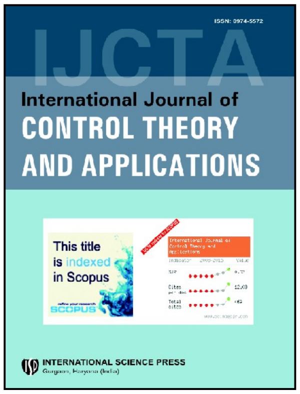

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ANFIS based Solar Radiation Data Forecasting for Energy & Economic Study of Solar Water Heaters in Eastern India

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Abstract: This paper presents energy and economic analysis of solar water heaters based upon predicted global solar radiation data of Bhubaneswar, India. Adaptive Neuro-Fuzzy Inference System (ANFIS) modeling was used for this purpose. A comparison of the predicted and measured value of daily global solar radiation (GSR) data on a horizontal surface is presented. The input parameters of the model used in this paper are sunshine duration, temperature, humidity whereas the clearness index is considered as an output parameter. The solar radiation data for 1825 days (Year 2000-2005 in Bhubaneswar, India having longitude 74^{0}E and 20^{0}N Latitude) are used for training the ANFIS and the data for 365 days are used for testing. Based upon the predicted solar radiation data using ANFIS, the energy as well as economic analysis of solar water heaters are carried out. The outlet temperature of fluid from the heater and the efficiency of heater are major portions of energy analysis. Feasibility study related to economics of water heaters are carried out with emphasis on Net Present Value (NPV), Discounted Payback Period, and Profitability Index

Keywords: Global solar radiation, Sunshine duration, ANFIS, NPV, Profitability Index

I. INTRODUCTION

Due to the increasing prices of the primary energy resources and their associated environmental issues, so now a day the use of renewable resources, generally, the solar energy is increasingly on demand in both developing and developed countries. The most common use of solar energy is the solar water heaters. Because Hot water is required for domestic and industrial uses such as houses, hotels, hospitals, and mass-production and service industries. A techno-economic assessment of the solar water heating systems in Bhubaneswar was carried out[1-3]. For designing solar water heater measurement of solar radiation for a particular location is most important. It has been observed in last few years that four coastal states of India (West Bengal, Andhra Pradesh, Odisha and Tamil Nadu) on the East Coast of India and one State (Gujarat) on the West Coast of India are more vulnerable to cyclone disasters. So solar radiation insolation in these areas is haphazard in nature as the solar radiation directly or indirectly influence high wind flow. For setting up any renewable energy systems such as solar photovoltaic (PV) or solar thermal system, the solar radiation data analysis in those areas becomes crucial. Traditional approaches have been used to measure solar radiation in almost all Indian cities, it has been observed that most of time no measuring equipment are used in these coastal regions due to high wind effects which cause damage to the solar radiation measuring equipment. To overcome this some soft computing model like ANFIS solar radiation measuring techniques to predict the solar radiation data in these coastal areas and in turn studying energy and economic analysis of solar water heating system.Some climatological parameters are needed to develop and estimate the global diffused solar radiation.To estimate the amount of solar energy incident on a horizontal surface, many models were developed to relate the global solar radiation (H_G) using various parameters such as relative humidity, sunshine duration, temperature, latitude, longitude, etc. Conventional mathematical tools are not well suited for dealing with ill-defined and uncertain systems. SoFuzzy rule-based systems using linguistic variables through a series of logical rules i.e. IF-THEN-ELSE rules that connect antecedent(s) and consequent(s) is implemented. Fuzzy rules can have multiple antecedents connected with logical AND or OR operators. ANFIS is the implementation of fuzzy Inference system (FIS) for developing fuzzy rules with suitable membership functions, required inputs and outputs [4-6].

Artificial neuro-fuzzy inference system was used to generate daily solar radiation data recorded on a horizontal surface in National Research Institute of Astronomy and Geophysics. The approach could not be used for the Helwan, Egypt (NRIAG) for a period of ten years (1991-2000), where solar radiation measurements were not available[7-8]. They used ANFIS as it combines fuzzy logic and neural network techniques that are used in order to get more efficiency. The prediction shows TS (Takagi Sugeno) fuzzy model gave a good accuracy of approximately 96% and a root mean square error lower than 6%.The results shows that the identified TS fuzzy model provides better performance.Fuzzy systems have been used for modeling the daily solar radiation datarecorded on a horizontal surface in Dakhla in Morocco [3]. The performances of the fuzzy model were compared to a linear model using the SOS (Second Order Statistics) techniques. After prediction the model gave a result of TS fuzzy model (RMSE =0.52, Accuracy = 0.96) with .respect to linear model (RMSE=0.61, Accuracy=0.89). An adaptive neuro-fuzzy inference system (ANFIS) was used to predict the monthly global solar radiation (MGSR) in 31 districts of Tamilnadu, India. Comparison of the predicted and measured value of monthly global solar radiation (MGSR) on a horizontal surface was evaluated by calculating root mean square error (RMSE), mean bias error (MBE), and coefficient of determination (R^2) for testing locations described in [4]. Statistical analysis shows the four gbell input membership function gives maximum regression value, R (R=0.99) in comparison to the use of other membership function (Two g bell, Three g bell).

Themonthly mean clearness index(K_t) with daily solar insolation data in isolated areas of Algerian plane have been predicted using adaptive neuro fuzzy inference system(ANFIS).The model has been created based upon by the geographical coordinates like latitude, longitude and altitude) with meteorologicalparameters like temperature, humidity and wind speed[5]. Comparison has been made using ANFIS and ANN calculating the mean square error (RMSE)and the mean absolute percentage error(MAPE).The advantage of this model is that it can estimate K_t (clearness index) only by using geographical coordinates of the site. But the difficulty is that the proposed technique does not depend on the intrinsic properties of parameters are wind, humidity, temperature, etc. To generalize this methodology in other parts of the world, a long database would be required for covering data in different countries, which can be obtained from (2004). A comparative study of artificial neural networks (ANN) and Adaptive-neuro-fuzzy inference system (ANFIS) has been presented in [6] for predicting daily global solar radiation (GSR) in Tehran province of Iran. By calculating mean absolute error, root mean square error it was observed that ANN performs better than ANFIS[9-10].

Generalized neural network (GNN), and a modified approach of artificial neural network (ANN) used to estimate solar energy in India [7] from 1986–2000 based on different meteorological and climatological parameter such as sunshine per hour, temperature ratio, clearness index, latitude, longitude and altitude. The results of the GNN model and the fuzzy-logic-based model considering the same input parameters was compared on the basis of mean relative error. The mean relative error in the estimation of global solar energy in GNN model was found around 4%whereas the same using fuzzy logic was 6%.

The thermal performance of a solar water heating system with flat plate collectors were carried by researchers in [8]. The result showed that annual average daily energy collected was 19.6 MJ/d, energy delivered by the solar coil was 16.2 MJ/d, collector efficiency was 45.6% and system efficiency was 37.8%.Experimental based study with soft computing has been carried out earlier for solar air heaters [9]).Comparison between predicted and experimental results indicates that the proposed mathematical model used for estimating the thermal performance of solar air heaters gives reasonable accuracy.

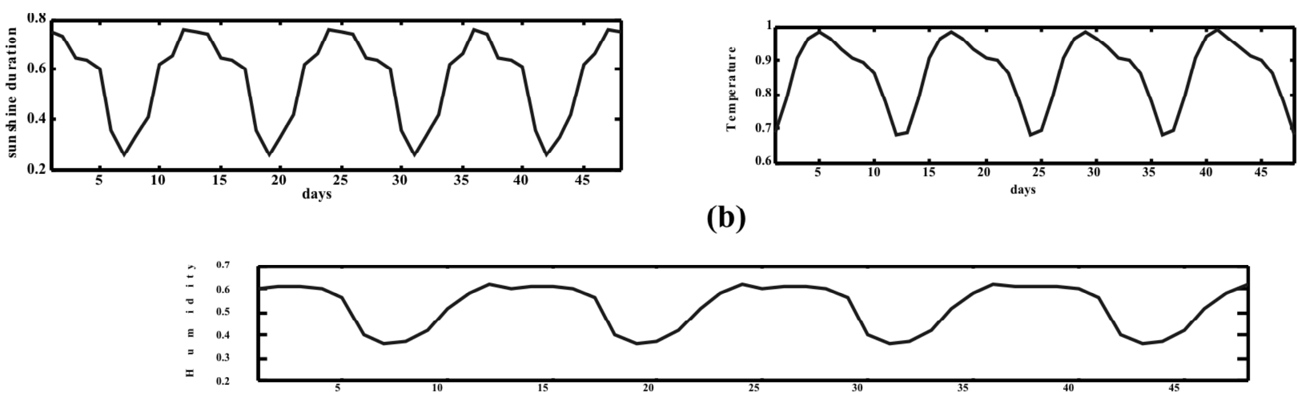
Multilayer perceptron (MLP) and adaptive neuro fuzzy interface system (ANFIS) has been used in [10] to predict the efficiency of flat-plate solar collectors based on input parameters i.e. Solar irradiance, ambient temperature, collector tilt angle and working fluid mass flow rate. The model MLP uses Levenberg-Marquardt learning algorithm and logistic sigmoid transfer function. ANFIS models gave better prediction with lower root mean square error, and mean bias error (MBE). Analytical and experimental studies has been carried out to perform on a solar assisted heat pump water heating system, by using unglazed, flat plate solar collectors as an evaporator in [11].The results obtained after simulation were used for the optimum design of the system using solar fraction and auxiliary energy requirement for a particular application. By using ANN a solar water heater consists of a flat plate collector and four water reservoirs have been prepared .

METHODOLOGY ADOPTED FOR PREDICTION OF SOLAR RADIATION

2.1. Dataset Description

15 years data for the period of 1984-2000 like monthly average value of Temperature, Humidity and Sunshine duration data are collected from solar radiation handbook and National renewable energy source laboratory.

The solar forecasting data for the period of 1984-1996 has been utilized for training and the remaining 3 years are used for testing. Fig. 1.(a-c) shows monthly average sunshine duration, temperature and humidity for the period of 1984-2000.



(b)

(c)

Figure 1: Monthly average Sunshine duration, Temperature and Humidity

2.2. Adaptive neuro-fuzzy inference system (ANFIS)

In this case artificial neuro fuzzy inference system has been used to predict daily global solar insolation of Bhubaneswar India.Data related to daily solar radiation, sunshine duration, Humidity, Temperature for a span of 1984 - 2000 have been utilized from renewable energy source laboratory, NASA and from solar radiation handbook 2008. The used architecture of ANFIS [15, 16, 17, and 18] is a popular and advanced system with a good

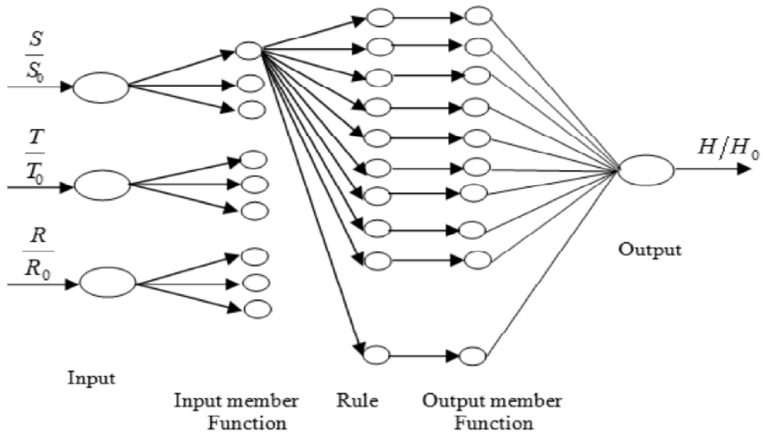


Figure 2: ANFIS model structure having three inputs and three membership functions

software support. (Jang (1991, 1993)) have described the architecture of ANFIS with its application modeling which is a nonlinear function and is a chaotic time series prediction.

A general adaptive neural network has been depicted in Fig. 2. It uses a complete network configuration having number of nodes inter connected through directional links.Each and every node has been characterized by node function with fixed or flexible parameters. The learning and training phase of neural network determines the parameter values to fit all the training data. Back propagation method is the basic learning rule that seeks to minimize error between the sum of squared difference between network's output & desired output. By the consideration of first order fuzzy inference system, a fuzzy reasoning has been developed. A Fuzzy model has been considered which consists of two rules.

$$\text{Rule no 1: if } x_1 \text{ is } A_1 \,\&\, y_1 \text{ is } A_2, \text{ then } M1 = p_i x + q_i y + r_1 \tag{1}$$

$$\text{Rule no 2: if } x_1 \text{ is } B_1 \,\&\, y_1 \text{ is } B_2, \text{ then } N_1 = p_j x + q_j y + r_2 \tag{2}$$

Where x_1 and y_1 are inputs, M1 and N_1 are outputs and A_1 and A_2 are fuzzy sets.

The model contains six types of input membership function (i.e. Triangular MF,Gaussian MF, two-sided Gaussian MF, bell MF, difference sigmoid MF and trapezoidal MF) and two types of output membership function (i.e. linear, constant).

2.4. Simulation

A computer codes for ANFIS model is developed in the Mat Lab software (Version 12.0.The model is trained until the best performance is obtained having Lower RMSE and MSE. Once this criterion is achieved the optimal parameters with Input and Output membership functions of the network are saved and used for training and testing the ANFIS-models. The Optimization is done either by using hybrid learning algorithm or the back-propagation method for identifying the MF (input and output) parameters. A combination of least-squares and back propagation gradient descent methods is used for training fuzzy inference system (Sugeno type FIS).The Output Membership function (linear or constant) is be used for training fuzzy inference system.

Here some statistical test (Root mean square error 'RMSE', Mean squared error 'MSE' and mean absolute percentage error 'MAPE' between the measured and predicted global solar radiation data by using different input-output membership function of the ANFIS is performed. The ANFIS model uses the grid partitioning method and two output membership function: constant and linear. Figs. 3.Shows the training and testing MSE curves by the use of Gauss2 input and constant output memberships function. As the training epoch number increases, the forecast of radiation with ANFIS becomes better.

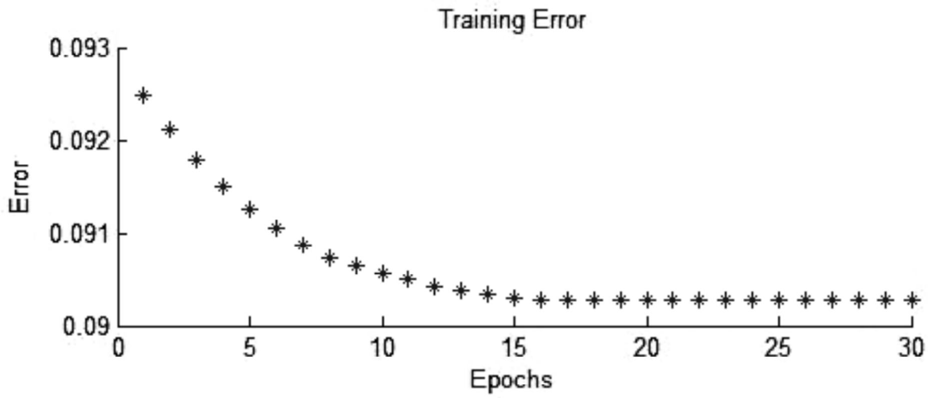


Figure 3: Gauss2 input MF with constant output MF

The results are summarized in Table 1.After simulation by using different input and output membership function the best performance is obtained with a lower value of Statistical errors.

Table 1
Performance ofanfis models w. r. t to the i/o membership functions during training and testing.

Input mfType	*Output mf type*	*RMSE*	*MSE*	*MAPE*	*Test error*	*Train error*
trimf	Linear	0.0875	0.0077	0.2349	0.0875	0.0910
	Constant	0.0917	0.0084	0.2495	0.0917	0.0960
gbell mf	Linear	0.0860	0.0074	0.2281	0.0868	0.0888
	Constant	0.0923	0.0085	0.2298	0.0923	0.0967
gauss mf	Linear	0.0845	0.0071	0.2225	0.0845	0.0887
	Constant	0.0923	0.0085	0.2421	0.0923	0.0960
gauss2mf	Linear	0.0854	0.0073	0.2274	0.0854	0.0892
	Constant	0.0914	0.0084	0.2418	0.0914	0.0976
dsig MF	Linear	0.0864	0.0075	0.2275	0.0864	0.0900
	Constant	0.0925	0.0085	0.2305	0.0915	0.0965

Fig. 6. shows the predicted and measured global solar radiation data after training and testing. In comparison to all the methods used earlier, it is observed that ANFIS model having gauss input membership function and linear output function gives better performance (i.e.at epoch 100, the statistical value of MSE=0.0071, RMSE=0.0845 and MAPE=0.2225) in comparison to other input-output membership function.

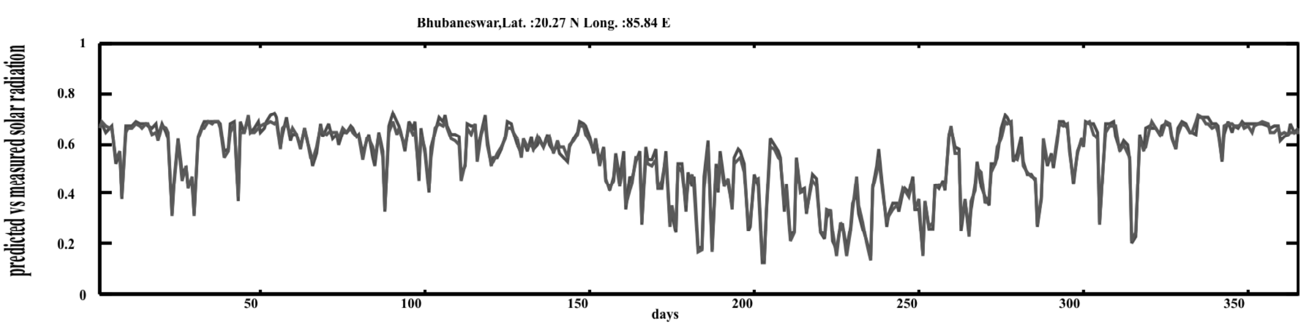


Figure 4: Measured and predicted solar radiation using ANFIS Model with Gaussian i/p MF and Constant o/p MF

3. MODELING AND ENERGY ANALYSIS OF SOLAR WATER HEATER

Based on the predicted solar radiation data, Energy and Economic analysis of solar water heater has been carried out .The most common use of solar energy is the solar water heaters. Because Hot water is required for domestic and industrial uses such as houses, hotels, hospitals, and mass-production and service industries.

3.1. Energy Modeling

This section focuses on energy modeling of solar collector. For designing a active solar heating system Solar collectors are the main component. The purpose of solar water heating system is to collect sun's energy, transform its radiation into heat, then transfer that heat to a fluid (generally water or air). There are a large number of solar collector designs. These designs are classified in two different types of solar collectors:

- Flat-plate collectors –Where the absorbing surface is approximately as large as the overall collector area that intercepts the sun's rays.
- Concentrating collectors – Where large areas of mirrors or lenses focus the sunlight onto a smaller absorber.

The most common solar collector for solar water –heating systems is the flat-plate collectors used in homes and solar space heating shown in Fig. 5. A general flat-plate collector is an insulated metal box having a glass or Plastic cover and a dark-colored absorber plate.

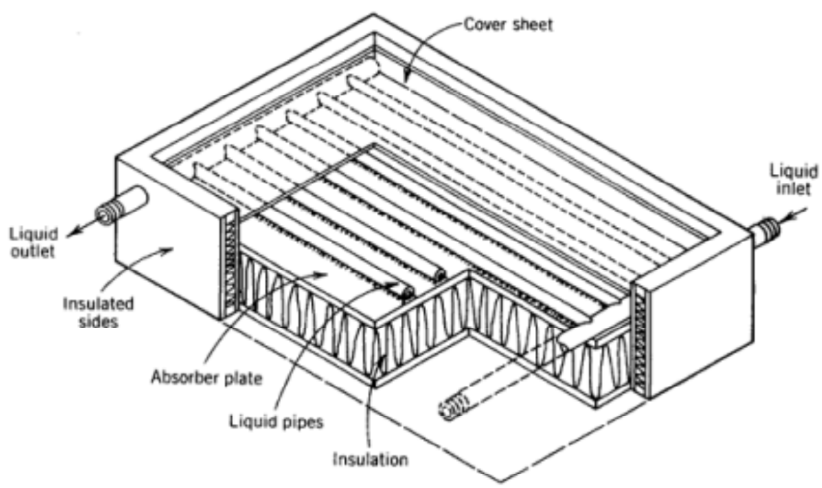


Figure 5: Flat Plate Collector

Here flat plate collector has been considered for modeling and performance analysis. The absorber is usually a sheet of high-thermal-conductivity metal with tubes or ducts either integral or attached. Its surface is painted or coated with selective coating to maximize radiant energy absorption and to minimize radiation heat loss emission. The insulated box provides structure and sealing and reduces heat loss from the black or sides of the collector. The transparent cover sheets usually made of glass cover allow sunlight to pass through to the absorber and simultaneouslyminimize convective heat losses. Metallic tubes are soldered, brazed or pressure bonded to the bottom of the absorber plate. Usually water, air are kinds of fluid is circulated in tubes which carry the absorbed heat. Flat plate collectors are used as they are simple in design, durable low cost, less maintenance [,] can work on cloudy days.

The steady state useful energy of the collector is analyzed using [19]

$$q_u = \dot{m}c_p\left(T_{fo} - T_{fi}\right) = F_R A_p\left[S_I - U_L\left(T_{fi} - T_a\right)\right] \quad (3)$$

Where q_u is useful heat absorbed by the fluid, m is rate of mass flow. T_{fo} and T_{fi} are outlet and inlet temperature of fluid flowing through tubes. F_r is hat removal factor and U_L is overall heat loss coefficient. T_a is atmospheric temperature.

Heat absorbed by absorber plate is rewritten as $S_I = I_T\eta_{optical}$ (4) Where I_T is total radiation on horizontal surface which is otherwise called as Direct Normal Irradiation (DNI) and $\eta_{optical}$ is optical efficiency of the thermal system. I_T and H is related by the following equation assuming tilt factors to be almost unity.

$$H = \frac{180}{15\pi}\sum_{-\omega_s}^{\omega_s} I_T d\omega \quad (5)$$

$$\eta_i = \frac{q_u}{A_c I_T} \quad (6)$$

Where q_u is the useful energy of the collector, A_c stands for collector area and I_T is the global solar radiation on the collector.ù is called as hour angle

3.2. Simulation and Result

The monthly average clearness index (K_t) is the ratio of monthly average daily solar radiation on a horizontal surface (H) to monthly average daily extraterrestrial radiation on a horizontal surface (H_0). The value of H_0 can be obtained by using the following equation Based on the predicted value of H, hourly radiation data (I_T) has been obtained using Eq. 5. Solar insolation data on the absorber plate is found from Eq. 4 with consideration of approximate optical efficiency value as 0.85. Eq. 3 and Eq. 6 are used to measure the outlet fluid temperature and efficiency respectively. Geometrical and operating data of the flat plate collector under consideration is mentioned in Table 2.

Table 2
Geometrical and operating data of the flat plate collector under consideration

Items	*Value*	*Items*	*Value*
Length of absorber plate	2m	Tube pitch	0.113m
Width of absorber plate	1.13m	Absorptivity of glass cover	0.88
Plate to cover distance	0.025m	Emissivity of glass cover	0.88
Thermal conductivity of plate	350W/mK	Thickness of glass cover	0.04m
thickness of plate	0.00015m	Thermal diffusivity of adhesive	0
Absorptivity of plate	0.94	Water flow rate	70 kg/s
Emissivity of plate	0.14	Water inlet temperature	60 c
Outer diameter of the tube	0.0137	Ambient temperature	25 c
Inner diameter of the tube	0.0125	Heat transfer coefficient above glass cover	16.4 W/m^{2}K

Fig. 6. Depicts the instantaneous efficiency of solar collector with respect to solar radiation absorbed by the absorber plate. On the basis of different atmospheric temperatures (20°C,30°C,40°C), the outlet temperature as shown in this figure, it is observed that the efficiency value increases from 31% to 71% as the solar radiation increases from 500 to 900 W/m^2. Similarly the efficiency value increases as the atmospheric temperature increases but at a slower rate.

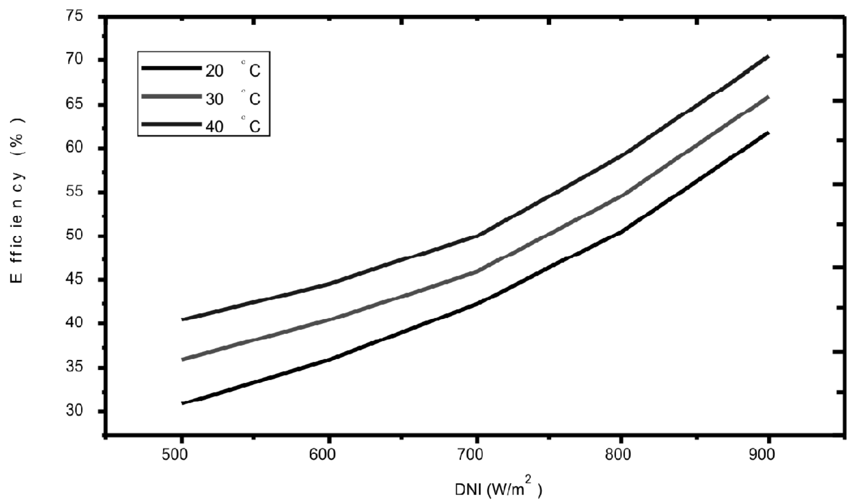


Figure 6: Variation of efficiency w. r. t. DNI levels

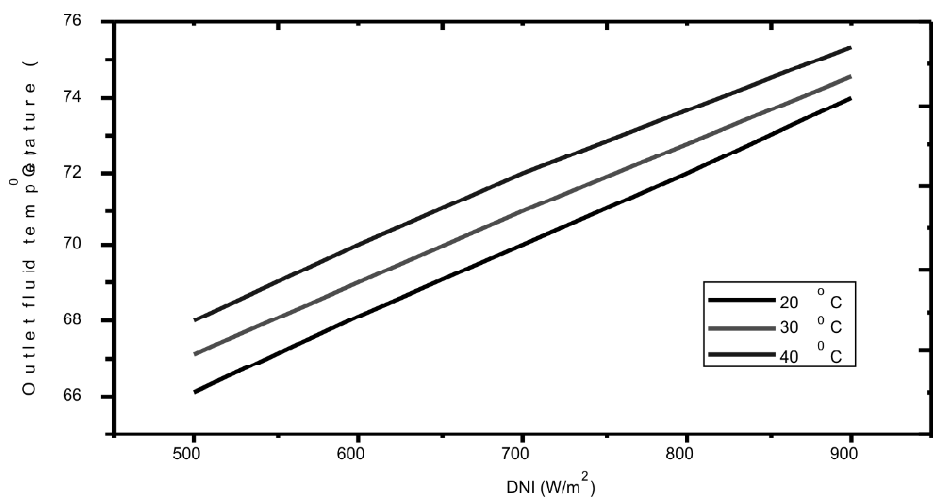


Figure 7: Variation of outlet fluid temperature w. r. t. DNI levels

Fig. 7. Shows the outlet fluid temperature for various solar radiation absorbed by plate and atmospheric temperature levels which is linear for both the cases. As the solar radiance and atmospheric temperature increases, the outlet fluid temperature also goes on increasing. The increased temperature is around in the range of 6-18°C.

4.1. Analysis of Solar Water Heater

The economic analysis of solar energy systems to determine the least cost of energy needs has been done adopting the following different investment evaluation criteria.

4.1.1. Simple Payback Period

(i) The simple payback period (SPP) is the number of years in which the investment pays for itself. This is defined as ratio of initial investment to annual savings, i.e.

(ii) $$SPP = \frac{\text{Initial Investment}}{\text{Annual Saving}} \tag{7}$$

In case of an energy conservation option(ECO)/renewable option, usually the annual saving is only due to energy savings and hence is the product of the energy saved and the price of energy. But in case of unequal cash inflows payback period can be found out by adding up the cash inflows until the total is equal to initial cash outlay.

4.1.2. Discounted Payback

Main demerit of this payback method is that it never discounts the cash flows for determining the payback period.The discount cash flow and payback are calculated. Discount payback period indicates the number of periods taken in finding out the investment outlay on the present value basis. This discounted payback period fails to consider the cash flows occurring.

4.1.3. Profitability Index (Benefit-Cost Ratio)

It indicates another time adjusted method of calculating the investment proposal like benefit to cost ratio or profitability index (PI). The profitability index is the ratio of the present presentvalues of cash flow at the required rate of return to the initial cash outflow of investment. The main formula for getting benefit cost ratio of profitability index is

$$PI=\frac{\text{PV of cash in flow}}{\text{Initial cash outlay}}=\frac{PV(C_t)}{C_0}=\sum_{t=1}^{n}\frac{C_t}{(1+k)^t}\div C_0 \tag{8}$$

Where Ct = net cash inflow during the period t

C_0 = Total initial investment cost, t = no of time periods, k = discount rate

4.1.4. Net present value method

The net present value (NPV) method is quite a popular method for making evaluation of the investment proposals.The discounted cash flow technique recognizes time value for money.It correctly defines the cash flows at different time periods and are comparable whenever their equivalent present values are found out.During the calculation of NPV few steps are followed and are listed below.

1. Relying on the realistic approximations cash flows of the investment project forecasted.
2. The approximate discount rate has been found out which forecasts cash flow.The actual discount rate indicates the opportunity cost of capital of the project. It is also equal to the required rate of return of the investors on investments of equivalent risk.
3. The present value of cash flow is determined calculating the opportunity cost of capital with the discount rate.
4. The net present value is determined by deducting present value of cash outflow from Net present value is found out by subtracting present value of cash outflows from present value of cash inflows. The project should be accepted if NPV is positive (i.e. NPV > 0).

$$NVP=\left[\frac{C_1}{(1+k)^1}+\frac{C_2}{(1+k)^2}+\frac{C_3}{(1+k)^3}+\ldots\ldots+\frac{C_n}{(1+k)^n}\right]-C_0=\sum_{t=1}^{n}\frac{C_t}{(1+k)^t}-C_0 \tag{9}$$

In this case C_1, C2 ….stand for net cash flowing in the year 1, 2,….k, Cost of investment and n stands for expected life of investment having constant value.

For an ideal economic, the NPV should go beyond zero. In that case project is accepted if profitability index becomes more than 1. It is different if profitability is zero. The project is not accepted if the profitability index becomes less than 1. During comparison of 2 projects, ptoject with higher NPV value gets selected.

4.1.5. Results

Key Assumptions in economic analysis of the considered region are mentioned in Table 4.

Items	*Value*
Inflation per annum	3%
Discount rate	12%, 15%, 20%
Average Electricity cost per unit in 1st year	Rs. 4/-
Salvage Value	Rs.1000/-
Service Life	15 years, 20 years, 25 years
Maintenance cost	Nil
Initial investment(cost of Solar FPC including transportation and installation)	Rs 20000/-
cylinder per month for a family	one
Cost of a single cylinder	Rs 420/-
cost is saved due to solar FPC	40%

The effect of NPV and PI vs Discount rate is depicted in Fig.8. It is clear from Fig.8. that when discount rate increases, present value of cash flow decreases an NPV and PI both the parameters decrease. Discount rate has been varied from 12% to 20% and it is found that the relationship of NPV vs Discount rate and PI vs Discount rate are varying linearly having negative slope. Discounted Payback Period vs Discount Rate has been shown in Fig .9. Here, the discount rate has been varied from 12% to 20%. When discount rate increases more time is needed to recover the initial capital invested as present value of the cash flows decreases. The discounted payback Period linearly increases with discount rate.

The relationship of NPV &PI vs Service Life has been shown in Fig .10. The service life has been varied from 14 to 26 years. As the service life increases present value of cash flows contribute each year. Thereby the NPV and PI value increases linearly with service life with a positive slope line.

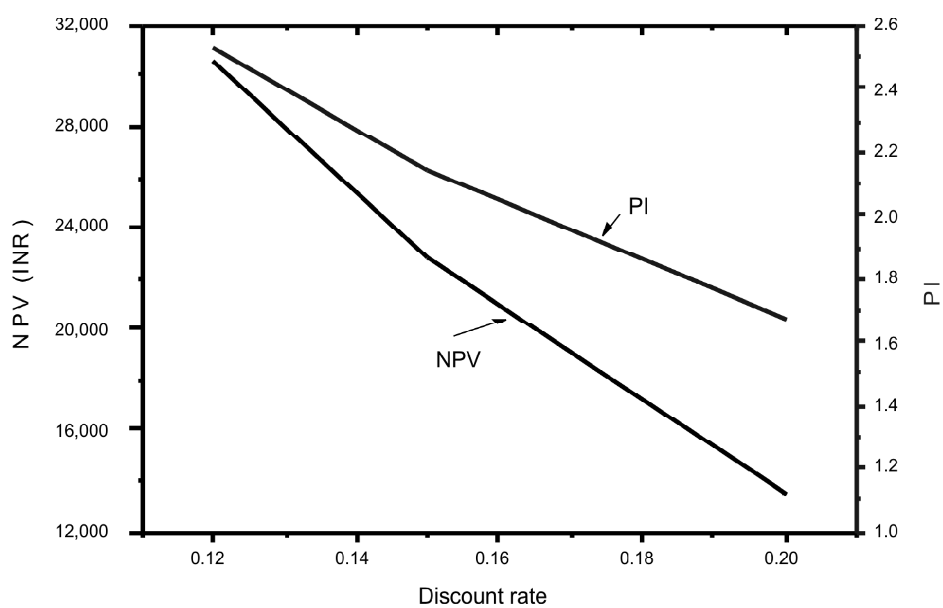


Figure 8: Effect of NPV and PI vs Discount rate

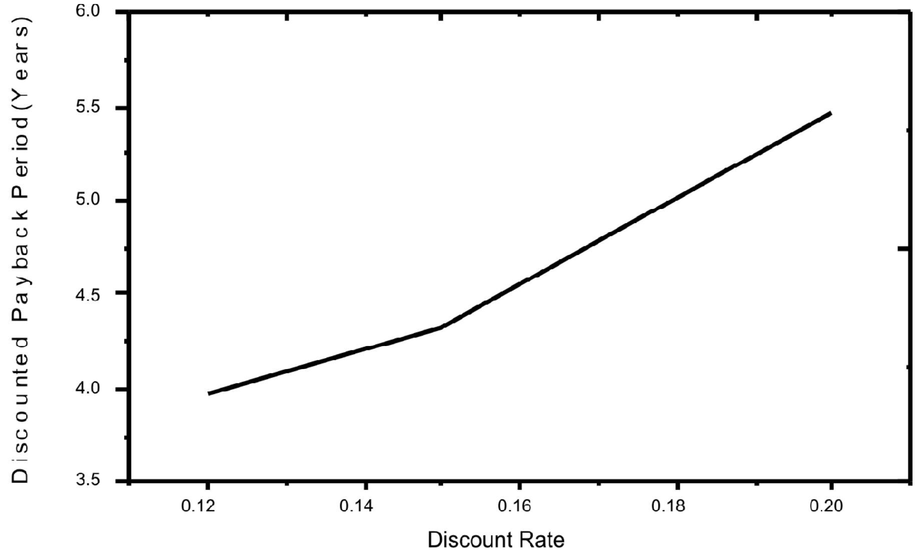


Figure 9: Effect of Discounted Payback Period vs Discount Rate

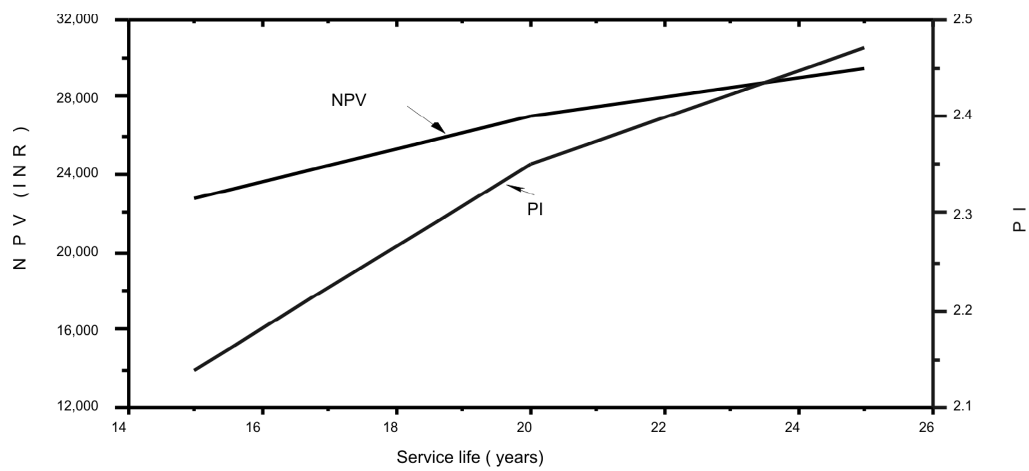


Figure 10: Relationship of NPV and PI vs Service Life

5. CONCLUSION

Energy and Economic analysis of solar water heater has been achieved with ANFIS based prediction method of daily global solar radiation.Climatological parameters like sunshine duration,temperature and humidity can be used for prediction with ANFIS type of soft computing method.Hence this tool seems to be promising to estimate solar data for the places where costly equipments for measuring solar data cannot be installed.

Furthermore the results like solar radiation data obtained from the ANFIS were used to study the performance of the solar water heater. Energy and economic analysis has been carried out to see the feasibility of installing of solar water heaters in these coastal regions. It was found that the efficiency varied from 30-70% in most of the days in a year while the increased temperature of fluid is upto 20 °C. Hence it is concluded that ANFIS can be used a better tool for prediction for solar radiation data in the eastern zone of India which in turn can be utilized for design of solar thermal systems. Future work can be made of sizing and design of photovoltaic system and thermal systems for consumer and industrial uses.

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