Thermal Modeling of a Greenhouse Fish Pond System

Bikash Sarkar and G.N.Tiwari [1]
Centre for Energy Studies, Indian Institute of Technology Delhi
Hauz Khas, New Delhi – 110016, India
[1] Corresponding author e-mail: gntiwari@ces.iitd.ernet.in (G.N.Tiwari)

ABSTRACT

A thermal model has been developed for heating the aquaculture pond by even span greenhouse. Numerical computations have been performed for a typical day in the month of January, 2005 for the composite climate of New Delhi. The energy balance equations have been written considering the effects of conduction, convection, radiation, evaporation and ventilation, etc. The model has been validated with the experimental data. From the results, it was observed that the predicted values of room temperature and water temperature in the tanks of the greenhouse obtained from the proposed model exhibited fair agreement with the experimental values.

Key words: Aquaculture pond; fish; Greenhouse; Predicted greenhouse temperature; Predicted water temperature

1. INTRODUCTION

Fish culture depends not only on nutritional requirements, but also on the water temperature levels for proper growth of fish. One of the most important factors influencing fish growth is the water temperature as reported by Corey et al. (1983). In low temperature regions, the metabolic activity of fish is greatly reduced, which affects the growth of fish (Halver, 1972). Hence, the colder climate requires- the additional or supplemental heat to increase the water temperature. Generally, heat is often available for aquaculture purposes in the form of power plant waste heat, geothermal hot water and greenhouse by passive and active heating mode.

Zhu et al. (1998) investigated that greenhouse ponds are good alternatives to maintain the water temperature. As far as data of fish cultures inside the greenhouse is concerned, an extremely wide range is given in the literature, depending largely on the management practices and the species used (Wisely et. al., 1981; Wood and. Ghannudi [2], 1985; Frei and Becker, 2005). Several researchers such as Klemetson and Rogers (1985) and Losordoa and Piedrahitab (1990) reported on open air-pond temperature modeling to predict water temperature. Klemetson and Rogers (1985) tested on a greenhouse or plastic shelter pond that could achieve a 2.8 – 4.4 ^{o}C increase in water temperature for each month of the year when compared with an open – air pond. Brooks and Kimball (1987) reported that a 9 ^{o}C rise in water temperature can be achieved in January in Phoenix, USA in a solar heated aquaculture pond. Zhu et al. (1998) reported greenhouse pond system can achieve 5.2 ^{o}C improvements in the water temperature of a 1 m pond, as compared with the outside air temperature. Thermal modeling of greenhouses for agriculture, horticulture and floriculture purposes has been carried out since long back. A good number of models have been developed by several researchers, Khatry et al. (1978), Chandra and Albright (1980),Tiwari and Dhiman (1986), Santamouries et al. (1994b), Rebuck et al. (1997), Tiwari (2003) and Ghosal et al. (2005) to predict the greenhouse thermal environment under both steady and transient condition. A very few articles are available for thermal modeling of a greenhouse fish pond systems and most of them are based on agricultural greenhouse and their thermal behavior are not well understood.

Keeping in view the importance of aquaculture sector, a study has been carried out in this communication, to develop a thermal model for a greenhouse fish pond system based on the design and climatic parameters.

2. MATERIALS AND METHODS

2.1 Working Principle of a Greenhouse

The working principle of a greenhouse is shown in figure 1. During sunshine hours the solar radiation, I (t), is incident on the covering of greenhouse. A fraction of solar radiation $\{r\ I\ (t)\}$ is reflected back from the covering of greenhouse. A part of the rest radiation, $\{(1\text{-}r)\ \tau\ I\ (t)\}$, is transmitted inside greenhouse and a fraction of this $\{F_t\ (1\text{-}r)\ \tau\ I\ (t)\}$, falls on the north wall. After reflection from the surface, part of radiation, $\{\alpha_n\ F_t\ (1\text{-}r)\ (1\text{-}r_n)\ \tau\ I\ (t)\}$, is absorbed by north wall and remaining part is lost to the ambient through conduction (Gupta, 2004). There are convective and radiative heat losses from the wall to room air. Further, the rest part of solar radiation $\{F_{t1}\ (1\text{-}F_t)\ (1\text{-}r)\ \tau\ I\ (t)$ and $\{F_{t2}\ (1\text{-}F_{t1})\ (1\text{-}F_t)\ (1\text{-}r)\ \tau\ I\ (t)\}$ falls on the tanks 1 and 2, respectively. Some part $\{\alpha_g\ (1\text{-}F_{t1})\ (1\text{-}F_{t2})\ (1\text{-}F_t)\ (1\text{-}r)\ \tau\ I\ (t)\}$ comes to the floor of the greenhouse and the rest is conducted inside the ground. After absorption by the floor, there are convective and radiative heat losses from the floor to room air. The convected and radiated energy from the floor and wall raises the temperature of air inside greenhouse. There are also convective, radiative and evaporative heat losses from the water tanks to enclosed room air.

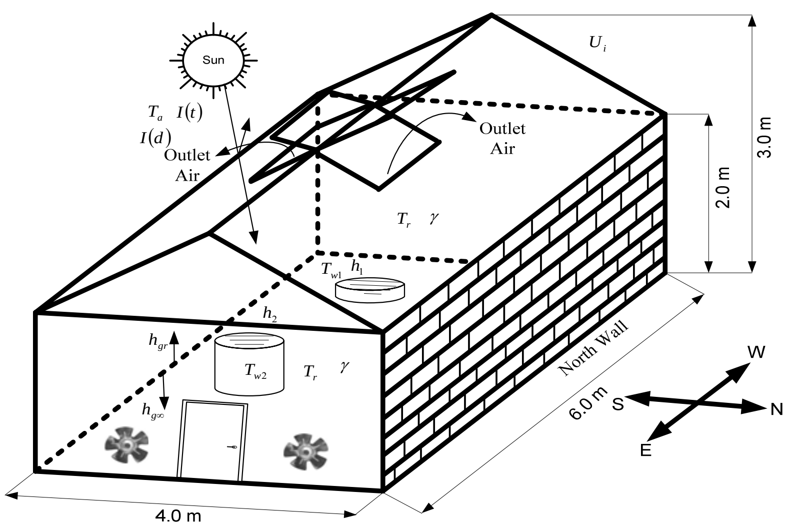

Figure 1. Layout diagram of the experimental greenhouse

2.2 Design of the Experimental Set-up

A roof type of even span greenhouse with effective floor area of 6 x 4 m^2 was used for experimental purposes, which is covered with transparent UV-stabilized low density polyethylene film (LDPE) of 250 micron at Indian Institute of Technology (IITD), New Delhi. The climate of the place was composite i.e., it remained hot dry for five months, warm and humid for three months, moderate for one month and cold for three months. This is situated at a Latitude-28°35′ N, Longitude – 77 ° 12′ E and an altitude of 216 m above mean sea level. This type of greenhouse was quite convenient and suitable for Indian climatic condition (Tiwari, 2002). The orientation of the greenhouse was from east to west direction. The inclinations of south and north roof were 27° and 27° from the horizontal plane to get maximum solar radiation. Its northern side was made up of a brick wall of 0.275 m thick for thermal storage. The height to the ridge and the height of north wall were 3m and 2m, respectively. There are provisions for two exhaust fans as well as one door in east wall of the greenhouse. Two vents each of 1 x 1m^2 are also provided one on the north roof and other on the south roof for natural ventilation purposes during over heating inside greenhouse, if any. During off-sunshine hours the greenhouse was covered with curtain cloth to prevent excessive heat losses. There are two treatments: Case-I: the cylindrical tank of capacity (636 l) is buried inside the greenhouse with water level 1.0 m (Tank-1). Case-II: the cylindrical tank of capacity (636 l) is above the ground kept inside the greenhouse with water level 1.0 m (Tank-2).

The experimental tanks were fabricated from PVC liner supported by aluminum sheet of 0.9 m diameter and 1.2 m height. The schematic view of the greenhouse with experimental set-up is shown in figure 2.

Figure 2. Photograph of the experimental set-up

2.3 Biological Experiment

The 105 days growth trial was carried out in greenhouse to evaluate growth performance and survivability during winter months without soil base. Common carp (*Cyprinus carpio*) of mean weight 26.15 $\pm$ 0.24 g (total weight $\pm$ S.D.) were stocked 25 nos in each tank. Supplementary feed was given @ 2% of body weight twice a day. To keep the water temperature stable, only 15-20 l water was exchanged daily. The fish sampling was done once in 15 days interval through out the experiment to obtained length and weight for each species.

2.4 Experimental Observation

Hourly water temperature (T_w), ambient air (T_a) and inside greenhouse air temperature (T_g) were measured by calibrated alcohol- filled, glass-bulb thermometer having least count of 1^oC. The thermometer used to measure room air temperature (T_g) was placed in the middle of the greenhouse, in mid-way from the floor, and the roof. The thermometer to measure ambient temperature (T_a) was hung outside at a similar height and its bulb was shaded from direct sun light. The covering of greenhouse, ground, bottom of the water tank and brick wall temperature was measured using Infrared thermometer of the least count 0.1^oC (Raytek-Mini temperature, Model AG-42). A digital humidity meter (Model- Lutron HT-3003) was used to measure the relative humidity (γ) inside greenhouse (with a least count of 0.1%).

The air velocity of inside greenhouse was measured with an electronic digital anemometer (Model -Lutron AM4201). It had a least count of 0.1 m/s with $\pm$ 2% on full-scale range of 0.2-40.0 m/s but these values are negligible.

Similarly, the solar intensity data was recorded (total and diffuse) both inside and outside on a horizontal surface at hourly basis. Solar intensity was measured by a Solarimeter, locally named Suryamapi (Make: CEL, India). It had a least count of 2 mW/cm^2 with $\pm$ 2% accuracy over the full-scale range of 0-120 mW/cm^2. The beam radiation was thus found by subtracting the diffused radiation from total radiation. The diffuse radiation was measured by correction method with shadow – band. The total radiation on each wall and roof was computed by using the Liu and Jordan formula (Liu and Jordan, 1962) for determining the total solar energy received by the greenhouse and was used as an input value for the computation of room and water temperature.
The hourly observations were taken for duration of 24 hours with regular and equal time intervals of 60 minutes once in a week during November, 2004 to February, 2005. However, the experimental validation was done for a typical day on 5.1.2005.

2.5 Thermal Analysis

Energy balance equations
In order to write energy balance equations for the different component of the greenhouse, the following assumptions have been made:

(i) Absorptivity and heat capacity of the enclosed air is neglected
(ii) Heat flow is one dimensional in a quasi-steady state condition.
(iii) Storage capacity of the material of roofs, walls and tanks is neglected.
(iv) There is no radiative heat exchange between the walls and roofs of greenhouse due to negligible temperature differences.
(v) Reflected parts of solar radiation from the floor and the north wall inside the greenhouse are neglected due to their small values.

Energy balance equations in greenhouse with brick north wall

a) North wall

$$\alpha_n \left\{\sum A_i I_i \tau_i\right\} F_t = h_{nr}\left(T\big|_{y=0} - T_r\right)A_n + h_{na}\left(T_n\big|_{y=0} - T_a\right)A_n \quad (1)$$

b) Water tank-1

$$\alpha_{s1} F_{t1}\left(1 - F_t\right)\sum A_i I_i \tau_i = M_1 C_1 \frac{dT_{w1}}{dt} + h_1\left(T_{w1} - T_r\right)A_1 + U_1\left(T_{w1} - \overline{T_\infty}\right)A_1 \quad (2)$$

c) Water tank-2

$$\alpha_{w2} F_{t2}\left(1 - F_{t1}\right)\left(1 - F_t\right)\sum A_i I_i \tau_i = M_2 C_2 \frac{dT_{w2}}{dt} + h_2\left(T_{w2} - T_r\right)A_{t2} + U_s\left(T_{w2} - T_r\right)A_s + U_b\left(T_{w2} - \overline{T}_\infty\right)A_b \quad (3)$$

d) Floor

$$\alpha_g\left(1 - F_t\right)\left(1 - F_{t1} - F_{t2}\right)\left\{\sum A_i I_i \tau_i\right\} = h_{gr}\left(T\big|_{x=0} - T_r\right)A_g - K_g \frac{\partial T_g}{\partial x}\Big|_{x=0} A_g \quad (4)$$

Assuming the rate of thermal energy conducted into the ground is equal to the rate of heat transferred from floor to the larger depth of ground,

$$-K_g \frac{\partial T_g}{\partial x}\Big|_{x=0} A_g = h_{g\infty}\left(T\big|_{x=0} - T_\infty\right)A_g \quad (4\text{ a})$$

At larger depths, the temperature of ground is assumed to be equal to mean annual ambient air temperature, $T_\infty = T_a$, then equation (4a) becomes

$$-K_g \frac{\partial T_g}{\partial x}\Big|_{x=0} A_g = h_{g\infty}\left(T\big|_{x=0} - T_a\right)A_g \quad (4\text{ b})$$

Putting Eq. (4 b) in Eq (4), the energy balance equation of floor becomes

$$\alpha_g\left(1 - F_t\right)\left(1 - F_{t1} - F_{t2}\right)\left\{\sum A_i I_i \tau_i\right\} = h_{gr}\left(T\big|_{x=0} - T_r\right)A_g - h_{g\infty}\left(T_g\big|_{x=0} - T_a\right)A_g \quad (4\text{c})$$

The various heat transfer coefficients used in equations (1-4) have been computed by using an appropriate formula given by Muneer (2003) and Tiwari (2002) (Appendix).

e) Greenhouse air

$$(1-\alpha_n)F_t\sum A_iI_i\tau_i + \{(1-\alpha_g)(1-F_t)(1-F_{t1}-F_{t2})\}\sum A_iI_i\tau_i$$
$$+ h_{w1}(T_{w1}-T_r)A_{t1} + h_{w2}(T_{w2}-T_r)A_{t2} + h_{nr}\left(T\big|_{y=0}-T_r\right)A_n$$
$$+ h_{gr}\left(T\big|_{x=0}-T_r\right)A_g = 0.33\,NV\,(T_r-T_a) + \sum A_iU_i(T_r-T_a) \tag{5}$$

Eliminating $T_n\big|_{y=o}$ from Eq. (1) and after rearrangement,

$$h_{nr}\left(T_n\big|_{y=0}-T_r\right) = F_1\frac{I_{effN}}{A_n} - U_n(T_r-T_a) \tag{6}$$

where $h_{nr} = h_i$

$h_i = 5.7 + 3.8v = 5.7$ (if velocity of air inside greenhouse is taken zero)

$$F_1 = \frac{h_{nr}}{h_{nr}+h_{na}}$$

$$I_{effN} = \alpha_n F_t\left(\sum A_iI_i\tau_i\right)$$

$$F_t = (\alpha\tau)_{eff1} + (\alpha\tau)_{eff2} + F_1\frac{I_{effN}}{A_n} + F_2\frac{I_{effF}}{A_g}$$

$$(\alpha\tau)_{eff1} = (1-\alpha_n)F_t\sum A_iI_i\tau_i$$

$$(\alpha\tau)_{eff2} = \{(1-\alpha_g)(1-F_t)(1-F_{t1}-F_{t2})\}\sum A_iI_i\tau_i$$

$$U_n = \frac{(h_{nr})(h_{na})}{(h_{nr}+h_{na})}$$

$$\left(\sum A_iI_i\tau_i\right) = (A_eI_e\tau_e) + (A_{ww}I_{ww}\tau_{ww}) + (A_{sr}I_{sr}\tau_{sr}) + (A_{nr}I_{nr}\tau_{nr}) + (A_sI_s\tau_s)$$

$$\tau_e = \tau_{ww} = \tau_{sr} = \tau_{nr} = \tau_s = \tau$$

Similarly eliminating $T_g\big|_{x=0}$ from Eq. (4 c) and after rearrangement,

$$h_{gr}\left(T_g\big|_{x=0}-T_r\right) = F_2\frac{I_{effF}}{A_g} - U_g(T_r-T_a) \tag{7}$$

where $h_{gr} = h_i$

$h_i = 5.7 + 3.8v = 5.7$ (when v=0)

$$F_2 = \frac{h_{gr}}{h_{gr}+h_{g\infty}}$$

$$I_{effF} = \alpha_g(1-F_t)(1-F_{t1}-F_{t2})\left\{\sum A_iI_i\tau_i\right\}$$

$$U_g = \frac{(h_{gr})(h_{g\infty})}{(h_{gr} + h_{g\infty})}$$

Now substituting, Eq. (6) and (7) in Eq. (5) and simplifying, Eq. (5) can be written

$$T_r = \frac{F_t + T_a (UA)_{eff} + h_1 T_{w1} A_{t1} + h_2 T_{w2} A_{t2}}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}} \tag{8}$$

W
here $(UA)_{eff} = \left(U_n + U_g + 0.33NV + \sum A_i U_i\right)$

$$\sum A_i U_i = A_e U_e + A_{ww} U_{ww} + A_{sr} U_{sr} + A_{nr} U_{nr} + A_s U_s$$

$$U_e = U_{ww} = U_{sr} = U_{nr} = U_s = U$$

$$U = \left[\frac{1}{h_i} + \frac{1}{h_0}\right]^{-1}$$

$$h_0 = 5.7 + 3.8v$$

$$h_1 = h_{cw} + h_{rw} + h_{ew}$$

$$h_2 = h_{cw} + h_{rw} + h_{ew}$$

Now, Eq. (8) can be written

$$h_1 (T_{w1} - T_r) A_{t1} = (UA)_{eff1} T_{w1} - (UA)_{eff2} T_{w2} - (HA)_1 \left[F_t + (UA)_{eff} T_a\right] \tag{9}$$

Putting Eq. (9) in Eq. (2) and simplifying, Eq. (2) can be written in the following first order differential equation

$$\frac{dT_{w1}}{dt} + a_1 T_{w1} + a_2 T_{w2} = f_1(t) \tag{10}$$

where $a_1 = \left[\frac{(UA)_{eff1} + U_1 A_{t1}}{M_1 C_1}\right]$

$$a_2 = -\left[\frac{(UA)_{eff2}}{M_1 C_1}\right]$$

$$f_1(t) = \left[\frac{\alpha_{w1} F_{t1} (1 - F_t) \sum A_i I_i \tau_i + U_1 A_{t11} T_{av1} + (HA)_1 \left\{F_t + (UA)_{eff} T_a\right\}}{M_1 C_1}\right]$$

$$U_1 = \left[\frac{L_1}{K_1} + \frac{L_b}{K_b}\right]^{-1}$$

$$(HA)_1 = \left[\frac{h_1 A_{t1}}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}}\right]$$

Again Eq. (8) can be written in terms of T_{w2}

$$(T_{w2} - T_r) = (UA)_{eff\,3} T_{w2} - (UA)_{eff\,4} T_{w1} - (HA)_2 \left[F_t + T_a (UA)_{eff}\right] \tag{11}$$

Putting Eq. (11) in Eq. (3) and simplifying, Eq. (3) can be written in the following first order differential equation

$$\frac{dT_{w2}}{dt} + b_2 T_{w2} + b_1 T_{w1} = f_2(t) \tag{12}$$

where $b_1 = -\left[\frac{(UA)_{eff\,4}(UA)_1}{M_2 C_2}\right] T_{w1}$

$$b_2 = \left[\frac{(UA)_{eff\,3}(UA)_1 + U_b A_b}{M_2 C_2}\right] T_{w2}$$

$$f_2(t) = \left[\frac{\alpha_{w2} F_{t2}(1 - F_{t1})(1 - F_t) \sum A_i I_i \tau_i + U_b A_b T_{av2} + (HA)_2 \{F_t + (UA)_{eff} T_a\} (UA)_1}{M_2 C_2}\right]$$

$$U_b = \left[\frac{L_2}{K_2} + \frac{L_b}{K_b}\right]^{-1}$$

$$(HA)_2 = \left[\frac{1}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}}\right]$$

$$(UA)_1 = h_2 A_{t2} + A_s U_s$$

Analytical solution of Eqs. (10) and (12) can be written by using

$T_{w1}\big|_{t=0} = T_{w1o}$ and $T_{w2}\big|_{t=0} = T_{w20}$ as

$$T_{w1} = \frac{1}{(\alpha_- - \alpha_+)} \left\{ \left[\alpha_- F_1(t) - \alpha_+ F_2(t)\right] + \left[\alpha_- e^{-C_+ t} - \alpha_+ e^{-C_- t}\right] T_{w10} + \left[\alpha_- \alpha_+ e^{-C_+ t} - \alpha_+ \alpha_- e^{-C_- t}\right] T_{w20} \right\} \tag{13}$$

and

$$T_{w2} = \frac{1}{(\alpha_+ - \alpha_-)} \left\{ \left[F_1(t) - F_2(t)\right] + \left[e^{-C_+ t} - e^{-C_- t}\right] T_{w10} + \left[\alpha_+ e^{-C_+ t} - \alpha_- e^{-C_- t}\right] T_{w20} \right\} \tag{14}$$

where $F_1(t) = \dfrac{\bar{f}_1(t) + \alpha_+ \bar{f}_2(t)}{C_+} \left(1 - e^{-C_+ t}\right)$

$$F_2(t) = \frac{\bar{f}_1(t) - \alpha_- \bar{f}_2(t)}{C_-}\left(1 - e^{+C_- t}\right)$$

From Eq. (13 and 14) water temperatures can be determined for analysis. After knowing the T_{w1o} and T_{w2o} the temperature of air inside greenhouse can be determined using Eq. (8). $\alpha_{\pm}$ and $C_{\pm}$ are the roots of quadratic equation.

3. COMPUTATION, RESULTS AND DISCUSSION

The developed thermal model has been solved with the help of computer program based on Matlab software. The values of input parameters for validation have been given in table 1. Equations 13 and 14 have been used to evaluate water temperature of both the tanks. After knowing the water temperatures (T_w), the room air temperature has been obtained from Eq.(8).The climatic parameters for the model are ambient temperature, solar intensity, wind velocity and relative humidity inside greenhouse (averaged over one hour period). The output of the programme gives the hourly average temperature of greenhouse enclosure and water temperature. In order to verify the accuracy of the developed model, experimental validations were carried out for a typical day. The closeness of predicted and experimental values of greenhouse room air and water temperatures has been presented with coefficient of correlation (r) and root mean square of percent deviation (e) (fig. 4-7).

Table 1. Input parameters used for computation

Parameters	Values	Parameters	Values	Parameters	Values
A_{ew}	8.3 m^2	F_{t2}	0.0589	L_{as}	0.012 m
A_{nw}	12.0 m^2	h_i	5.7 $W/m^2\ {}^oC$	L_n	0.275m
A_{nr}	13.8 m^2	$h_{g\infty}$	0.52 $W/m^2\ {}^oC$	M_{w1}=M_{w2}	636 Kg
A_{sw}	12.0 m^2	h_{na}	5.7 $W/m^2\ {}^oC$	N	4
A_{sr}	13.8 m^2	h_{gr}	5.7 $W/m^2\ {}^oC$	v	0.1-0.3 m/s
A_{ww}	10.0 m^2	h_{nr}	5.7 $W/m^2\ {}^oC$	V	60 m^3
A_g	24.0 m^2	K_g	0.52 W/m^oC	γ	0.25-0.93
A_{t1}=A_{t2}=A_b	0.636 m^2	K_1=K_2=K_{ps}	0.16 W/m^oC	α_g	0.40
C_{w1}=C_{w2}	4190J/Kg^{o}C	K_{as}	211 W/m^oC	α_n	0.60
e_w	0.9	K_n	0.84 W/m^oC	α_{w1}	0.90
Ft	0.31	L_g	1.0m	α_{w2}	0.90
F_{t1}	0.0265	L_1= L_2=L_{ps}	0.001m	τ	0.60

The hourly variations of total solar radiation available on the cover of greenhouse, room air temperature and ambient air have been shown in figure 3.

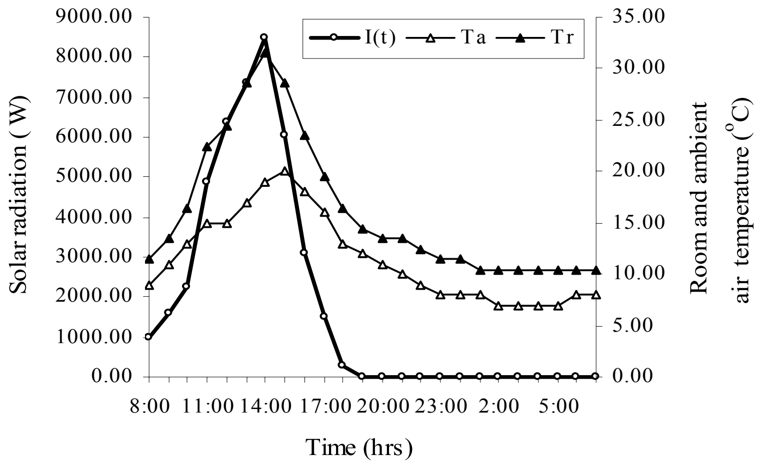

Figure 3. Hourly variations of total solar radiation, observed room and ambient air temperature on 5.01.2005

The total radiation on the cover of greenhouse have been computed by using Liu and Jordon formula for known hourly beam and diffuse radiation (Tiwari,2002). From the figure, it is seen that the global solar radiation varies from 293.27 - 8500.38W. The room air temperature increases proportionately with increase of solar intensity and vice-versa. The predicted and experimental water temperatures have been plotted in figures 4 and 5, respectively.

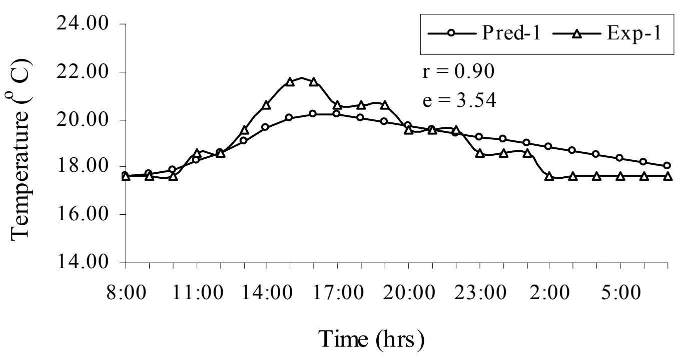

Figure 4. Hourly variations of predicted and observed water temperature in the tank-1

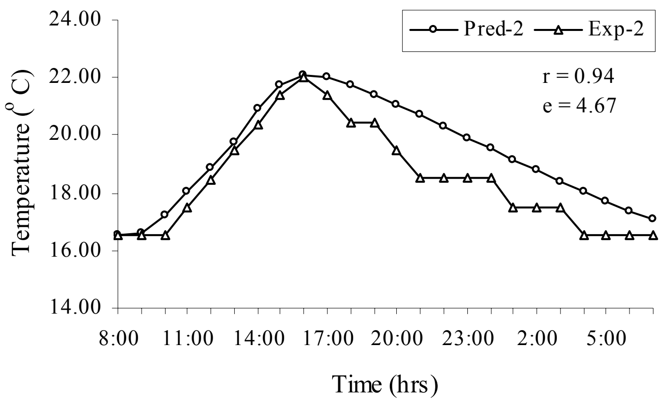

Figure 5. Hourly variations of predicted and observed water temperature in the tank-2

It has been observed that in tank-1 showed uniform water temperature throughout the day and night due to lower heat losses, while tank-2 showed more heat losses resulting higher fluctuations of water temperature. From our study, tank 2 showed higher water temperature in day time between 1400- 1500 h due to large variations of water and inside greenhouse air temperature resulting in higher fluctuations of water temperature and fast release of heat in night time. In case of tank 1, showed uniform water temperature throughout the day and night due to contact with earth, which has higher heat capacity. Daily variation of inside ground temperature at the depth of about 1 m is constant (ASHRAE, 1982). For the climate of Delhi, this temperature remains in the range of 22-28 ^{o}C as reported by Khatry et al. (1978) and Ghosal et al. (2005), which is normally higher in winter and lower in summer than the temperature of ambient air. Hence, water temperature in tank 1 remained uniform due to exchange of heat between soil and water through conduction. The predicted and experimental results showed fair agreement with coefficient of correlation and root mean square of percent deviation to be 0.90 as well as 3.54% for tank-1 and 0.94 and 4.67% for tank-2, respectively.

The hourly variations of predicted and experimental room air temperature have been presented in figure 6.

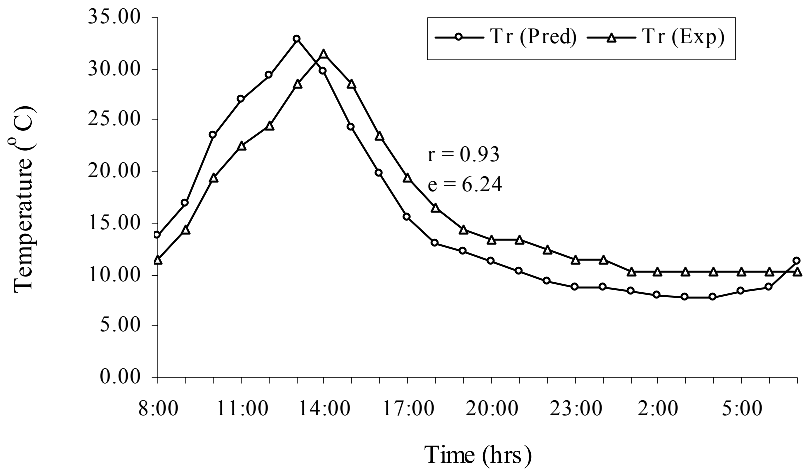

Figure 6. Hourly variations of predicted and observed room temperature

From the figure, it is seen that the room temperature reaches maximum (1300 to 1400 h) during sunshine hours while minimum values were shown at night time (0100 to 0700 h). The predicted room air temperature exhibited good agreement with the values of coefficient of correlation (0.93) and root mean square percent deviation (6.24%), respectively.

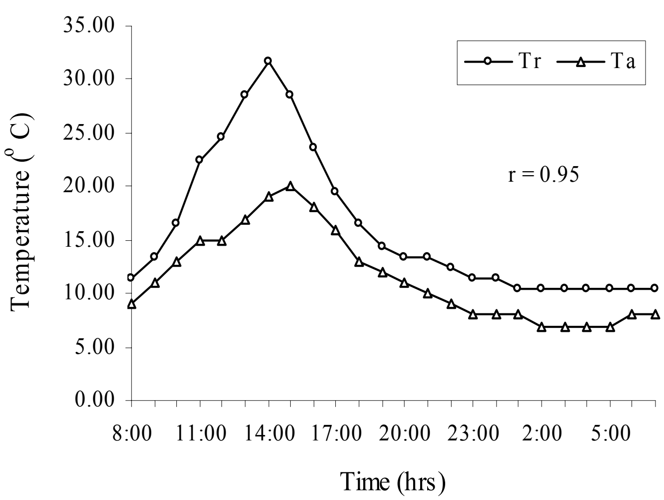

Figure 7. Hourly variations of ambient and observed greenhouse air temperature

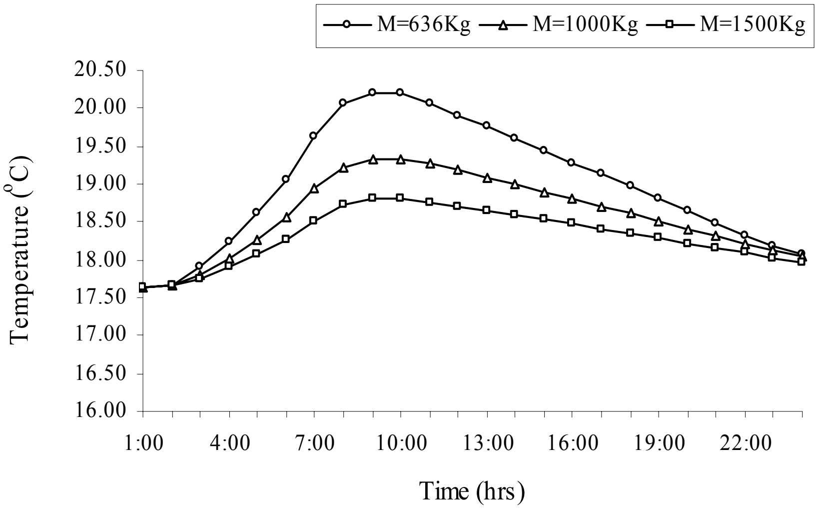

Figure 8. Hourly variations of effect of water mass and water temperature in the tank-1

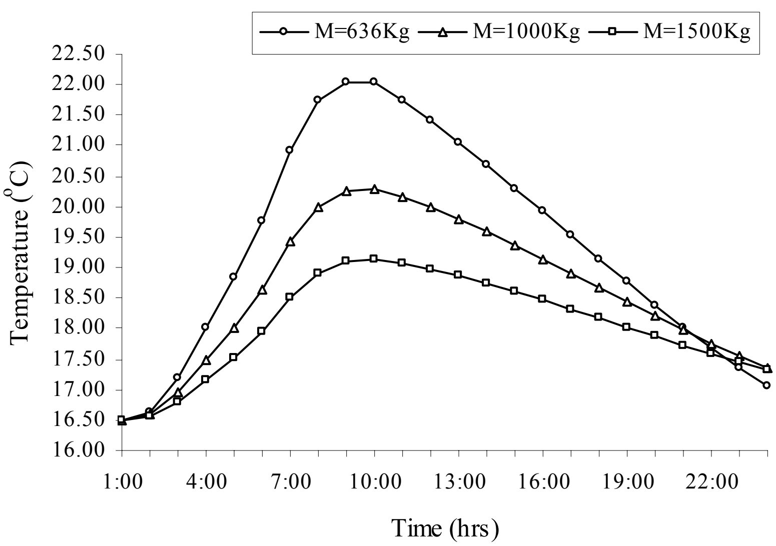

Figure 9. Hourly variations of effect of water mass and water temperature in the tank-2

Similarly, the calculated values of room temperature and experimental outside ambient temperatures have been shown in figure 7. From our study, it was observed that there is an increase of 3.58 – 6.79 ^{o}C (5.18 ^{o}C) water temperature as compared to open water. The results are within the range as reported by Klemetson and Rogers (1985), Brooks and Kimball (1987) and Zhu et al. (1998). The slight variation of water temperature may be due to change in climatic parameters or location of the experimental sites. The effect of water mass on water temperature has been shown in figure 8 and 9. It is seen from the figures that the water temperature decreases sharply with increase of water mass from 636 to 1500 kg in both the treatments. The lowering in water temperatures in both the tanks may be attributed to higher specific heat capacity of water by the increased water mass.

Mean individual weight of common carp in the tanks increased over the 105 days of the experiment. The total body weight increased from 26.15 $\pm$ 0.24 g to 116.40 $\pm$ 0.92 g and 112.80 $\pm$ 0.62 g, for tank 1 and 2, respectively. In both the tanks, the fish appeared healthy and no mortality was observed. The results showed that carp growth was modestly but statistically significant.

4. CONCLUSION

i) The mathematical model presented in this paper is quite simple and very comprehensive to predict greenhouse air and water temperature.
ii) On an average, the even span passive greenhouse can increase 3.58 – 6.79 ^{o}C (5.08 ^{o}C) higher temperature, as compared with the out side water temperature for the month of January,2005 in the composite climate of New Delhi.
iii) For uniform water temperature inside the greenhouse, the tank should be buried in the ground.
iv) The predicted and experimental values of greenhouse air and water temperatures are in fair agreement.

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6. NOMENCLATURE

A	area (m^2)
C	specific heat (J/kg ^oC)
e	root mean square of percent deviation (percentage)
F_t	fraction of solar intensity falling on north wall
F_{t1}	fraction of solar intensity falling on tank-1
F_{t2}	fraction of solar intensity falling on tank-2
h_i	heat transfer coefficient from greenhouse cover to inside greenhouse(W/m^2 ^oC)
h_o	heat transfer coefficient from greenhouse cover to the ambient environment (W/m^2 ^oC)
h_{gr}	heat transfer coefficient from floor to the air in greenhouse (W/m^2 ^oC)
$h_{g\infty}$	heat transfer coefficient from floor of greenhouse to higher depth of ground (W/m^2 ^oC)
h_{na}	heat transfer coefficient from the surface of north wall to the ambient air (W/m^2 ^oC)
h_{nr}	heat transfer coefficient from the surface of north wall to the greenhouse air (W/m^2 ^oC)
h_{cw}	convective heat transfer coefficient from water to greenhouse cover (W/m^2 ^oC)
h_{rw}	radiative heat transfer coefficient from water to sky (W/m^2 ^oC)
h_{ew}	evaporative heat transfer coefficient from water to greenhouse cover (W/m^2 ^oC)
h_1	sum of convective, radiative and evaporative heat transfer coefficient from the water surface of tank 1to room air (W/m^2 ^oC)
h_2	sum of convective, radiative and evaporative heat transfer coefficient from the water surface of tank 2 to room air (W/m^2 ^oC)
I	solar radiation falling on inclined surface or greenhouse cover (W/m^2)
I_b	beam radiation falling on horizontal surface(W/m^2)
I_d	diffuse radiation falling on horizontal surface (W/m^2)
I_h	solar radiation falling on horizontal surface (W/m^2)

K_g	thermal conductivity of ground (W/m^{o}C)
Kps	thermal conductivity of plastic (W/m^{o}C)
Kas	thermal conductivity of aluminum (W/m^{o}C)
L	length of greenhouse (m)
L_g	thickness of ground (m)
L_n	thickness of north brick wall (m)
L_1,L_2 &L_{ps}	thickness of plastic liner (0.001m)
L_{as}	thickness of aluminum sheet (0.012 m)
M	mass(kg)
N	number of air changes per hour in greenhouse
r	correlation coefficient (decimal)
T_w	water temperature (^{o}C)
P_w	saturated vapor pressure at water temperature (Pa)
P_g	saturated vapor pressure at greenhouse air temperature (Pa)
t	time in seconds
T	temperature (^{o}C)
U_i	overall heat loss coefficient from greenhouse air to the ambient air through greenhouse cover (W/m^2 ^{o}C)
U_g	overall heat transfer coefficient from greenhouse air to the floor (W/m^2 ^{o}C)
U_n	overall heat transfer coefficient from greenhouse air to the ambient air through north wall (W/m^2 ^{o}C)
U_o	overall convective and radiative heat transfer coefficient from inside wall surface to ambient air (W/m^2 ^{o}C)
U_b	overall heat transfer coefficient from bottom of tank 2 to underground (W/m^2 ^{o}C)
U_s	overall heat transfer coefficient from side of tank1 to greenhouse air (W/m^2 ^{o}C)
v	velocity of air (m/s)
V	volume of greenhouse (m^3)
x	position coordinate or depth of ground (m)

6.1 Greek Letters

α	absorptivity (decimal)
γ	relative humidity (decimal)
ε	emissivity, dimensionless
τ	transmissivity of greenhouse cover, dimensionless
ρ	density (kg/m^3)
σ	stefan-Boltzmann constant (5.67x10^{-8} W/m^2 k^4)
∞	infinity (ground at larger depth)

6.2 Subscripts

a	air or ambient air
e	east wall of greenhouse
g	ground in greenhouse or floor of greenhouse

i	number of walls and roofs of greenhouse
n	north wall of greenhouse
w	water
1	fish rearing tank-1 burried inside greenhouse
2	fish rearing tank-2 above the ground
r	room (greenhouse enclosure)
sw	south wall of greenhouse
er	east roof
gc	greenhouse cover
nr	north roof
sr	south roof
wr	west roof of greenhouse
ww	west wall of greenhouse
$\big\rvert_{x=0}$	surface of floor of greenhouse
$\big\rvert_{y=0}$	surface of north wall of greenhouse

7. APPENDIX

Following expressions have been used to evaluate various heat transfer coefficients, Muneer (2003) and Tiwari (2002):

$$h_{na} = \left[\frac{L_n}{K_n} + \frac{1}{h_0}\right]^{-1}$$

h_{cw}= 2.8+3.0v (for $0 \le v \le 7$ m/s, by Watmuff et al. (1977)

$$h_{rw} = \frac{\varepsilon_{eff}\,\sigma\left[(T_w + 273)^4 - (T_g + 273)^4\right]}{T_w - T_g}$$

$$h_{ew} = \frac{16.273\,x10^{-3}\ h_{cw}\left(P_w - \gamma\ P_g\right)}{T_w - T_g}$$

$$\varepsilon_{eff} = \left[\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_{gc}} - 1\right]^{-1},\ \varepsilon_w = \varepsilon_{gc} = 0.9$$

$$P\left(T_w\right) = \exp\left(25.317 - \frac{5144}{273 + T_w}\right)$$

$$P\left(T_g\right) = \exp\left(25.317 - \frac{5144}{273 + T_g}\right)$$

$$U_s = \left[\frac{L_s}{K_s} + \frac{L_s}{K_s} + \frac{1}{h_i}\right]^{-1}$$

$$h_{g\infty} = \left[\frac{L_g}{K_g} \right]^{-1}$$

$$(UA)_{eff\,1} = A_{t1}\ h_1 \left[\frac{(UA)_{eff} + h_2 A_{t2}}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}} \right]$$

$$(UA)_{eff\,2} = \left[\frac{A_{t1} h_1 h_2 A_{t2}}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}} \right]$$

$$(UA)_{eff\,3} = \left[\frac{(UA)_{eff} + h_1 A_{t1}}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}} \right]$$

$$(UA)_{eff\,4} = \left[\frac{A_{t1}\ h_1}{(UA)_{eff} + h_1 A_{t1} + h_2 A_{t2}} \right]$$