



Asian Journal of Scientific Research

ISSN 1992-1454

science
alert
<http://www.scialert.net>

ANSI*net*
an open access publisher
<http://ansinet.com>

Modeling the Thermal Performance of Solar Heated Fish Pond: An Experimental Validation

¹Lopa Ghosh, ¹G.N. Tiwari, ¹Tribeni Das and ²Bikash Sarkar

¹Centre for Energy Studies, Indian Institute of Technology Delhi Hauz Khas,
New Delhi-110016, India

²Central Institute of Freshwater Aquaculture (Indian Council of Agricultural Research)
Kausalyaganga, Bhubaneswar-751002, India

Abstract: An analytical model is presented to study the effectiveness of a low cost arch shape greenhouse used for heating the fishpond during extreme winter. The model was solved for the climatic conditions of New Delhi (Latitude-28° 35' N, Longitude-77° 12' E and an altitude of 216 m above mean sea level). Parametric studies involved the effects of different greenhouse fishpond related parameters including depth of pond water, transmissivity of greenhouse cover and number of air changes in the greenhouse on water heating in the fishpond. The thermal performance of fishpond was assessed in terms of thermal load leveling. A 4.76-5.83°C rise in water temperature could be achieved as compared to open pond of the day. The maximum heat gain and loss are around 14:00 to 17:00 and 1:00 to 7:00 h of the day, respectively. From production point of view greenhouse fish pond showed better performance compared to open pond.

Key words: Greenhouse, fish, water temperature, thermal modeling, solar radiation

INTRODUCTION

In recent years, the fish farming in greenhouse is gaining popularity in the colder region of India. Usually, the water temperature of this region drops below 15°C in the winter season. Temperature is a critical water quality parameter in aquaculture. Because fish are ectothermic, temperature affects their growth rate (Davis, 1961; Galtsoff, 1964). For indoor rearing conditions, heater and chillers are commercially available to do this, but for outdoor earthen pond, controlling the water temperature is more difficult and expensive.

Greenhouse is suitable to enhance water temperature. Thermal modeling of greenhouse in relation to heating and cooling have been experimented in different climatic conditions and found effectively for crop production and drying (Jain, 2002). Over the past few years, many researchers reported fish or prawn culture in greenhouse (Ra'anan and Cohen, 1980/1981; Wood and Ghannudi, 1985; Kumar *et al.*, 2000; Frei and Becker, 2005; Ghosh *et al.*, 2007). Information regarding design aspects and thermal performance of GH-FP system is very limited. Mathematical modeling is important tools for determine the energy efficient design as well as predicting overall system performance (Tiwari and Sarkar, 2007).

Therefore, the objective of the present study is to analyze the thermal performance of the arch shape greenhouse by developing mathematical model and to study the effect of greenhouse fish pond related parameters on water temperature during winter period.

Corresponding Author: Lopa Ghosh, Centre for Energy Studies, Indian Institute of Technology Delhi Hauz Khas,
New Delhi-110016, India

MATERIALS AND METHODS

Description of Greenhouse

The greenhouse experiment was carried out during 15 October, 2006 to Feb, 2007 at Solar Energy Park, IIT Delhi (Latitude-28° 35' N, Longitude-77° 12' E and an altitude of 216 m above mean sea level). The arch shape greenhouse having length 4.5 m, width 3.0 m and central height of 2.0 m was used for experimental purpose. The effective floor and water area of greenhouse were 13.5 and 8 m², respectively. It had an advantage of being economic and easy to construct. The orientation of the greenhouse was from east to west direction. The volume of the greenhouse enclosure was 19 m³. The frame of the greenhouse was constructed from aluminum flat and is covered by UV-stabilized low-density polyethylene film. The view of the experimental greenhouse (Fig. 1).

Principles of Greenhouse

During sunshine hours total solar radiation received by the greenhouse cover is partly reflected, absorbed and transmitted inside the greenhouse. A large portion of inside radiation is absorbed by water. This is utilized in raising the water temperature. The floor absorbs rest part of radiation. This absorbed thermal energy is conducted and convected into the ground and room air, respectively. During off sunshine hours, when room air temperature drops, a process of convective, evaporative and radiative heat exchanges takes place among floor, water and room air. This heat exchange is a form of long wave radiation, which is trapped inside the transparent greenhouse cover and consequently heats up the room air, which in turn leads to the sudden fall in water temperature (Fig. 2).

Experimentation

Two rectangular ponds of size 4×2 m with depth of 1.1 m were constructed inside and outside of greenhouse. The effective water volume is 8 m³ with water depth level maintained at 1.0 m. The ponds were stocked with 40 numbers of fish with Indian major carp such as *Catla catla* (average weight 2.45±0.27 g; average length 7.4±0.3 cm) and *Labeo rohita* (average weight 2.53±0.19 g; average length 7.6±0.28 cm) in the ratio of 3:1 in each pond. The tanks were prepared as per the recommended practices (APHA, 1985). The fish were fed primarily with supplementary feed (ground nut oil cake 50% and rice bran 50%) at the rate of 2% live fish biomass twice a day throughout the 137 days experimental period. Feeding rates were adjusted periodically for weight gain by fish. The fish sampling was done at 15 days interval to measure length and weight for each species. During study period no fish were died in both systems.



Fig. 1: View of the experimental greenhouse

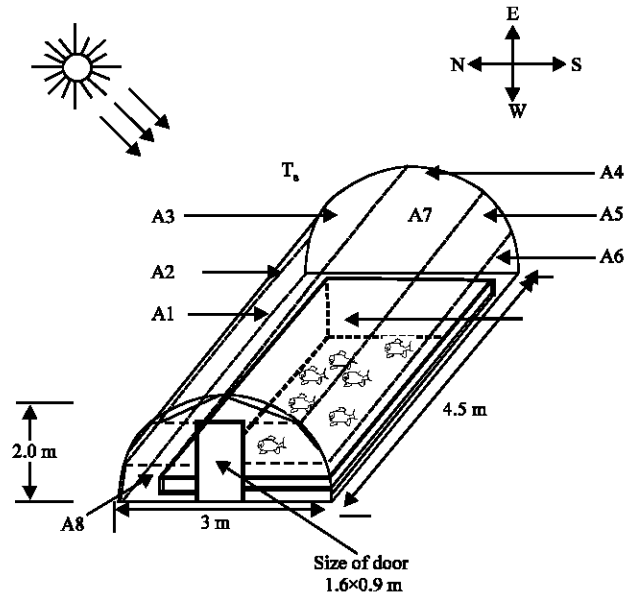


Fig. 2: Cross-sectional view of the greenhouse

Data Acquisition

Total solar radiation on a horizontal water surface on an hourly basis was measured by a datalogger model R10 provided with probes. The average radiation based on 10 h duration sunshine was taken into consideration. Water temperature (T_w) at surface (0 to 4 cm), ambient air (T_a) and inside greenhouse air temperature (T_g) were measured by alcohol-filled glass bulb thermometer having least count of 1°C on an hourly basis. A digital humidity meter was used to measure the relative humidity (γ) inside greenhouse with a least count of 0.1%. The air velocity was measured with an electronic digital anemometer (least count 0.1 m sec^{-1}).

THERMAL MODELING

Energy Balance Equations

The energy balance equations for the different parts of the GH-FP are written on the following assumptions:

- Absorptivity and heat capacity of air is neglected.
- Heat flow is one-dimensional and in a quasi-steady state condition.
- Storage capacity of the greenhouse covering materials is neglected.
- Radiative heat exchange between the walls and roofs of greenhouse is negligible.
- There is no stratification along the depth of water as we consider a shallow pond.
- GH-FP is east-west direction.
- Fish in the tank are very less in number and small in size.

The energy balance equation for various components like fishpond, greenhouse air of greenhouse can be written as follow:

a) For fish pond:

$$\alpha_w \sum_{i=1}^8 A_i I_i \tau_i \sum \mu_j e^{n_j d_w} = M_w C_w \frac{dT_w}{dt} + h (T_w - T_r) A_w + U_b \left(T_w - \bar{T}_{\infty} \right) A_b + U_s \left(T_w - \bar{T}_{\infty} \right) A_s \quad (1)$$

Where:

$$\sum \mu_j e^{n_j d_w} = \text{Attenuation factor (Tiwari, 2002)}$$

b) For greenhouse air:

$$h (T_w - T_r) A_w = (UA)_{\text{eff}} (T_r - T_a) \quad (2)$$

After simplifying, the Eq. 2 can be written as:

$$T_r = \frac{A_w h T_w + (UA)_{\text{eff}} T_a}{A_w h + (UA)_{\text{eff}}} \quad (3)$$

Now, Eq. 3 can be rewrite

$$A_w (T_w - T_r) h = A_w h \left\{ (UA)_{\text{eff}} (T_w - T_a) \right\} \quad (4)$$

Substituting Eq. 4 in the Eq. 1 and simplifying, Eq. 4 can be written in the following first order differential equation.

$$\frac{dT_w}{dt} + a T_w = f_1(t) \quad (5)$$

Where:

$$a = \frac{A_w h (UA)_{\text{eff}} + U_b A_b + U_s A_s}{M_w C_w}$$

$$f_1(t) = \frac{\alpha_w \sum A_i I_i \tau_i + (UA)_{\text{eff}} A_w h T_a + \bar{T}_{\infty} (U_b A_b + U_s A_s)}{M_w C_w}$$

The analytical solution of Eq. 5 can be written as:

$$T_w = \frac{\bar{f}(t)}{a} (1 - e^{-at}) + T_{w0} e^{-at} \quad (6)$$

Where:

T_{w0} = The water temperature at $t = 0$

$\bar{f}_1(t)$ = The average value of $f_1(t)$ for the time interval between 0 and t

a = Constant during the time

Once the numerical value T_w is determined, then the greenhouse air temperature T_r can be evaluated from Eq. 3.

Thermal Performance of the System

Thermal Load Leveling (TLL)

Since the greenhouse air temperature $T(r)$ is a function of time and ambient temperature. The greenhouse air temperature plays the vital role on water temperature, which affects the health of the fish in the pond. The TLL for water of fishpond can be defined as:

$$TLL = \frac{T_{w \max} - T_{w \min}}{T_{w \max} + T_{w \min}} \quad (7)$$

TLL gives an idea about the fluctuation of temperature of water in the fishpond. For the given temperature difference, the denominator should be as maximum as for fish growth due to the heating in water; therefore, TLL should be minimum for winter condition (Tiwari and Sarkar, 2007). Therefore, TLL is an important index for optimizing the parameters of fishpond while heating with greenhouse.

STATISTICAL ANALYSIS

Coefficient of Correlation (r)

When predicted values are validated with the experimental data then correlation between predicted and experimental values is presented with a coefficient known as coefficient of correlation. The coefficient of correlation can be evaluated with the following expression (Chapra and Canale, 1989).

$$r = \frac{N \sum x_i y_i - \sum (x_i) \sum (y_i)}{\sqrt{N \sum x_i^2 - (\sum x_i)^2} \sqrt{N \sum y_i^2 - (\sum y_i)^2}} \quad (8)$$

Root Mean Square of Percent Deviation (e)

The prediction is done with the help of thermal modeling. The predicted values are validated with experimental data. The closeness of predicted values and experimental data can be presented in terms of root mean square of percent deviation. The expression used for this purpose is as follows (Chapra and Canale, 1989).

$$e = \sqrt{\frac{\sum (e_i)^2}{n}} \quad (9)$$

Where:

$$e_i = \frac{X_{\text{pred}} - Y_{\text{exp}}}{X_{\text{pred}}}$$

COMPUTATIONAL PROCEDURE AND INPUT PARAMETERS

The developed thermal model has been solved with the help of MATLAB-7.0 software. Numerical calculations were made corresponding to the hourly variations of water, ambient air, inside greenhouse air, greenhouse cover temperature, solar radiation, relative humidity and wind velocity for a typical winter day i.e., is on 17.1. 2007 of New Delhi, India. Since, 17th January was the coldest day during the experimentation. Values of solar intensity (total and diffuse) recorded on a horizontal surface

Table 1: Design parameters used for computation

Parameters	Values	Parameters	Values
at_u	0.35	H	2.0 (m)
A_w	8.00 (m ²)	K_b	1.279 (W m ⁻² °C)
A_b	8.00 (m ²)	K_s	0.84 (W m ⁻² °C)
A_s	12.00 (m ²)	K_g	0.52 (W m ⁻² °C)
A_1	3.60 (m ²)	L_b	0.1 (m)
A_2	3.40 (m ²)	L_g	1.0 (m)
A_3	5.40 (m ²)	L_s	0.15 (m)
A_4	5.40 (m ²)	M_w	8000 (kg)
A_5	3.40 (m ²)	N	10
A_6	3.60 (m ²)	T_{∞}	25°C
A_7	6.53 (m ²)	v	0 m sec ⁻¹
A_8	6.53 (m ²)	K_p	0.84 (W m ⁻² °C)
C_w	4190.00 (J kg ⁻¹ °C)	V	19 (m ³)
dw	1.00 (m)	γ	0.33-0.83
e_w	0.90	α_w	0.90
e_{gc}	0.90	τ	0.65
h_i	5.70 (W m ⁻² °C)		

outside the greenhouse were converted on each section ($i = 1$ to 8) on greenhouse cover with the help of Liu and Jordon (1962) formula. This was multiplied by its respective area and effective transmissivity of greenhouse cover in order to obtain solar radiation transmitted inside greenhouse. While studying the effects of parameters on water temperature like depth of pond water, transmissivity and number of air changes of greenhouse parameters were changed and others were kept constant. In order to verify the accuracy of the model, the predicted values of greenhouse water and room air temperature were validated against the experimental results (Table 1).

RESULTS AND DISCUSSION

The hourly variations of average solar radiation and ambient air temperature have been shown in Fig. 3. The solar radiation varies from 80-470 W m⁻² of the day. Maximum solar radiation was observed 12:00 to 13:00 h of sunshine period. The greenhouse air temperature also increases proportionately with increase of solar intensity and vice-versa.

The greenhouse air temperature was predicted from Eq. 3. The room temperature reaches maximum at 14:00 to 15:00 during sunshine hours, while minimum values were shown at night between 4:00 to 7:00 h (Fig. 4). The predicted room air temperature exhibited good agreement with experimental air temperature with coefficient of correlation (0.91) and root mean square percent deviation (5.87%), respectively. The predicted fish pond water temperature has been evaluated by using the developed Eq. 6. From the Fig. 5, it is noted that the water temperature reaches maximum between (12:00 to 16:00) during sunshine hours while minimum values were observed at night between (5:00 to 6:00). From present study, it was observed that there is an increase of 4.76-5.83°C ($\Delta T = 4.9^\circ\text{C}$) of water temperature as compared to outdoor pond water. Similar observations were obtained by Zhu *et al.* (1998) and Tiwari and Sarkar (2007). In this study slight variation of water temperature may be attributed due to the shape of greenhouse and climatic parameters. There is a good correlation exhibited between predicted and experimental water temperature with the values of coefficient of correlation ($r = 0.94$) and root mean square percent deviation ($e = 3.47\%$), respectively. The depth of fishpond was varied from 0.5 to 1.0 m with 0.5 m increment, increasing the pond depth indicates absorbed more solar radiation but less fraction of solar radiation available in pond water which results lowering water temperature (Fig. 6). The results also reveal that increasing depth of water is not suitable towards the thermal gain. However, shallow pond shows better results for heat gaining. The transmissivity mainly depends on the property of the greenhouse cover materials. The increase of transmissivity has a negligible effect on the water mass (Fig. 7). There is slight increase of water temperature with

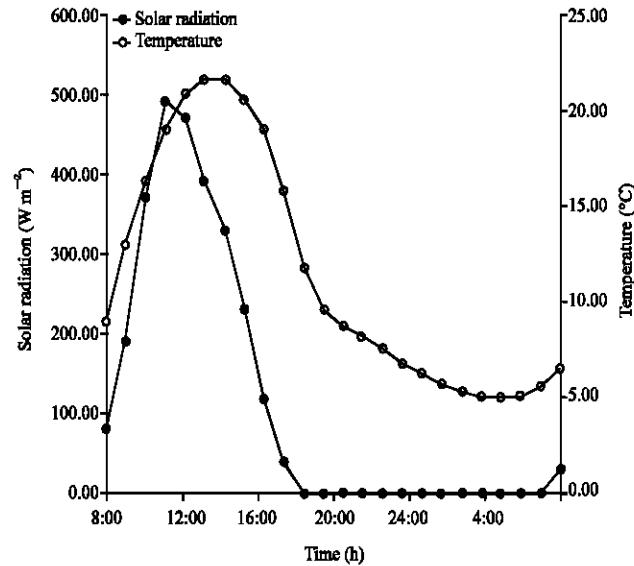


Fig. 3: Diurnal variation of average solar radiation and ambient temperature on 17.1.2007

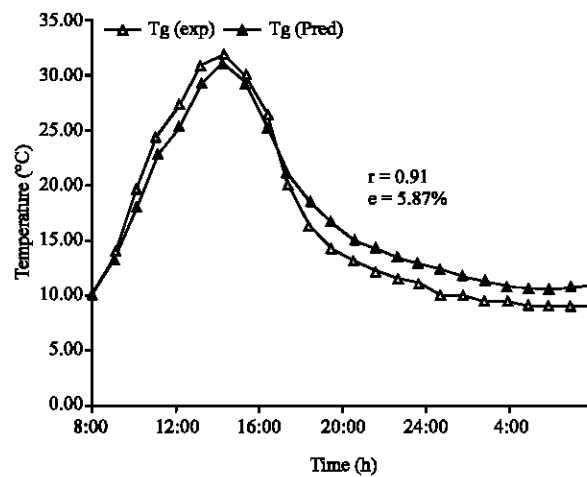


Fig. 4: Hourly variations of predicted and experimental room temperature inside greenhouse

increasing transmissivity during sunshine hours, but due to availability of more solar radiation results in increasing greenhouse room air and simultaneously water temperature. The air change in GH-FP is necessary to provide fresh air and removal of hot air from greenhouse. Number of air changes in greenhouse affects the variation of air temperature, which is ultimately affects the water temperature in the pond. The water temperature decreases with the increase of the number of air changes in greenhouse. This may occur with the increase of number of air changes, convective and evaporative heat transfer from pond water surface to the greenhouse air is enhanced (Fig. 8). The larger the depth of water gives lower TLL, which is most favorable for fishpond. TLL is declined from 0.10 to 0.09 with the change of pond water depth from 0.5 to 1.0 m. However, higher thermal performance can be obtained in larger depth of water (Fig. 9). There are no results available for comparison. Because most of the previous studies on thermal modeling dealt with the even span shape greenhouse without TLL.

Table 2: Final weight, length and total production in open and greenhouse pond after 137 days experimental period

Types of fish	Initial		Final			
			Open pond		Green house pond	
	Weight (g)	Length (cm)	Weight (g)	Length (cm)	Weight (g)	Length (cm)
<i>Catla catla</i> (30 No.)	2.45±0.27	7.4±0.3	19.46±0.24	11.5±0.22	35.22±0.22	14.2±0.24
<i>Labeo rohita</i> (10 No.)	2.53±0.19	7.6±0.28	15.16±0.32	10.5±0.28	31.60±0.28	14.1±0.21
	2.45×30 = 73.5		19.46×30 = 583.80		35.22×30 = 1056.6	
	2.53×10 = 25.3		15.16×10 = 151.60		31.60×10 = 316.0	
Total Weight (g)	98.8		735.4		1372.6	
Production (kg)	-		0.735-0.099 = 0.636		1.372-0.099 = 1.273	

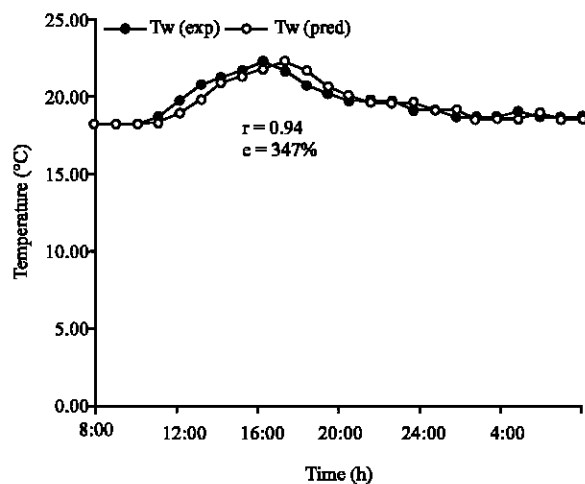


Fig. 5: Hourly variations of predicted and observed water temperature inside greenhouse

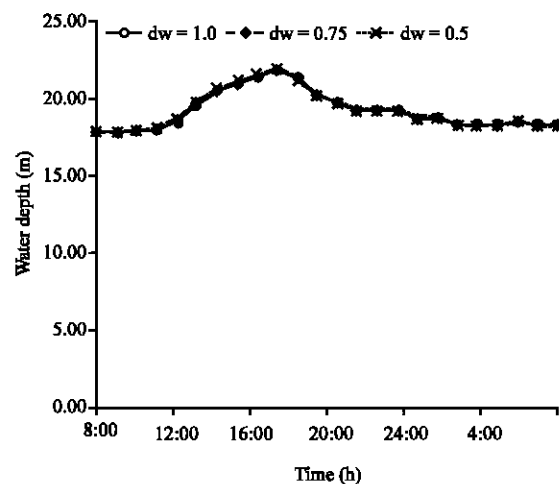


Fig. 6: Effect of depth of pond mass on water temperature

Growth performance revealed that of *Catla catla* was higher in both the systems compared to *Labeo rohita* (Table 2). From present results we can conclude that the fish management especially the species composition plays a vital role in this respect. Total fish production in the greenhouse pond

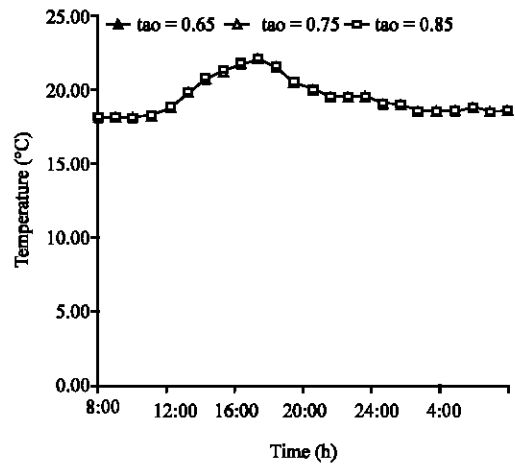


Fig. 7: Effect of transmissivity of greenhouse cover on water temperature

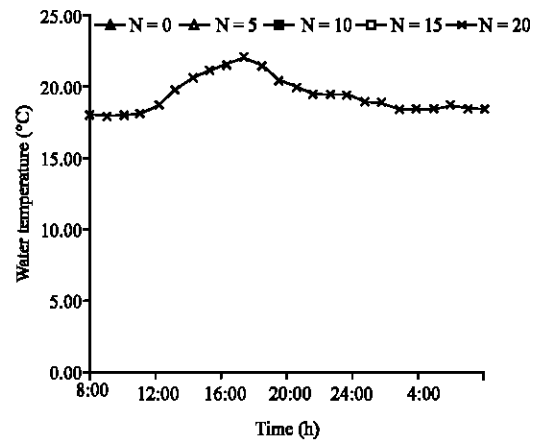


Fig. 8: Effect of number of air changes per hour on water temperature

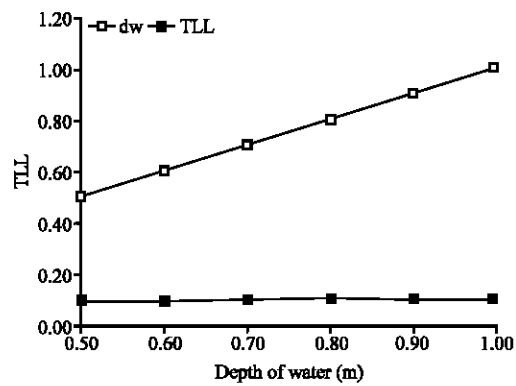


Fig. 9: Effect of depth of pond on Thermal Load Leveling (TLL)

was about 1.273 kg. On the other hand, the open pond delivers a lower fish yield of 0.636 kg. This is reflected in the substantially higher metabolic growth rate in greenhouse pond compared to open pond. The difference in fish production in both the systems clearly indicates that the better thermal performance of the greenhouse.

CONCLUSION

The greenhouse fishpond heating has been studied with the help of thermal modeling. The greenhouse fishpond system can provide 18.5 to 21.5°C against 13.0 to 15.5°C temperature of open pond water for fish farming during winter study period. The effects of different parameters on thermal performance of greenhouse reveal that 1.0 m pond water depth is suitable to get optimum water temperature during winter period. Greenhouse pond contributes significantly ($\Delta T = 4.9^\circ\text{C}$) more temperature over open pond during winter period. So, before designing any greenhouse pond, one should keep in mind that TLL should be minimized for better thermal efficiency of the pond. Difference in fish production was also greater in greenhouse pond than open pond due to higher water temperature prevailed during study period. On the basis of the present study it can be concluded that the developed thermal model is quite simple and reliable to predict water temperature for greenhouse fishpond in any location.

ACKNOWLEDGMENTS

The authors acknowledge the financial support provided by the Department of Science and Technology, Govt. of India. The authors are also thankful to Dr. (Mrs.) Vinita Sharma, Scientist F and Dr. (Ms.) Usha Dixit, Scientist, Department of Science and Technology, Govt. of India for their encouragement and moral support.

NOMENCLATURE

- A = Area (m^2).
- C = Specific heat ($\text{J kg}^{-1} ^\circ\text{C}$).
- e = Root mean square of percent deviation (percentage).
- h_i = Heat transfer coefficient from greenhouse cover to inside greenhouse ($\text{W m}^{-2} ^\circ\text{C}$).
- h_o = Heat transfer coefficient from greenhouse cover to the ambient environment ($\text{W m}^{-2} ^\circ\text{C}$).
- h_{cw} = Convective heat transfer coefficient from water to greenhouse cover ($\text{W m}^{-2} ^\circ\text{C}$).
- h_{rw} = Radiative heat transfer coefficient from water to sky ($\text{W m}^{-2} ^\circ\text{C}$).
- h_{ew} = Evaporative heat transfer coefficient from water to greenhouse cover ($\text{W m}^{-2} ^\circ\text{C}$).
- $h_{cw} = \frac{\text{NuK}}{X}$
- h = Sum of convective, radiative and evaporative heat transfer coefficient from the water surface to inside greenhouse room ($\text{W m}^{-2} ^\circ\text{C}$).
- I = Solar radiation falling on inclined surface on greenhouse cover (W m^{-2}).
- K = Thermal conductivity of humid air (W mK^{-1}).
- K_g = Thermal conductivity of ground ($\text{W m}^{-1} ^\circ\text{C}$).
- K_c = Thermal conductivity of concrete ($\text{W m}^{-2} ^\circ\text{C}$).
- K_b = Thermal conductivity of brick ($\text{W m}^{-2} ^\circ\text{C}$).
- L = Length of greenhouse (m).
- L_g = Thickness of ground (m).
- M = Mass (kg).

- N = No. of air changes per hour in greenhouse.
 Nu = Nusselt number.
 r = Correlation coefficient (decimal).
 T_w = Water temperature ($^{\circ}C$).
 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 ($^{\circ}C$).
 U_i = Overall heat loss coefficient from greenhouse air to the ambient air through greenhouse cover ($W\ m^{-2}\ ^{\circ}C$).
 v = Velocity of air ($m\ sec^{-1}$).
 V = Volume of greenhouse (m^3).
 X = Characteristic dimension (m).

Greek letters

- a = Absorptivity (decimal).
 γ = Relative humidity (decimal).
 ϵ = Emissivity, dimensionless.
 τ = transmissivity of greenhouse cover, dimensionless.
 ρ = Density ($kg\ m^{-3}$).
 σ = Stefan-Boltzmann constant ($5.67 \times 10^{-8}\ W\ m^{-2}\ K^4$).
 ∞ = Infinity (ground at larger depth).

Subscripts

- a = Air or ambient air.
 g = Ground in greenhouse or floor of greenhouse.
 i = No. of walls and roofs of greenhouse.
 w = Water.
 r = Room (greenhouse enclosure).
 gc = Greenhouse cover.

APPENDIX A

$$h = h_{cw} + h_{rw} + h_{ew} \quad (A.1)$$

$$h_i = h_0 = 5.7 + 3.8v = 5.7 \text{ (if velocity of air inside greenhouse is taken zero)} \quad (A.2)$$

$$h_{cw} = 2.8 + 3.0v \text{ (for } 0 \leq v \leq 7\ m\ sec^{-1} \text{ (Watmuff } et\ al., 1977))} \quad (A.3)$$

$$h_{rw} = \frac{\epsilon_{eff} \sigma \left[(T_w + 273)^4 - (T_g + 273)^4 \right]}{T_w - T_g} \quad (A.4)$$

$$h_{ew} = \frac{16.273 \times 10^{-3} h_{cw} (P_w - \gamma P_g)}{T_w - T_g} \quad (A.5)$$

$$\epsilon_{\text{eff}} = \left[\frac{1}{\epsilon_w} + \frac{1}{\epsilon_{gc}} - 1 \right]^{-1} \quad (\text{A.6})$$

$$\epsilon_w = \epsilon_{gc} = 0.9 \quad (\text{A.7})$$

$$P(T_g) = \exp \left(25.317 - \frac{5144}{273 + T_g} \right) \quad (\text{A.8})$$

$$P(T_w) = \exp \left(25.317 - \frac{5144}{273 + T_w} \right) \quad (\text{A.9})$$

$$\bar{T}_{\infty} = 25^{\circ}\text{C} \text{ (Khatry *et al.*, 1978)} \quad (\text{A.10})$$

$$(UA)_{\text{eff}} = 0.33NV + \sum A_i U_i \quad (\text{A.11})$$

$$\sum A_i U_i = A_{ew} U_{ew} + A_{ww} U_{ww} + A_{sr} U_{sr} + A_{nr} U_{nr} + A_{sw} U_{sw} + A_{nw} U_{nw} \quad (\text{A.12})$$

$$U_{ew} = U_{ww} = U_{sr} = U_{nr} = U_{sw} = U_{nw} = U \quad (\text{A.13})$$

$$\tau_{ew} = \tau_{ww} = \tau_{sr} = \tau_{nr} = \tau_{sw} = \tau_{nw} = \tau \text{ (transmissivity of greenhouse cover)} \quad (\text{A.14})$$

$$U = \left[\frac{1}{h_i} + \frac{1}{h_0} \right]^{-1} \quad (\text{A.15})$$

$$U_b = \left[\frac{L_b}{K_b} + \frac{L_g}{K_g} \right]^{-1} \quad (\text{A.16})$$

$$U_s = \left[\frac{L_s}{K_s} + \frac{L_g}{K_g} \right]^{-1} \quad (\text{A.17})$$

$$(UA)_{\text{eff1}} = \frac{(UA)_{\text{eff}}}{(UA)_{\text{eff}} + A_w h} \quad (\text{A.18})$$

REFERENCES

- APHA., 1985. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC., pp: 1268.
- Chapra, S.C. and R.P. Canale, 1989. Numerical Methods for Engineers. McGraw-Hill, New York.
- Davis, H.S., 1961. Culture and Diseases of Game fishes, University of California Press. Berkly and Los Angles, California, pp: 332.

- Frei, M. and K. Becker, 2005. A greenhouse experiment on growth and yield effects in integrated rice-fish culture. *Aquaculture*, 244: 119-128.
- Galtsoff, P.S., 1964. The American oyster, *Cra virginica*. Fishery Bulletin of the Fish and Wildlife Service. Superintendent of Documents, US Government Printing Office, Washington, DC, 64: 480.
- Ghosh, L., G.N. Tiwari and G.S. Sandhu, 2007. Design and Construction of Low Cost Aquaculture Greenhouse. Proceedings of 3rd International Conference on Solar Radiation and Day Lighting. Anamaya Publishers, 1: 285-292.
- Jain, 2002. Application of greenhouse for crop production and drying. Ph.D Thesis, Indian Institute of Technology Delhi, India.
- Kumar, A., C.K. Pandey and N. Kumar, 2000. Effects of polyhouse on growth of common carp at high altitude of Central Himalayas during winter. *J. Aquacult.*, 8: 73-75.
- Liu, B.Y.H. and R.C. Jordan, 1962. Daily insolation on surface tilted towards the equator. *ASHRAE J.*, 3: 53.
- Ra'anan, Z. and D. Cohen, 1980/1981. Production of the water prawn *Macrobrachium rosenbergii*, in Israel. Winter Activities 1980/1981. *Bamidgeh*, 34: 47-58.
- Tiwari, G.N., 2002. Solar Energy: Fundamentals, Design, Modeling and Applications. Narosha Publishing House, New Delhi/CRC Press, New York.
- Tiwari, G.N. and B. Sarkar, 2007. Fundamentals of Aquaculture Greenhouse. Anamaya Publishers, New Delhi 11006, pp: 1-225.
- Watmuff, J.H., W.W.S. Charters and D. Proctor, 1977. Solar and wind induced external coefficients for solar collectors. *COMPLES.*, 2: 56.
- Wood, C.S. and S.A. Ghannudi, 1985. Study of a shallow carp (*Cyprinus carpio*) pond and its relevance to inland fish farming in Libyan Jamahiriya. *Aquaculture*, 44: 125.
- Zhu, S., J. Deltour and S. Wang, 1998. Modeling the thermal characteristics of greenhouse pond systems. *Aquacult. Eng.*, 18: 201-217.