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Year Round Potential of Greenhouse as a Solar Dryer for Drying Crop Produce

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ABSTRACT

An experimental investigation was carried out to determine whether sufficiently higher temperatures are available inside the greenhouse for drying crop produce. The greenhouse air temperature was calculated using a steady-state model. Calculated and measured data compared well for different months of the year. The maximum temperature gain of about 25.1°C, 21.4°C and 14.5°C were obtained during May, September and December, 2015 respectively. However, during September the minimum gain was 7.5°C. The maximum temperature inside a bare greenhouse enclosure reached above 64°C. The model can also predict the relative humidity inside the greenhouse enclosure. The inside relative humidity varied from 13.8 to 35.2% in the year 2015 during 10:00 h to 16:00 h Validation of observed and predicted values of greenhouse temperature was carried out with higher R^2 values (0.991 to 0.999). The model can also be used to modify the design of the greenhouse according to the optimum temperature required.

Key words: *Greenhouse, Solar dryer, Temperature, Relative humidity.*

INTRODUCTION

The temperature inside a greenhouse increases due to greenhouse effect which needs to be reduced within desirable limits for crop production (Chandra *et.al*, 1989). In view of this, greenhouse drying assumes importance in a tropical climate, which is characterized by harsh outdoor conditions. In recent years, particular interest has been focused on solar energy as a substitute for fossil fuels and electricity in several agricultural processes. A typical example is the use of solar energy using the greenhouse solar system (Haung *et al.,* 1979 and 1983). The seasonal performance of greenhouse was experimentally analysed for both natural and convection mode in no load conditions (Kumar *et al.,* 2012). Experimental result showed that the temperature varied in a forced convection greenhouse dryer from 35°-65°C. It was supported by 100 Kw, LPG gas burner to supply hot air during cloudy days or rainy days (Janjai, 2013). It is possible to regulate the inside climate of a greenhouse so that drying of crop produce is maximized. A greenhouse is an enclosure in which the environment can be controlled to make it suitable for fast drying of different types of crop produce. Drying crop produce in a greenhouse is also possible when the greenhouses are left without crop The average temperature inside a greenhouse can be estimated depending on the outdoor conditions i.e. solar radiation, ambient temperature and relative humidity. The present communication throws light on the two important environmental parameters such as, temperature and relative humidity for using greenhouse as a dryer round the year.

MATERIALS AND METHODS

A quonset shaped plastic greenhouse 2x1.5 m was constructed at SEES, DAVV Indore. The volume of greenhouse was 2.36 m^3. It was clad with UV-resistant polyethylene sheet. However, the floor was dry. The temperature was measured using a cu-constantum thermo-couple. The temperatures were measured in the middle of the greenhouse at a height of 0.38 m. The solar radiation was measured using a pyranometer.

A simple thermal model proposed by (Landberg *et al.,* 1979) was used to predict the greenhouse temperature and humidity. The value of 'U' was taken to be 6.0 W $m^{-2}\,{}^{\circ}C^{-1}$. The overall solar transmittance was measured to be 0.65 (Singh *et al.,* 2000), reflectance was assumed to be 0.33. The bowen ratio (β) was taken as 20 for dry surface. For a greenhouse, the thermal behavior of inside air temperature is described by a differential equation based on a simplified sensible heat balance given as,

$$\rho V C_p (dT_i / dt) = H_Q - UA_c (T_i - T_a) - 0.33NV (T_i - T_a) \quad \ldots(1)$$

The radiation available for the floor is partitioned into ground loss, heat gain through sensible heat and latent heat. The energy balance for floor can be written as:

$$\tau(1 - \sigma).S.\,A_g = U_b.\,A_g (T_i - T_o) + H_Q + (H_Q / \beta) \quad \ldots(2)$$

$$\text{Or } H_Q = \tau(1 - \sigma)\,S.\,A_g - U_b A_g (T_i - T_o) + (\beta / \beta+1) \quad \ldots(3)$$

Substituting the values of H_Q from equation (3) into equation (1) and on rearranging we get the following first order differential equation,

$$dT_i / dt + aT_i = b \quad \ldots(4)$$

Where $a = (\beta / (\beta+1))\,Ub.Ag + UA_c + 0.33NV$

$b = (\beta / (\beta+1))\,[\tau(1 - \sigma)\,S.\,A_g\,U_b.A_g\,T_o] + (UA_c + 0.33\,NV)T_a$

For steady state condition,

$$T_i = b/a \quad \ldots(5)$$

Moisture Balance

In a simple approach, the moisture balance in a greenhouse air is given as,

$$\rho_a V\,(dWi / dt) = \rho_a\,Ver\,(Wa - Wi) + \tau(1 - \sigma).\,S\,A_g / \lambda\,(\beta+1) \quad \ldots(6)$$

On arranging these all we get the following equation

$$d.Wi / dt + CW_a = D \quad \ldots(7)$$

Where $C = Ver. / V$

and $D = (Ver./V)\,W_a + [\tau(1 - \sigma).S\,A_g / \{\lambda\,(\beta+1)\,\rho_a\,.\,V\}]$

The solution of equation (7) for steady state condition, is given by

$$W_i = D/C \quad \ldots(8)$$

The value of actual vapour pressure inside greenhouse can be gives as,

$$P_{wi} = P\,Wi_{/}\,(0.62198 + W_i) \quad \ldots(9)$$

The value of relative humidity inside greenhouse is given as the ratio of actual vapour pressure and saturation vapour pressure. It is as given below;

$$\gamma ip\% = 100\,(P_{wi} / P_{sTip}) \quad \ldots(10)$$

The value of saturation vapour pressure P_{sTip} in Pascal (Pa) was computed by using equation (11) given by (Dilley 1968)

$$P_{sTip} = 610.78 \exp\left(\frac{17.269\,T}{237.3+T}\right) \quad \ldots(11)$$

$(0^{0}C \leq T \leq 63.0^{0}C)$

RESULTS AND DISCUSSION

Using the steady-state model, numerical calculations have been made for typical summer day (12th May, 2015) for the climate of Indore, India. For this, the values of solar irradiance and ambient temperature were recorded. The values of other relevant data have been taken from Table 1 (Singh *et al.,* 2000). It is clear from Table 2 that the greenhouse temperature varied from 53.8°C to 64.5°C between 10:00 h and 16:00 h. The inside relative humidity varied from 13.8 to 21.1 % between 10:00 h and 16:00 h. The values of inputs (Ta, Tw and S) for the greenhouse were taken and it was observed that the values of tip predicted by model are in close

Table 1: Values of different parameters used in solar greenhouse

Symbols	Values	Units
A_g	3.0	m^2
Ac	6.48	m^2
Cp	1000	J $kg^{-1°}$ C
U	6.0	W m-2 º C
σ	0.33	
τ	0.65	
ρ	1.2	kg m^{-3}
V	2.36	m^3
N	6.0	Number of air change/ h

proximity with the experimental values (Table 2). Temperature conditions inside the greenhouse for another extreme month December, 2015 has also been observed and calculated. The analysis has shown that greenhouse can be effectively used for drying crop produce as the inside temperature is significantly higher during summer It is clear from Table 3 that the greenhouse temperature varied from 34.5°C to 43.2°C between 11:00 h and 16:00 h. The inside relative humidity varied from 23.2 to 27.2% between 11:00 h and 16:00 h and even during December the temperature reaches as high as 43.2°C (Table 3), which is far better as compared to open sun drying. During September, the lowest and highest temperature observed were 42.5°C and 55.4°C and relative humidity varied from 23.8 to 30.3% between 10:00 h to 16:00 h. Such high temperature and low humidity ensure good drying capacity of greenhouse air. The model developed was also validated for three different months of the year and predicted values of temperature an relative humidity were found in close proximities with observed values (Table 2, 3 and 4) with high correlation coefficients and slopes of equations being very close to 1 (Table 5 and Fig. 1, 2 and 3).

CONCLUSION

An experimental investigation indicated greenhouse temperatures, which varied from 64.5°C to 34.5°C between 11:00 h and 16:00 h was sufficient for drying crop produce. The steady-state model predicted the greenhouse air temperature accurately. The model also predicted the relative humidity inside the greenhouse enclosure for known outside relative humidity. The inside relative humidity varied from 13.8 to 35.2% in the year during 10:00 h to 16:00 h.

Table 2: Observed and predicted values of greenhouse temperature (May, 2015)

Time (h)	T_a(˚C)	Y_a (%)	T_{io}(˚C)	Y_{io} (%)	Y_{ip}(%)	S(Wm^{-2})	T_{ip}(˚C)
8:00	29.5	63	41.0	45.2	45.8	430	41.0
9:00	30.5	64	46.5	27.0	27.6	600	46.6
10:00	33.0	62	53.8	21.1	21.9	760	54.1
11:00	35.5	58	58.6	17.9	18.6	880	58.8
12:00	37.8	46	59.6	15.5	16.2	900	61.5
13:00	39.0	51	63.0	15.6	15.9	960	62.1
14:00	39.4	51	64.5	15.0	15.6	900	63.9
15:00	38.4	47	63.0	14.0	14.8	720	61.8
16:00	39.0	31	54.9	13.8	14.6	580	54.7
17:00	37.5	24	47.9	14.2	15,1	380	47.2
18:00	35.5	21	39.4	16.8	17.6	150	39.1

Table 3: Observed and predicted values of greenhouse temperature (December, 2015)

Time (h)	T_a(˚C)	Y_a(%)	T_{io}(˚C)	Y_{io}(%)	Y_{ip}(%)	S(Wm^{-2})	T_{ip}(˚C)
8:00	15.3	62	20.3	55.6	56.4	250	21.3
9:00	17.7	56	23.8	38.8	39.2	410	24.4
10:00	21.5	48	28.7	31.2	31.8	560	29.4
11:00	23.0	56	35.6	27.2	27.9	650	36.1
12:00	24.9	54	38.4	25.2	26.0	700	38.9
13:00	26.2	57	40.2	25.9	26.8	640	40.8
14:00	28.7	55	43.2	24.6	25.2	570	43.6
15:00	26.3	51	39.2	24.9	25.6	430	39.8
16:00	25.0	40	34.5	23.2	23.8	260	35.3
17:00	23.4	39	31.6	24.4	25.2	120	32.2

Table 3: Observed and predicted values of greenhouse temperature (December, 2015)

Time (h)	T_a(˚C)	Y_a(%)	T_{io}(˚C)	Y_{io}(%)	Y_{ip}(%)	S(Wm^{-2})	T_{ip}(˚C)
8:00	15.3	62	20.3	55.6	56.4	250	21.3
9:00	17.7	56	23.8	38.8	39.2	410	24.4
10:00	21.5	48	28.7	31.2	31.8	560	29.4
11:00	23.0	56	35.6	27.2	27.9	650	36.1
12:00	24.9	54	38.4	25.2	26.0	700	38.9
13:00	26.2	57	40.2	25.9	26.8	640	40.8
14:00	28.7	55	43.2	24.6	25.2	570	43.6
15:00	26.3	51	39.2	24.9	25.6	430	39.8
16:00	25.0	40	34.5	23.2	23.8	260	35.3
17:00	23.4	39	31.6	24.4	25.2	120	32.2

Table 4: Observed and predicted values of greenhouse temperature (September, 2015)

Time (hr)	T_a(˚C)	Y_a (%)	T_{io}(˚ C)	Y_{io} (%)	Y_{ip} (%)	S(Wm^{-2})	T_{ip}(˚C)
8:00	25.8	77	33.3	50.2	50.8	440	32.8
9:00	27.4	76	37.8	42.3	43.4	640	36.9
10:00	29.1	74	42.5	35.2	35.8	780	42.5
11:00	30.8	65	44.8	30.3	31.0	870	45.1
12:00	32.4	62	49.5	25	25.7	890	50.2
13:00	33.8	63	52.2	24.2	24.8	870	53.2
14:00	34.8	72	55.4	24.8	25.4	780	55.9
15:00	337	72	54.2	25	25.8	630	54.6
16:00	33.5	58	50.3	23.8	24.6	440	50.8
17:00	32.5	53	46.8	24.8	25.4	230	47.4
18:00	31.0	50	42.8	25.8	26.2	190	43.2

Table 5: Validation of observed and predicted values of greenhouse temperature and relative humidity

Month	Validation model	R^2	Validation model	R^2
May, 2015	$T_{ip}= 0.992T_{io}+0.290$	0.991	$Y_{ip}=0.994\ Y_{io}+0.820$	0.999
December, 2015	$T_{ip} =0.983T_{io}+1.185$	0.999	$Y_{ip}=0.999\ Y_{io}+0.717$	0.999
September, 2015	$T_{ip} =1.055T_{io}-2.39$	0.996	$Y_{ip}=1.003\ Y_{io}+0.596$	0.999

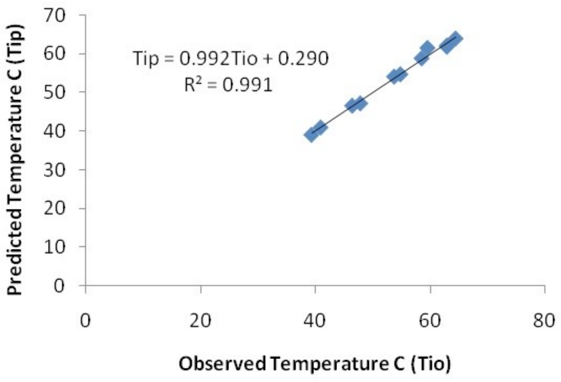

Fig. 1: Observed and predicted values of greenhouse temperature (°C) for May, 2015

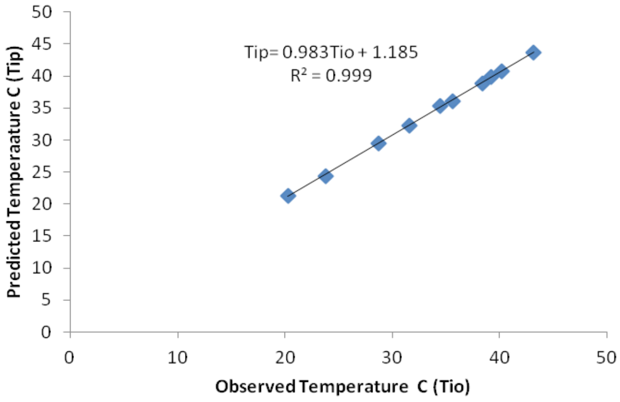

Fig. 2: Observed and predicted values of greenhouse temperature (°C) for December, 2015

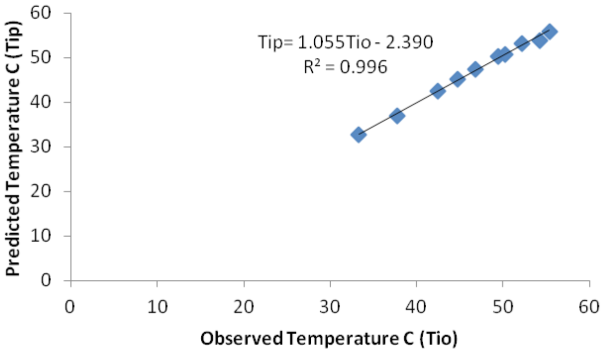

Fig. 3: Observed and predicted values of greenhouse temperature (°C) for September, 2015

Such an environment with high temperature and low relative humidity can ensure a better drying option as compared to open sun drying, which is unsafe due dust, dirt, insect and rain. The model can also be used to modify the design of the greenhouse according to the optimum temperature required.

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Nomenclature

T = temperature (°C)

T_a = ambient air temperature (°C)

T_{io} = inside greenhouse temperature (observed) °C

Y_{io} = observed relative humidity (%)

Y_{ip} = predicted relative humidity (%)

T_{ip} = inside greenhouse temperature (predicted) °C

ρ = air density (kg m^{-3})

V = volume of greenhouse (m^{-3})

C_p = specific heat of air (J kg^{-1} °C)

H_R = sensible heat

A_c = surface area of greenhouse (m^2)

N = number of air change/h

T_i = inside temperature of greenhouse (°C)

U_b = heat loss coefficient of floor

A_g = floor area of greenhouse (m^2)

W_a = humidity ratio of ambient air water ($kg_{water}/kg_{dry\ air}$)

W_i = inside humidity ratio of greenhouse ($kg_{water}/kg_{dry\ air}$)

Ver = air mass flow rate (m^3/s^{-1})

λ = latent heat of water (J kg^{-1})

ρ = atmospheric pressure (101325 Pascal)