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

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ABSTRACT:

In India because of the least expensive cooling method of greenhouse, natural ventilated types of greenhouses are considered to be the most acceptablestructuresforgrowingofvegetableandflowercrops.Innatural 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, 24.4to46.62^{0}C,20.44^{0}Cto46.62^{0}C,20.57^{0}Cto41.35^{0}CforMarchmonth 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. ThevariationinaverageventilationrateperminutefromJanuarytoApril months were observed to be 1.7 to 1.9, 2.0 to 2.3 and 2.1 to 2.5 respectivelyfortype-I,IIandIII.The mathematical models developed for

Soil bed and pot cultivation condition susing 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 IIIrespectively.

INTRODUCTION

Theprimarypurposeofgreenhouseventilationistopreventexcessiverise 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 exchangebetweenthegreenhouseandtheenvironment.Atthesametime, ventilationcanalsoreducetheconcentrationofpollutantgases(e.g.,toxic gases generated by incomplete combustion in a heating system). Furthermore, ventilation is important since it generates air movement withinthegreenhouseandthusreducestheboundarylayerthicknessnear the leaves. This improves sensible and latent heat transfers from the crop to the greenhouse air and enhances CO_2transfer 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 ofenergyandlikelihoodofpowerfailuresincrease,thenaturalventilation 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 themajor assets of a good grower is the ability to maintain an “optimum” growing temperature. The

The advantages of simulation techniques in greenhouse environment predictionisthreefolds(i)Itismoreflexibleandversatiletoresearchers in constructing a fairly realistic model of the temperature response for raisingnurseriesandsimulatingtheresponseofthesystem.(ii)Itrequires less field data regarding physical characteristics of the system and responseofthesystemcanbeanalyzedbychanginganycoefficients.(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 bepossibletomaintaindesiredinsidetemperature.So,amodelisdesired 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 ofgreenhouse.

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 insideair temperature during winter and summer season i.e. January to April monthsforthreeselectednaturallyventilatedgreenhousesandtodevelop 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 ofgreenhouses.

Objectives:

1. Tostudythetemperatureprofilefornaturalventilated greenhouses

2. To evaluate diurnal variationin inside air temperature .

3.Tostudythedifferentthreegreenhousestructureforinside airtemperature

4.Topredictinsideairtemperaturewithtemperatureprediction modelin

THEORATICAL ANALYSIS

1. DEVELOPMENT OF MATHEMATICALMODELS:

The energy and mass balance equations and computer programme presentedinannexureofthepreviousyear'sannualreportweremodified 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 transferintheanalysisisassumedtobeunsteadystate.Themathematical 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 inTable-4.1.

Assumptions:

1. Heat flow is onedimensional
2. The effect of shading due to structural members isnegligible
3. Moisture is freely available at various surfaces forevaporation
4. Edge losses of greenhouse arenegligible
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 DIFFERENTSETS OFCONDITIONS:

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

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

2.2 PLANTS GROWN IN POTS USING GROWINGMEDIA (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 computedas

$M_{gh} W_{gh}/dt = A_p Lif(W_{sp} - W_{gh}) + Aco(h_{cogh}/C_{gh})(W_{sco} - W_{gh}) + A_{gm}\, (h_{gmgh}/C_{gh})(W_{sgm} - W_{gh}) - E_{nv}$(4.15)

Inaboveequations,theheatloss(H_{nv})andmassloss(E_{nv})werecalculated as

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

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

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

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

Inaboveequations,thesaturatedvapourpressureatdifferentcomponents of greenhouse system was calculatedas

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

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

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

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

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

In above equations, the heat of vaporization at cover, plant canopy, greenhouseair,growingmediaandfloortemperaturecanbeexpressedas

$\lambda_{co}/\ \lambda_{gh}\ /\ \lambda_p/\ \lambda_{gm}/\ \lambda_s = 2500.78 - 2.3601\ T_{co}\ /\ T_{gh}/T_p/\ T_{gm}/\ T_s$ (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:

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

Where,
η = Model efficiency
x = Observed data
$\bar{x}$ = Mean of observed data
Y = Predicted data

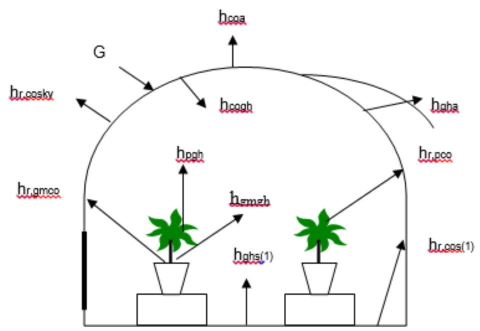

Fig. 1 The schematic veiw of various coefficients of heat transfer occurringatdifferentcomponentsofthetype-igreenhouse(plants grown in pot using growingmedia)

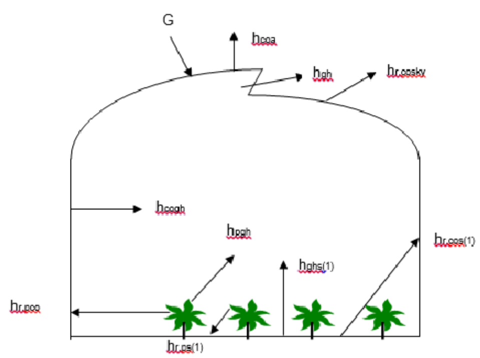

Fig. 2 The schematic view of various coefficients of heat transfer occurring at different components of the type-ii & type-iii (plants grown in soil bed)

METHODOLOGY

1. EXPERIMENTALGREENHOUSE:

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 andanticondensationPEsheet.Two48”sizepropellertypeSSfanswere 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 curtainroll-upmechanismisprovided.50%lightreductionblack&white shading net was provided at eveheight.

Type II: The experimental greenhouse of 70ft (L) x 30ft (W) x 21ft (H) gothicarcdesigncoveredwith200micronthickUVstabilizedyellowish plastic film. The greenhouse is equipped with ridge vent and all fourside 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 ofthesideventsis653ft^2(61m^2).Alltheventilatorswereoperatedusing motorized mechanism. The insect net is provided inside both the vents. 50%lightreducingshadescreen(net)atgutterheightisprovidedto reduce the light level and thereby inside air temperature. The shade net openingandclosingisdonebyusingrackandpinionmechanismoperated by0.2hpDCmotor.Thefoggersareprovidedforcoolingduringextreme adversecondition.

TYPE-I GREEN HOUSESPHOTOS:

TYPE-II GREEN HOUSEPHOTOS:-


SHOT ON REDMI NOTE5 PRO
MI DUAL CAMERA


SHOT ON REDMI NOTE5 PRO
MI DUAL CAMERA


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MI DUAL CAMERA

TypeIII:Theexperimentalgreenhouseis180ft(L)x85ft(W)x21ft(H) gothic arc design. It is a multi span aero dynamic structure type of greenhousewith6spansinwhicheachspanisof26ftx80ft(8mx24.5m) coveredwith200micronthicktransparentdiffuselighttransmittancetype UVstabilizedLDPEsheet.Thegreenhouseconsistsofmanuallyoperated 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 ofgreenhouse.

TYPE-III GREEN HOUSE PHOTO:

2. OPERATION OF GREENHOUSE TEMPRATURECONTROL 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 peripherysidewallsofthegreenhouseat4fthighcurtaintypeventilators 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 toreducethelightlevelandtherebyinsideairtemperature.Theshadenet openingandclosingisdonebyusingrackandpinionmechanismoperated by0.2hpDCmotor.Thefoggersareprovidedforcoolingduringextreme 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 ofMarch.

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 openthroughout24hours.Theshadingwasdoneinthisgreenhousefrom 10:00a.m.to6:00p.m.andfoggingwasdoneforcoolingduringextreme adverse condition before floweringstage

3. MEASURMENT OF ENVIRONMENTPARAMETERS:

The environmental parameters like temperature, relative humidity, solar radiationandwindvelocityforthedurationJanuary-08toApril-08were obtained and measured. The hourlyambient environmental parameters like temperature, relative humidity, solar radiation and wind velocity for the duration January-08 to April -08 were obtained from Automatic WeatherStation(AWS)installedatJ.A.U.,Junagadh.Thedailymeasured data are converted to weekly and monthlybasis.

RESULTS AND DISCUSSION:

1. AMBIRNT ENVIRONMENTALDATA:

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), AgronomyInstructional Farm, Junagadh Agricultural University, Junagadh. The data are presentedinTable-2wereanalyzedtoobtainweeklyandmonthlyaverage hourly data to use them in development ofmodels.

2. GREENHOUSEENVIRONMENT:

2.1 INSIDE AIRTEMPRATURE

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 5^0C lower in type-III as compared to type-II.

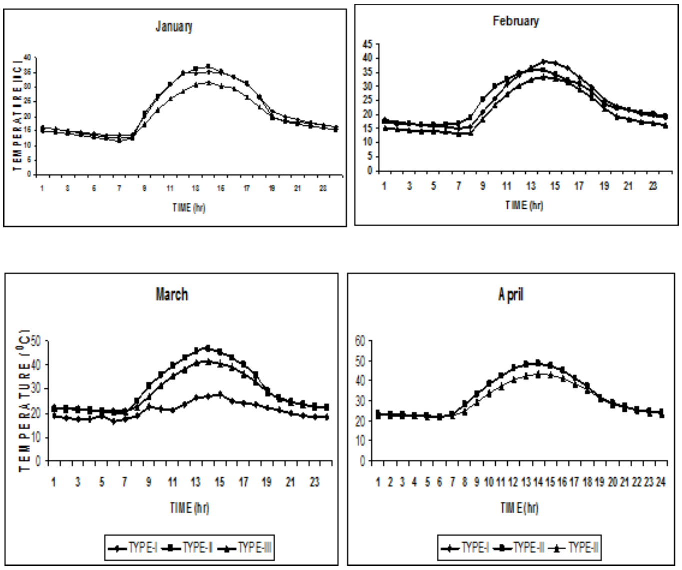


Fig.3 Diurnal variation of monthly average t_{gh} for different types of greenhouses

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 12.51^0C to 44.20^0C, 13.98^0C to 40.79^0C, 13.03^0C to 36.73^0C and 14.91^0C to 31.86^0C 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 20.64^0C 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 12.97^0C 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 1stto4thweekT_{gh}wasvariedfrom12.60^{0}Cto32.45^{0}C,14.48^{0}Cto37.29^0 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°C to 20.66°C, 14.14 °C to 23.63°C, 16.12°C to 28.89°C and 17.34°C to 28.24°C respectively during off sunshine hours . Data on variation in T_{gh} in Type-II (1st to 3rd week) and type-III (1st 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 Crespectively.

March: In type-I greenhouse from Fig. 6, it can be seen that during 1st weekofMarchmonth,theweeklyaveragehourlyT_{gh}duringsunshineand off sunshine hours was varied from 20.03^0 C to 42.40^0 C and from18.56^0 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 airtemperature 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 during3[rd]weekT_{gh}wasvariedfrom19.89^{0}Cto42.25^{0}Cduringsunshine hoursandfrom19.84^{0}Cto26.83^{0}Cduringoff-sunshinehoursandduring 4[th] 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}Crespectively.Fromfigureitcanbeobservedthatthetemperature in 1[st] week is lower than the otherweeks.

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 onfan-padcoolingandnotnaturalventilation.Theresultsonvariationin T_{gh}forthesetwotypesofgreenhousearegiveninFig.7.Thefigureshows that the for type-II greenhouse the maximum T_{gh} during 1[st] to 4[th] week was observed to be 41.51^0 C, 48.99^{0}C, 49.36^{0}C and 54.45^{0}C 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 1[st] to 4[th] week were observed tobe39.27^{0}C,43.37^{0}C,45.04^{0}Cand45.05^{0}Crespectivelyandminimum 21.07^0 C, 21.93^0 C , 21.70^0 C and 23.81^0 C respectively. Thus for type-II 2.24^{o}C to 9.40^{o}C 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 RELATIVEHUMIDITY:

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% and96%forallthethreetypesofgreenhousesduringearlymorninghours (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 SOLARRADIATION:

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

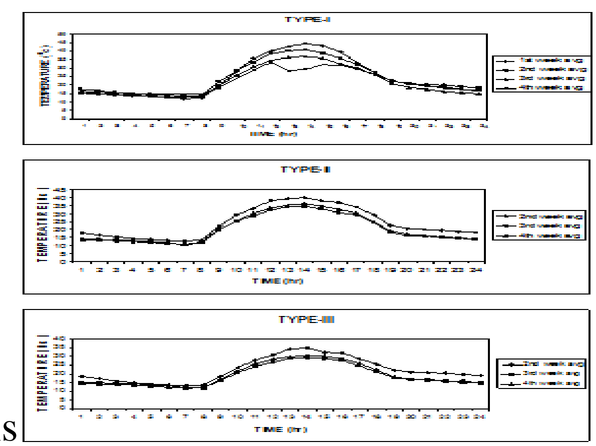
2.5 NUMBER OF AIR EXCHANGERATE:

The variation in average ventilation rate per minute greenhouses from JanuarytoAprilmonthswereobservedtobe1.7to1.9,2.0to2.3and2.1 to 2.5 respectively for type-I, II andIII.

2.6 VALIDATION OFMODELS:

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 MODELEFFICIENCY:



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

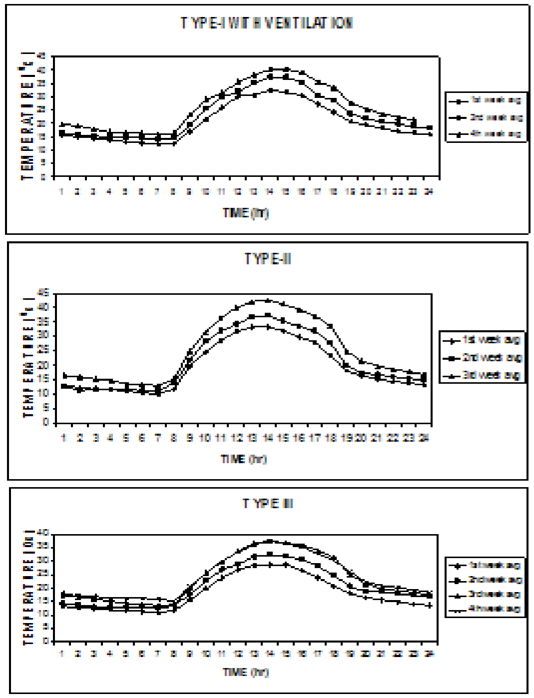


Fig.5 Diurnal variation in weekly average temperature fordifferent types of greenhouses in Februarymonth.

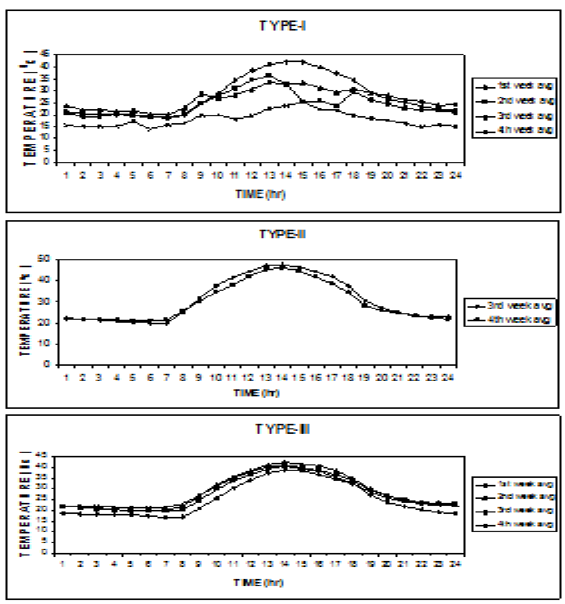


Fig.6 Diurnal variation in weekly average temperature in Marchmonth for different types of greenhouses.

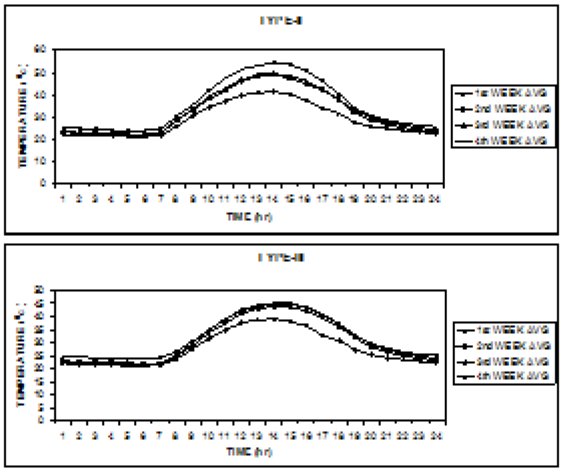


Fig.7 Diurnal variation in weekly average temperature in Aprilmonth for types-ii and type-iiigreenhouses.

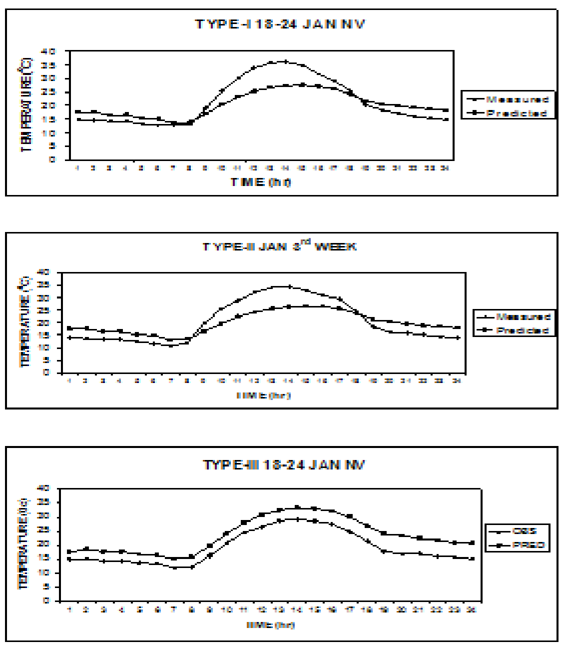


Fig.8 Simulation results of greenhouse air temperature for monthof January for different type of greenhouses (nv-natural ventilation0; obs-observed;pred-predicted).

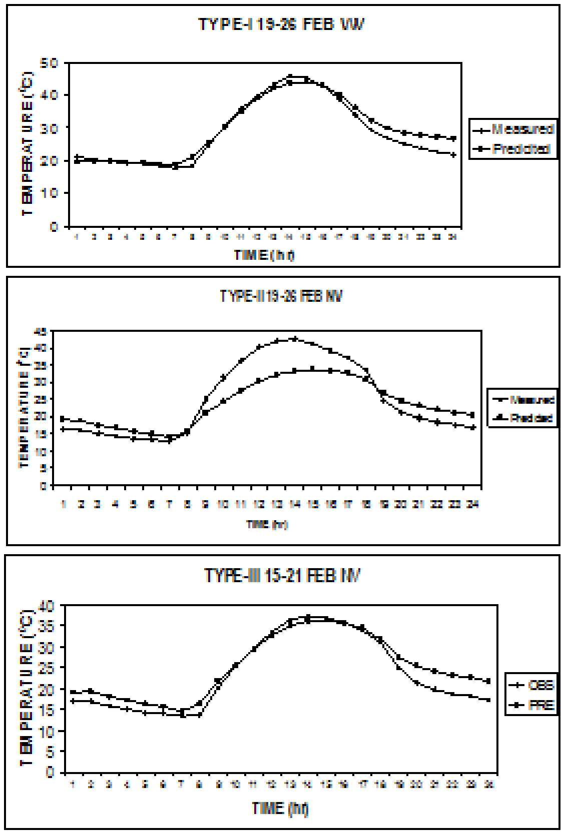


Fig. 9 Simulation results of greenhouse air temperature for month of February for different type of greenhouses (nv-natural ventilation0; obs-observed;pred-predicted).

Table 1: INPUT PARAMETERS FOR DEVLOPMENT OFMATHEMATICALMODEL

	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

	Height (m)				
2	Properties of glazing material Bulk density Thickness Specific heat Transmissivity Absorbtivity Emissivity	ρ_c c_c τ_c α_c ε_c	1000 kg/m^3 200 micron 0.23 kJ/kg^{o}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 Bulkdensity Specificheat 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

TABLE2: DIURNAL VARIATION IN WEEKLY AVERAGE AMBIENTTEMPERATURE DURING THE STUDYPERIOD

Time	January (week)/Temp °C				February (week)/Temp °C				March(week)/Temp °C				April(week)/Temp °C			
	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

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 03 Issue: 06 | June -2019 ISSN: 2590-1892

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
h heat transfer coefficient,W/m2^{o}C
k thermal conductivity,W/m^{o}C
Li leaf areaindex
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 humidityratio

Subscripts
a ambient
atm atmospheric
co cover
fv forced ventilation
gh greenhouse
gm growingmedia
(j) number of layers
nv naturalventilation
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 boltzmenconstant
Δt finite element oftime
α solarabsorptance
ρ density,kg/m^3
θ time, sec
Φ relativehumidity
ε porosity
τ solartransmittance

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Innovation:

Agricultureisthebackboneof Indianeconomywhichinturnreliesonthe 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_2content 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 ofprotectedcultivationi.e.greenhouseistoprovidesuitableenvironment for crop cultivation. The primary purpose of greenhouse ventilation is to prevent excessive rise of temperature and humidity and in some cases, it isappliedtopreventCO_2depletionduetothecropphotosynthesisand 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 greenhouseismainlyaffectedbythegreenhousegeometricaldimensions, vent's windward area, span and orientation of greenhouse etc. In the present study, efforts were made to analyze the effect of natural ventilationoninsideairtemperatureduringwinterandsummerseasoni.e. January to April months for three selected naturally ventilated greenhouses and to develop mathematical models for prediction ofinside temperature to help investigators to examine the variation in inside temperature for different location without actually building such types of greenhouses..Itcanbeutilizedasscientificrecommendationinfuture,for farmers and greenhouse growers for utilization of temperature prediction modeling.

Algorithm:

Step 1: Selection of three type of greenhouse

Step2:Operationofgreenhousecontrolsystem

Step 3: Measurement of environmental parameter

Step4:Evaluationandcomputingforinsideairtemperatureon weeklybasis

Step5:Simulationofgreenhouseairtemperaturewithtemperature predictionmodeling

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

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Acknowledgement:

I wish to express my sincere gratitude and thanks to my project guide Dr. P. M. Chauhan, Professor and Head, Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh for provide work facility and environment. I also record my sincere thanks to Dr.Viral Joshi from department of renewable energy engineering and all other staff of department for the help and support during experiments. I am grateful to Junagadh Agricultural University for this great opportunity.