calculated. The maximum RH was ranged between 90% and 96% for all the three types of greenhouses during early morning hours (i.e. between 3.00 to 6.00 hrs) whereas minimum RH was observed between 15% and 20% at 13.00 to 15.00 hrs for all three types of greenhouses

2.4 INSIDE SOLAR RADIATION:

From the average inside and outside solar radiation intensity the transmissivity of different greenhouses were found as 65% for type-I, 45% for type-II and 50% for type-III without shading and 26% for type-III with shading

2.5 NUMBER OF AIR EXCHANGE RATE:

The variation in average ventilation rate per minute greenhouses from January to April months were observed to be 1.7 to 1.9, 2.0 to 2.3 and 2.1 to 2.5 respectively for type-I, II and III.

2.6 VALIDATION OF MODELS:

The predicted greenhouse air temperature data obtained by the greenhouse microclimate mathematical model developed are incorporated in figure 9. From the figure it can be seen that theoretical results obtained have followed the similar pattern that is of experimental results. Thus, a good fitting of theoretical data is obtained with experimental data for greenhouse air temperature for all types of greenhouses.

2.7 MODEL EFFICIENCY:

The efficiency of different models varied between 68% (for type-I, in January month) to 98% (for type-III in Feb month).

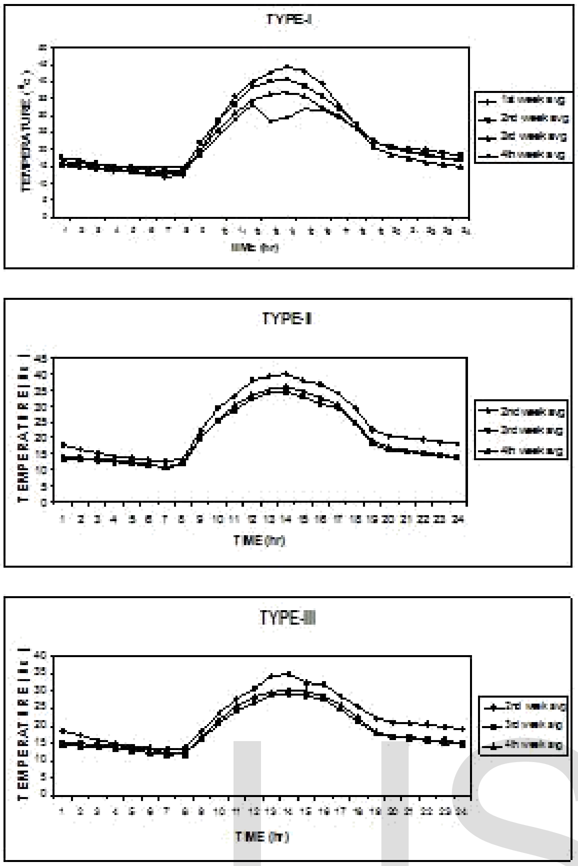


Fig. 4 Diurnal variation in weekly average temperature for different types of greenhouses in January month

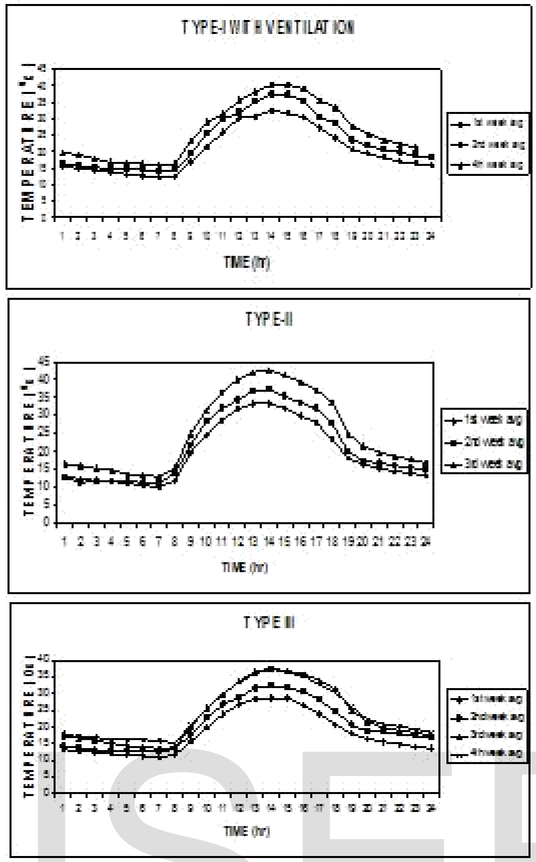
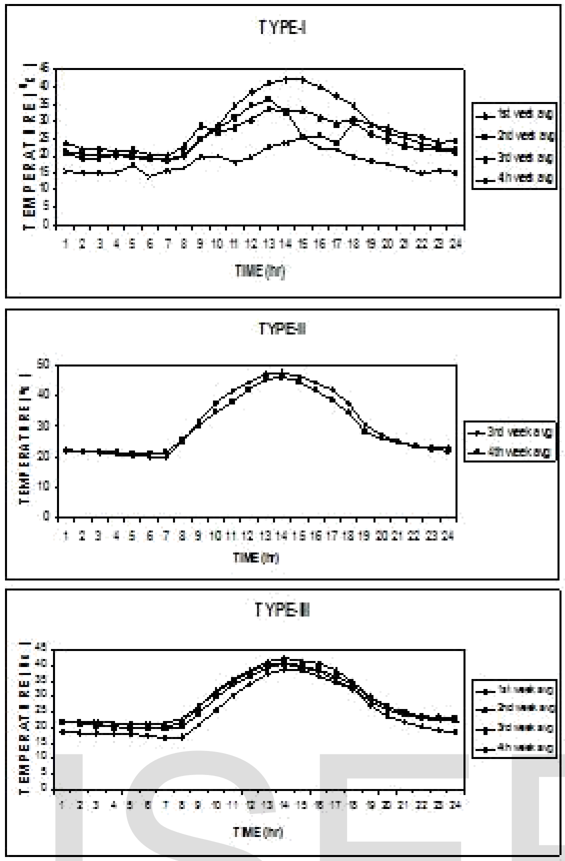
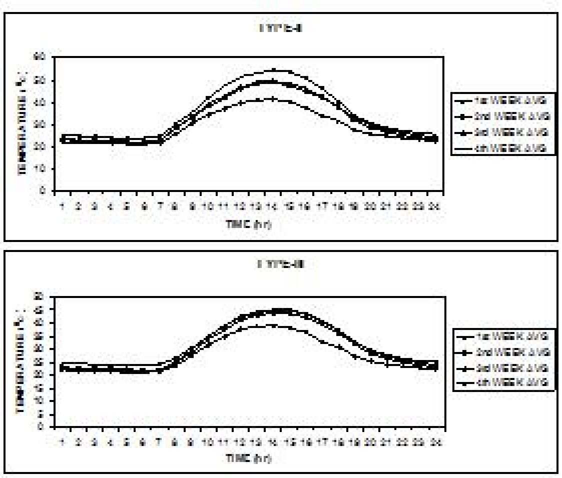


Fig. 5 Diurnal variation in weekly average temperature for different types of greenhouses in February month.



. 6 Diurnal variation in weekly average temperature in March month for different types of greenhouses.



ig. 7 Diurnal variation in weekly average temperature in April month for types-ii and type-iii greenhouses.

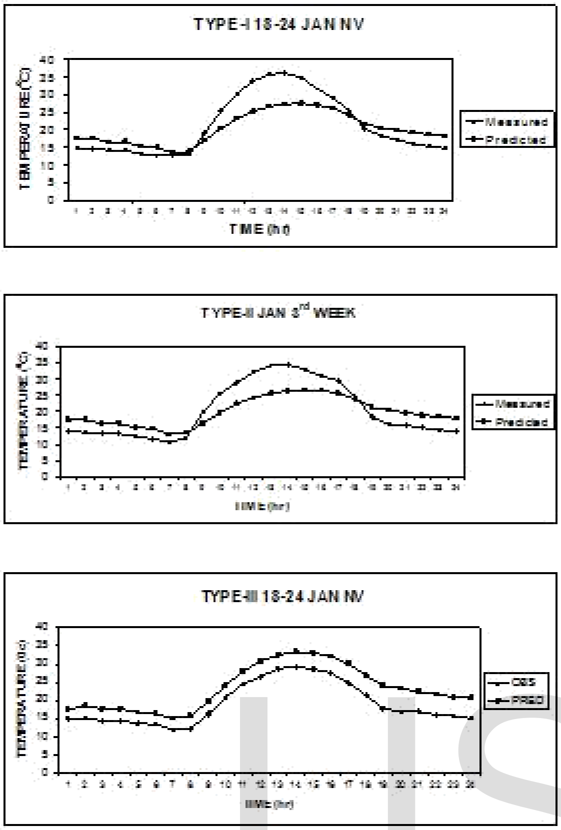


Fig. 8 Simulation results of greenhouse air temperature for month of January for different type of greenhouses (nv-natural ventilation0; obs-observed; pred-predicted).

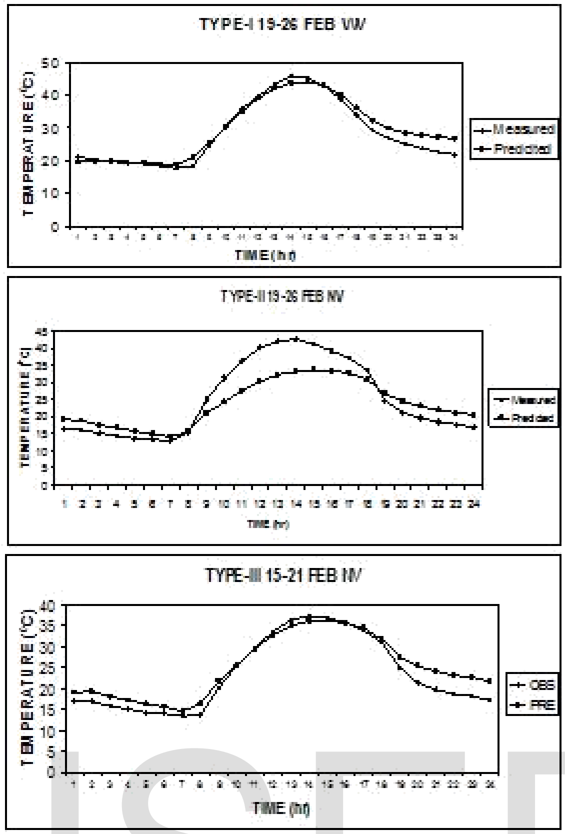


Fig. 9 Simulation results of greenhouse air temperature for month of February for different type of greenhouses (nv-natural ventilation0; obs-observed; pred-predicted).

Table 1: INPUT PARAMETERS FOR DEVLOPMENT OF MATHEMATICAL MODEL

	Input Parameter	Symbol	Value		
			Type I	Type II	Type III
1	Size of greenhouse structure Length (m) Width (m)	L B Z	25.1 9.5 5.6	25.1 9.5 6.4	48 24.5 6.4

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	Height (m)				
2	Properties of glazing material Bulk density Thickness Specific heat Transmissivity Absorbtivity Emissivity	ρ_c c_c c α_c ε_c	1000 kg/m^3 200 micron 0.23 kJ/kg^{0}C 0.65 0.05 0.9	1000 kg/m^3 200 micron 0.23 kJ/kg^{0}C 0.65 0.05 0.9	1000 kg/m^3 200 micron 0.23 kJ/kg^{0}C 0.75 0.05 0.9
3	Properties of growing media Bulk density Thickness Specific heat Emissivity Absorbtivity	ρ_{gm} c_{gm} ε_{gm} α_{gm}	795 kg/m^3 0.25m 3.2 kJ/kg^{0}C 0.75 0.9	1400 kg/m^3 0.25m 1.8 kJ/kg^{0}C 0.9 0.75	1400 kg/m^3 0.25m 1.8 kJ/kg^{0}C 0.9 0.75
4	Properties of plant Bulk density Specific heat Emissivity Absorbtivity Leaf area index	ρ_p c_p ε_p α_p Li	650 kg/m^3 3.5 kJ/kg^{0}C 0.98 0.65 3.0	650 kg/m^3 3.5 kJ/kg^{0}C 0.98 0.65 3.0	650 kg/m^3 3.5 kJ/kg^{0}C 0.98 0.65 3.0
5	Properties of floor material Bulk density Thickness Specific heat Thermal conductivity Absorbtivity	ρ_c c_s Ks α_p ε_p	1600 kg/m^3 0.3 m 2 kJ/kg^{0}C 1.38 W/m^{0}C	1400 kg/m^3 0.25m 1.8 kJ/kg^{0}C 1.38 W/m^{0}C	1400 kg/m^3 0.25m 1.8 kJ/kg^{0}C 1.38 W/m^{0}C

	Emissivity		0.95 0.75	0.9 0.75	0.9 0.75

TABLE 2: DIURNAL VARIATION IN WEEKLY AVERAGE AMBIENT TEMPERATURE DURING THE STUDY PERIOD

Time	January (week)/Temp ^oC				February (week)/Temp ^oC				March(week)/Temp ^oC				April(week)/Temp ^oC			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1	19.12	19.49	17.51	16.69	15.04	16.37	19.16	19.84	19.21	24.10	24.56	23.73	22.78	24.92	23.96	27.30
2	16.90	18.03	17.30	16.11	14.06	15.44	18.90	19.21	18.91	23.46	23.93	23.26	22.38	24.54	23.22	26.90
3	16.15	16.50	15.86	15.79	13.27	14.41	17.39	18.61	18.44	22.14	23.08	22.83	22.40	24.30	23.04	26.00
4	15.33	15.99	16.11	14.74	12.99	14.36	16.57	17.98	18.31	21.35	22.96	22.79	22.28	23.82	22.74	24.94
5	14.95	15.11	14.61	13.71	12.13	14.59	15.47	18.88	17.66	21.18	22.64	22.46	21.88	23.42	22.14	24.82
6	14.42	14.61	14.41	13.29	12.16	14.33	14.87	17.23	16.81	21.15	21.99	22.25	22.00	23.24	22.06	24.78
7	14.17	14.26	12.56	12.59	11.79	14.14	13.76	15.73	16.07	20.90	21.96	22.01	21.85	22.38	22.22	23.96
8	14.80	15.07	12.94	11.96	12.39	13.86	15.53	16.81	16.90	21.94	22.85	22.68	22.90	23.56	23.46	24.72
9	18.85	18.64	15.67	15.10	15.40	16.87	20.74	21.41	20.19	25.06	24.94	24.84	24.88	26.34	25.58	27.80

10	22.08	21.16	18.69	18.59	17.31	19.97	23.74	24.34	23.10	28.45	28.14	26.90	26.38	29.68	28.38	30.30
11	25.17	24.07	21.11	21.64	19.50	22.50	27.04	27.43	26.80	31.31	30.54	29.18	28.03	30.66	31.46	33.18
12	27.03	26.44	22.90	23.01	20.79	23.84	29.21	29.45	29.70	33.40	32.69	31.51	29.70	33.30	34.22	35.96
13	28.32	28.20	24.14	23.90	21.74	24.96	31.03	31.03	31.61	34.89	34.59	33.53	30.95	35.18	36.20	38.12
14	29.20	29.37	24.94	24.83	22.63	25.89	32.00	32.11	33.09	35.68	36.03	34.88	31.95	36.32	37.40	39.30
15	29.48	29.84	25.33	25.54	22.91	26.37	32.56	33.03	34.07	35.96	36.89	35.41	32.28	37.18	38.02	40.04
16	29.18	29.90	25.43	25.59	22.87	26.47	32.60	33.19	34.56	35.81	37.49	35.43	32.03	37.18	38.28	40.34
17	28.13	29.01	24.81	25.01	22.31	25.99	32.31	32.68	34.26	34.99	37.13	34.59	30.95	35.34	37.60	40.34
18	26.10	26.89	23.16	23.44	21.09	24.73	30.69	30.86	31.80	33.20	35.76	32.64	29.65	33.70	36.18	39.20
19	23.58	24.54	20.59	20.93	18.97	22.44	26.60	27.24	27.86	30.31	32.95	30.18	27.80	32.04	33.82	37.26
20	22.67	23.64	19.76	19.53	17.67	20.96	24.04	25.21	25.41	28.25	30.39	27.80	26.23	30.08	31.32	34.84
21	22.05	23.26	19.03	18.80	16.90	20.86	22.64	23.69	23.74	26.90	28.31	26.11	25.30	28.62	29.40	32.90

22	21.08	22.56	18.34	18.10	16.10	20.09	21.61	22.65	22.23	25.91	27.09	24.95	24.50	27.50	28.02	31.60
23	20.85	21.87	17.89	17.39	15.44	19.59	20.76	21.76	20.87	25.56	26.66	24.00	23.83	26.36	26.84	30.60
24	20.43	20.37	17.40	16.74	14.94	18.91	20.07	21.24	20.00	25.39	25.61	23.48	23.43	25.68	25.72	29.42

NOMENCLATURE

A greenhouse floor area, m2
B width of the greenhouse, m
C specific heat, J/kgoC
dh, dl distance element, m
ET transpiration rate, kg/hm^2
f coefficient of transpiration
G solar radiation, W/m^2
hheat transfer coefficient, W/m2^{o}C
kthermal conductivity, W/m^{o}C
Li leaf area index
L length of greenhouse, m
l characteristics length of plant leaves,
m M mass, kg
m mass flow rate, kg/s
P vapour pressure, kPa
Q ventilation/infiltration/air flow rate, m3/s
t temperature
V volume, m3
v wind velocity, m/s W
humidity ratio

Subscripts
a ambient
atm atmospheric
co cover
fv forced ventilation
gh greenhouse
gm growing media
(j) number of layers
nv natural ventilation
p plant
r radiative

R rankine
s soil / saturated
s(1) surface layer of soil / floor
ss soil-soil

Greek letters
ε emissivity
λ latent heat of vaporization, J/kg
σ Stephan boltzmen constant Δt
finite element of time
αsolar absorptance
ρdensity, kg/m3
time, sec
Φrelative humidity
porosity
solar transmittance

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Innovation:

Agriculture is the backbone of Indian economy which in turn relies on the monsoon season. Rising global temperature is not only causing climate change but also contributing to the irregular rainfall patterns. Uneven rainfall patterns, increased temperature, elevated CO_2 content in the atmosphere are important climatic parameters which affects the crop production. Research studies indicate that weathering parameters influence strongly (67%) compared to other factors like soil and nutrient management (33%) during the cropping season. The Intergovernmental Panel on Climate Change (IPCC) projected that the global mean surface temperature will likely rise and may result into uneven climatic changes. This rising temperature may affect crop yield at large scale. The purpose of protected cultivation i.e. greenhouse is to provide suitable environment for crop cultivation. The primary purpose of greenhouse ventilation is to prevent excessive rise of temperature and humidity and in some cases, it is applied to prevent CO_2 depletion due to the crop photosynthesis and non adequate air exchange between the greenhouse and the environment. At the same time, ventilation can also reduce the concentration of pollutant gases (e.g., toxic gases generated by incomplete combustion in a heating system). The cooling performance of the natural ventilated greenhouse is mainly affected by the greenhouse geometrical dimensions, vent's windward area, span and orientation of greenhouse etc. In the present study, efforts were made to analyze the effect of natural ventilation on inside air temperature during winter and summer season i.e. January to April months for three selected naturally ventilated greenhouses and to develop mathematical models for prediction of inside temperature to help investigators to examine the variation in inside temperature for different location without actually building such types of greenhouses..It can be utilized as scientific recommendation in future, for farmers and greenhouse growers for utilization of temperature prediction modeling.

Algorithm:

Step 1: Selection of three type of greenhouse

Step 2: Operation of greenhouse control system

Step 3: Measurement of environmental parameter

Step 4: Evaluation and computing for inside air temperature
on weekly basis

Step 5: Simulation of greenhouse air temperature with temperature prediction modeling

Step 6: Evaluation of temperature prediction model efficiency with fitting accuracy

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