Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
May 2024 5(5), 888–897

FORECASTING EVENTUAL OPERATIONAL PERFORMANCE OF THE SWH SYSTEM USING ANN APPROACH- SPECIAL REFERENCE TO BHOPAL (M.P.)

Ritul Saraf [1]

[1] Research Scholar, Department of Computer Science, LNCT University, Bhopal (MP)

ABSTRACT

Solar radiation is an important parameter in solar energy applications, while this parameter is directly related to the performance of solar thermal and photovoltaic systems. The present research work mainly focused on the implementation of ANN technique to predict Operational Performance of the SWH System Using ANN Approach. A distinctive method is used to predict how well the solar-powered water heater in Bhopal City will function. This is done by combining GSR as well as SWH ANN models. The output of GSR from the GSR-ANN simulation of Bhopal city is used as a parameter for input in the combination ANN model for the solar-powered water heating system. The output that was obtained is compared to the values that were tested. The error study showed that the mixed ANN model that was created is the best option for predicting SWH performance, as it has the lowest RMSE and MAPE along with the highest R.

DOI
10.29121/shodhkosh.v5.i5.2024.4711

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

1. INTRODUCTION

AI is a section of Computer Science focused on creating systems capable of human-like cognition to address intricate issues. The intelligence characterized by reasoning within a system is "artificial," as it is created by humans. Artificial Intelligence is closely associated with various scientific disciplines, including Philosophy, Biology, Mathematics, Psychology, and Cognition. Computers are optimal for programming, utilizing a fixed program. Their principles. This attribute enables artificial systems to operate effectively and accurately. Repeatedly with high velocity, however it is challenging for humans to accomplish. Conversely, unlike human intelligence, computers struggle to comprehend specific circumstances and adhere to prevailing conditions. Artificial Intelligence seeks to improve the capabilities of robots in addressing complex problems. Information and expertise utilised to develop computer programs that exhibit traits of intelligent behaviour.

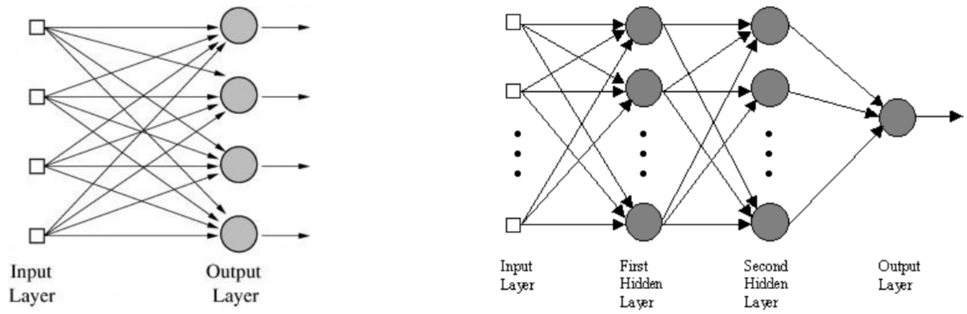

Fig .1 Fundamental Designs of ANN (Individual Layered on Left as well as Multi-Layer on Right)

It is a concept of data processing modelled after the manner in which neurons in the brain process information and communicate with one another. Neural computing is executed by Artificial Neural Networks (ANN). The brain is composed of neurons. It is exceedingly intricate, both on linear and parallel computing systems. Fig. 1 above illustrates basic artificial neural network designs. It possesses the ability to organize neurons for functional performance. Some computations are significantly faster than even fastest computer currently available. Neural networks can be utilised in recognition of pattern, perception, along with motor control during automobile operation.

A photovoltaic generator converts sunlight into electrical energy. The essential element of a solar energy arrangement is the solar energy cell, that may also be combined to form panels or modules. The panels can be combined to form a significant solar array, arranged in parallel or series. Panels set in parallel increase the current, whilst those positioned in series produce a larger output voltage. Electric fields produced among the positive level (P-type) as well as the opposite layer (N-type) of a cell drive free electrons to flow via the joining wire as DC (direct current) electricity. Fig 2 illustrates the entire conversion procedure.

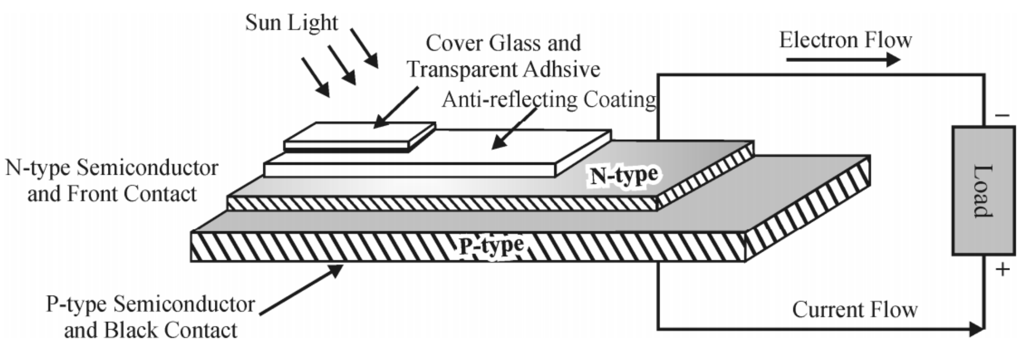

Fig. 2 Schematic of a PV Cell

Solar water heating is an increasingly popular technique in recent times. Hot water is essential for industries such as paper, textiles, processing of food, dairy, as well as edible oil. In addition to being used in homes, it is also necessary in large quantities for public buildings including hotels, hostels, healthcare facilities, and restaurants. Consequently, solar water heating systems can serve as an alternative to electric heating, reducing electricity expenses and conserving fossil fuel resources. Understanding solar collector performance globally is crucial for solar equipment design engineers and architects to implement appropriate and efficient solar water heating systems. The choice of solar collectors gets determined by application, geographical place, heat transmission properties, as well as maintenance expenses.

Performance of SWH is influenced by numerous climatological aspects, rendering its analysis a challenging endeavour. Over past two decades, numerous methodologies have been developed to ascertain the thermal behaviour of solar collectors, eliminating the need for complex and costly experimental studies while enhancing computational efficiency. ANN (ANN) models are being utilised across several domains, particularly for intricate jobs requiring rapid and precise computational performance. They can learn from examples, manage nonlinear issues, and once trained, they can execute predictions more rapidly. This work presents an effort to estimate the performance of solar water heaters (SWH) utilizing a widely recognized ANN technique.

2. EXPERIMENTAL SETUP

The solar water heating system is located at LNCT University in Bhopal, which is in the central part of Madhya Pradesh, India. The system has a flat plate collector made by TATA BP Solar and is set up for experimental purposes. A 36 SWG sheet of copper is used to make the absorbent surface of the setup used for the experiment. To attain a high absorbency above 0.95 as well as a low emission below 0.16, the absorber plate is coated with NALSUN, which is a black chromium bath at room temperature. The system is made up of nine copper tubes that are used for water circulation. Each tube has a radius of 6.45 mm and an internal thickness of 0.57 mm. Ultrasonic welding is used to attach the copper tubes to the absorber plate. The glazing, which is made of tempered translucent glass that is 2080 mm long and 1070 mm wide, allows solar radiation to enter the system while minimizing the amount of heat that is lost from the plate that absorbs radiation to the outside world.

Table 1 Specification of Experimental Setup

S. No.	Parts	Material and dimension
1	Glazing	Toughened clear glass
2	Glazing transmissivity	0.88
3	Material of insulation	Rock wool
4	Bottom insulation thickness	50×10^{-3}m
5	Side insulation thickness	25×10^{-3}m
6	Absorber plate material	Copper
7	Absorber plate thickness	36 SWG
8	Absorber plate coating	NALSUN
9	Absorber area	2m^2
10	Number of absorber plate	9
11	Absorber plate coating absorptivity	0.95
12	Absorber plate coating emissivity	0.16
13	Riser tube material	Copper
14	Number of riser tube	9
15	Riser tube diameter	12.9×10^{-3}m
16	Riser tube thickness	0.57×10^{-3}m
17	Length of the collector	2080×10^{-3}m
18	Width of the collector	1070×10^{-3}m
19	Storage tank material	Stainless steel of ASI 304 grade
20	Capacity of storage tank	100 liters

3. ANN APPROACH

The literature study indicates that the majority of research examined performance of SWH for brief durations, often one to two days or up to a week. Consequently, enhancing estimation accuracy necessitates the utilization of a larger number of data sets across the entire spectrum of operational conditions. This chapter discusses performance forecast of a thermosyphon SWH system with a FPC utilizing an ANN model. This ANN model is taught and evaluated using four distinct procedures.

A SWH including a FPC with an area of absorber of 2 m^2 is connected at a 9.9° tilting angle of to optimize solar radiation absorption year-round. The subsequent input parameters are utilised in the ANN model for forecasting outlet temperature of water (To) as output.

All measurements are obtained from the established experimental setup at LNCT University, Bhopal, in the central region of Madhya Pradesh, India, under various weather conditions. Measurements are recorded at ten-minute intervals from 10 AM to 5 PM daily for a duration of twenty days each month. The measurement technique was conducted for one year under varying weather conditions from January 2024 to December 2024. A total of 43 readings are conducted daily. A total of 10,320 readings are collected over the year and randomly allocated for testing & training of built ANN technique to forecast performance of the solar water heating system.

4. ANN MODEL FOR SWH

The thermosyphon SWH collects solar radiation and uses that energy to heat water with a collector made of flat plates panel. The heated water is then sent to the hot water storage vessel in the home. The basic purpose of this topic is the development and creation of an ANN model, that is going to be trained and assessed using four various ways, in order to discover the best method for forecasting the outcome temperature of the water (T0) of a water heater powered by solar energy in certain parts of India. A solar-powered water heater has been built to assess the output temperatures of water of the thermosyphon photovoltaic water warming system under different weather circumstances. The system consists of a single collector with a flat plate and a single tank for storage.

To predict how well a thermosyphon solar-powered water heating system will operate, the ANN model is developed utilizing a MATLAB program for MATLAB version 2012. The data entering and leaving the data sets are normalized based on the activation function that is used in the hidden layer. The buried layer uses the tangent sigmoid activation mechanism. As a result, the datasets that are measured are normalized to a range of -1 to +1 before they are used in the training process.

After the normalization process, 8,268 of the 10,320 total points of data collected (80%) are used for training, and the other 2,052 (20%) are used for testing. The constructed ANN model is trained and assessed using the input variables: date, month, year, inlet water temperature, time, storage vessel temperatures, as well as radiation from the sun to forecast the water at the outlet temperature (To) as the output. The testing approach is carried out in a step-by-step manner, after the gathering of the maximally trained ANN model.

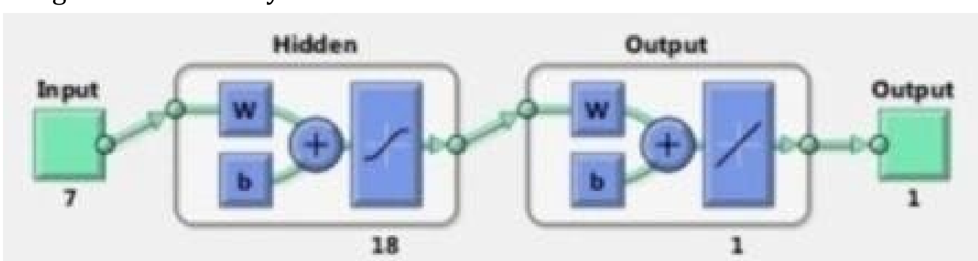

Fig 3 ANN Arrangement for the Present SWH Performance Prediction

A neural network with seven inputs, 18 neurons in a single concealed layer, and a single output is used to predict the outlet temperature of the water of a water heating system powered by sunlight with little error and to assess the performance of four algorithms. The architecture of the ANN employed for current SWH predictions of performance is portrayed in Fig 3.

A greater quantity of measured information is utilised to train and evaluate ANN model using four distinct techniques. The optimal ANN model is selected to assist solar system design engineers. Efficacy of ANN model is assessed using the least RMSE, minimum MAE, and maximum R obtained during the training and testing phases.

5. RESULTS & DISCUSSION

MAE, RMSE as well as R are used to evaluate how effective the ANN model is. The accuracy of the results from the development and testing of the ANN model, which consists of seven components, a concealed layer with 18 neurons, and only one result, using four different algorithms: Table 2 contains the encapsulation of GD, SCG, LM, and RP. The LM approach outperformed other algorithms in both the training and testing stages, earning the lowest RMSE, the lowest MAE, and the greatest R. As a result, the LM approach is considered to be the best fit for the current investigation.

Table 2 Results of Performance of ANN Model

Name of the algorithm	Training results			Testing results		
	MAE	RMSE	R	MAE	RMSE	R
GD	3.5745	4.5320	0.8882	9.6499	11.6337	0.8751
LM	**0.7512**	**0.9362**	**0.9885**	**1.8734**	**2.4186**	**0.9882**
RP	1.0192	1.3398	0.9772	2.6158	3.3763	0.9759
SCG	0.9246	1.2652	0.9823	2.2078	2.7257	0.9820

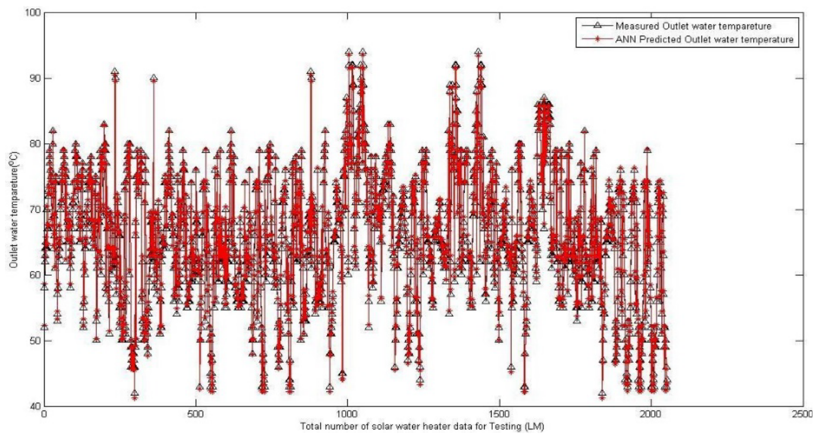

Fig 4 Performance Graph for Total Number of Testing Data

The graph of performance illustrating observed and ANN-predicted temperature of outlet water for the entire dataset and select subsets, utilizing the optimal method (LM) from this study, is presented in Fig 4 and 5, respectively. The performance graphs indicate that nearly all anticipated results closely align with the measured outlet water temperature readings.

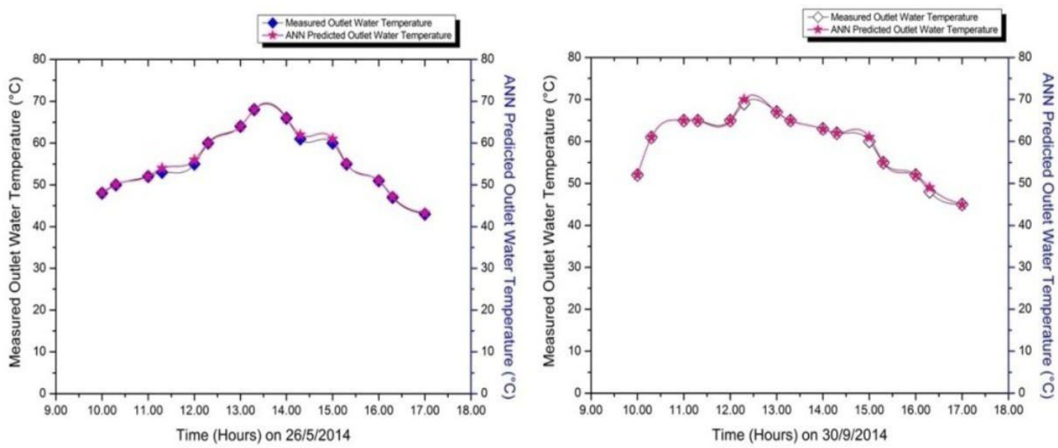

Fig 5 Performance Graph for Testing Data

Temperature of outlet water of an SWH is influenced by numerous factors. Day & time, (Sunny/Cloudy), along with GSR are regarded as critical criteria affecting the operation of solar water heating systems. Fig 6 illustrates the fluctuation of temperature of inlet water alongside the ANN-forecasted temperature of outlet water of SWH over time. Graph illustrates that temperature of outflow water progressively rises from morning, to its peak about midday, coinciding with the greatest solar radiation levels.

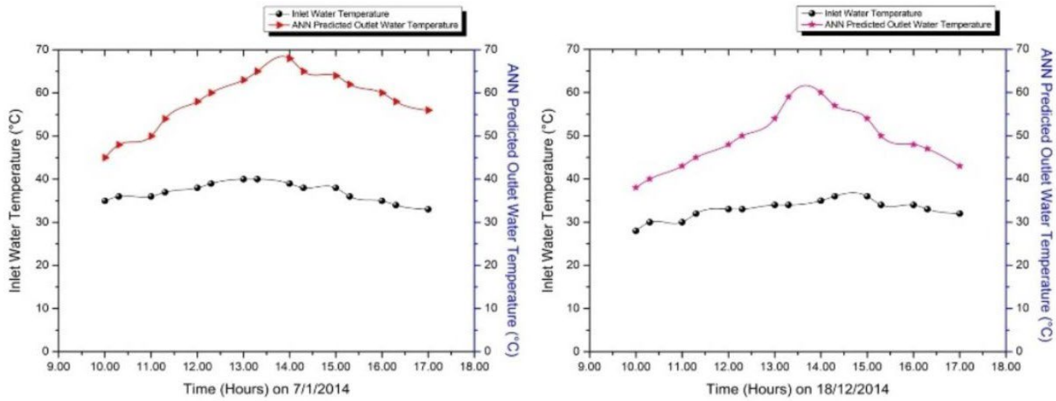

Fig 6 Temperature of Variation of Outlet & Inlet Water W.R.T. Time

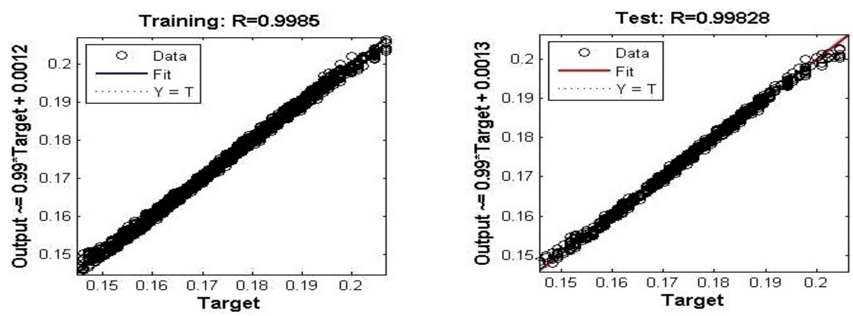

Fig 7 Regression Plot for Training as Well as Testing Data of SWH

Fig 7 shows a regression diagram that illustrates the correlation between the outlet water temperature measurements that were observed and those that were predicted by the artificial neural network (ANN) for both the training and testing datasets. The optimum algorithm (LM) was used for this analysis. The value of R for the training data is 0.9985, while the R value for the experimental dataset is 0.9982. The R values that were obtained provide additional evidence that the LM method that was proposed is the best option for predicting how well solar-powered water heaters would function.

The efficacy of SWH system is influenced by numerous climatological factors, with sun radiation being one of the most significant. The current investigation endeavour to establish a hybrid model utilizing ANN frameworks for predicting GSR and SWH performance. The construction of ANN for the combined model predicting SWH performance is illustrated in above Fig 8.

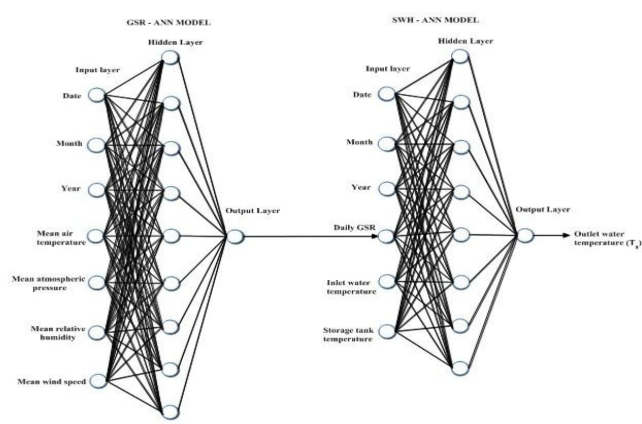

Fig 8 ANN Structure for the Combined Model of SWH Performance Prediction

Advantage of integrated ANN models is that they estimate performance of thermosyphon SWH without the need for measuring facilities for GSR. Therefore, in the integrated model, daily mean GSR recorded in Bhopal city is utilised as an input parameter for forecasting the temperature of output water of SWH system placed in Bhopal city. Prediction accuracy of GSR-ANN model and SWH-ANN model utilised in the combined model is independently validated for Bhopal city in the previous sections of the research.

The GSR incident on Earth is predominantly influenced by meteorological conditions; therefore, the atmospheric elements affecting solar radiation must be input into ANN model for accurate prediction of daily mean GSR. Consequently, daily average values of parameters including air temperature, relative humidity, atmospheric pressure and speed of wind are obtained from a weather monitoring station located at LNCT University, Bhopal (Madhya Pradesh). These values, along with the date, month, and year, serve as input for the GSR-ANN model to forecast daily average GSR as output.

Data was systematically collected on the 20th of each month from January 2023 to December 2023, utilised for evaluating a built ANN model employing the optimal LM algorithm to forecast the daily average GSR. Predictive accuracy of the GSR-ANN model employed in this integrated model is independently validated for Bhopal city. The ANN forecasted daily average GSR findings, along with the measured input and output parameters, are consolidated in Table 3.

Table 3 Predicted Results from GSR-ANN Model

Daily Average Data for Bhopal - January 2023 to December 2023						
Date- Month - Year	**Mean Pressure at Station Level (hPa)**	**Mean Temp (ºC)**	**Mean value of Relative Humidity (%)**	**Mean Wind Speed (km/hr)**	**Measured GSR (W/m²)**	**ANN Predicted GSR (W/m²)**
20/01/2023	993.58	35.57	35.91	0.7	658.04	660.77
20/02/2023	990.21	33.11	44.26	1.18	455.58	453.31
20/03/2023	998.21	33.24	48.11	1.16	600.26	603.73
20/04/2023	991.98	36.81	38.48	0.51	595.26	592.04
20/05/2023	988.96	36.33	46.91	0.44	542.14	539.96
20/06/2023	991.32	33.34	52.14	0.65	561.46	560.84
20/07/2023	990.32	33.67	39.93	1.51	553.94	556.57
20/08/2023	989.56	35.85	38.81	0.83	676.37	677.13
20/09/2023	990.24	31.71	58.78	0.24	576.89	578.22
20/10/2023	995.91	30.88	65.51	0.45	651.76	654.17
20/11/2023	990.84	31.16	62.23	0.62	491.01	492.56
20/12/2023	990.96	32.61	51.35	0.56	615.23	613.84

Table 4 ANN Predicted Performance Results of Combined Model

Date- Month - Year	**Inlet Water Temperature (˚C)**	**GSR (W/m²)**	**Measured Outlet Water Temperature (˚C)**	**ANN Predicted Outlet Water Temperature (˚C)**
20/01/2023	37	660.77	59	61
20/02/2023	33	453.31	50	49
20/03/2023	39	603.73	60	63
20/04/2023	41	592.04	68	69
20/05/2023	42	539.96	66	67

20/06/2023	40	560.84	63	63
20/07/2023	34	556.57	67	65
20/08/2023	37	677.19	65	68
20/09/2023	40	578.24	69	66
20/10/2023	38	654.17	66	69
20/11/2023	35	492.56	51	48
20/12/2023	33	613.84	54	55

The output water temperature of a solar water heater is influenced by various elements, including the date, month, year, GSR, time, temperature of inlet water and storage tank. Global sun radiation is regarded as a significant factor affecting the efficacy of SWH systems. Nonetheless, time is excluded as an input parameter in the combined model for predicting the daily average outlet water temperature. Consequently, to evaluate the efficacy of the integrated model, the projected daily average GSR from GSR-ANN model in this analysis serves as a critical input parameter for the SWH-ANN model, in conjunction with the recorded inlet and storage tank temperatures, to forecast the outlet water temperature (T0) for the installed SWH system at LNCT University, Bhopal, in the central region of Madhya Pradesh, India, under varying weather conditions. Table 4 presents the performance results derived from the integrated model and its input parameters.

Table 5 Results of Error Analysis of Combined ANN Approach

Name of error analysis terms	Results
MAE	2.34
RMSE	2.56
MAPE	4.09
C_D^2	0.91

SEA results for the testing data set of combined models are seen in above Table 5. Minimum RMSE, MAE, MAPE, and maximum coefficient of determination, namely 99.81%, of the anticipated outlet water temperature values demonstrate that the predicted values closely align with measured values across all data sets utilised in combined model of this study.

Ultimately, to validate the statistical error analysis results derived from the combined model, a comparison will be made with the error analysis results of the individual SWH-ANN (Independent model). Table 6 presents a comparison of error analysis results for both the combined and independent models, clearly indicating that all error values are minimal, namely below 5%.

Table 6 Comparison of Combined and Independent ANN Model

Name of the error analysis terms	Results from combined model	Results from independent model
MAE	2.34	1.83
RMSE	2.56	2.49
MAPE (%)	4.09	1.65
C_D^2	0.91	0.96

The error analysis in Table 6 demonstrated that the created combination model is highly effective for predicting SWH performance with significant accuracy, eliminating the need for expensive GSR measuring facilities.

6. CONCLUSION

Solar energy from the solar system is available to everyone all over the world. In today's society, the majority of household activities require hot water that is below 60 degrees Celsius. In domestic settings, solar water heaters can be used instead of an electric heater, and in industrial applications, it can be used as a pre-warmer if temperatures exceed 60 degrees Celsius. The best way to meet your hot water needs is to use solar water heating.

This chapter examines forecasting of the outcomes of a solar-powered water heating system utilizing a thermosyphon collector with a flat plate and a horizontal heated water storage tank utilizing an ANN model. An ANN model is trained and evaluated using data that was collected over the course of a year under a variety of meteorological conditions. The effectiveness of four different algorithms GD, SCG, LM, and RP is evaluated by looking at the minimal RMSE, minimal MAE, as well as maximal linear correlation coefficient (R). Among the four methods, the algorithm known as LM is considered to be the most successful for the present review.

A distinctive method is used to predict how well the solar-powered water heater in Bhopal City will function. This is done by combining GSR as well as SWH ANN models. The output of GSR from the GSR-ANN simulation of Bhopal city is used as a parameter for input in the combination ANN model for the solar-powered water heating system. The output that was obtained is compared to the values that were tested. The error study showed that the mixed ANN model that was created is the best option for predicting SWH performance, as it has the lowest RMSE and MAPE and the highest.

As a result, design architects and engineers can effectively use the optimized ANN model, which has been trained with the more effective LM technique, to predict the effectiveness of thermosyphon solar heaters on any given day. This is done by utilizing GSR, inlet temperature of the water, and storage tank temperatures, which eliminates the need for intricate and expensive field experiments for particular areas in India. The integrated ANN model developed in this study is capable of accurately predicting how well thermosyphon solar-powered water heating systems would operate without requiring costly monitoring equipment for GSR.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

A. K. Yadav, H. Malik, and S.S. Chandel, “Selection of most relevant input parameters using WEKA for artificial neural network based solar radiation prediction models,” Renewable and Sustainable Energy Reviews, vol. 31, pp. 509-519, 2014.

Adhikari, A, Dotel, UR, Pokhrel, R & Hagen, ST 2013, “Thermal efficiency test of locally manufactured solar flat plate collector of Nepal”, IEEE, pp. 1- 4.

Aminmohammad Saberian, Hizam H, Radzi MAM,Ab Kadir MZA, and Maryam Mirzaei.,” Research Article Modelling and Prediction of Photovoltaic Power Output Using Artificial Neural Network”, International Journal of Photo energy, Article ID 469701,10 pages, 2014.

Amit Kumar Yadav, Chandel SS., “Solar energy potential assessment of western Himalayan Indian state of Himachal Pradesh using J48 algorithm of WEKA in ANN based prediction model”, Renewable Energy, 75, pp.675-693, 2015.

Arekete, SA 2013, “Performance of solar water heater in Akure, Nigeria”, Journal of Energy Technologies and Policy, vol. 03, no. 6, pp. 01-08.

Assi AH, Shamisi M & Hejase HA 2012, “MATLAB tool for predicting the global solar radiation in UAE”, International Conference on Renewable Energies for Developing Countries (REDEC), pp. 1-8.

Ayompe, LM & Duffy, A 2013, “Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate”, Applied Thermal Engineering, vol. 58, pp. 447- 454.

B. Ihya, A. Mechaqrane, R. Tadili, and M. N. Bargach, “Prediction of hourly and daily diffuse solar fraction in the city of Fez (Morocco),” Theor Appl Climatol, vol. 120, issue 3, pp. 737-749. 2014.

Egeonu, DI, Njoku, HO, Okolo PN, Enibe SO., "Comparative assessment of temperature-based ANN and angstrom type models for predicting global solar radiation", Advances in Intelligent Systems and Computing, 334, pp.109-122,2015.

Fariba Besharat, Dehghan, AA, & Faghih, AR 2013, "Empirical models for estimating global solar radiation: A review and case study", Renewable and Sustainable Energy Reviews, vol. 21, pp. 798-821.

Javier Almorox, Monica Bocco, & Enrique Willington 2013, "Estimation of daily global solar radiation from measured temperatures at Cañada de Luque, Córdoba, Argentina", Renewable Energy, vol. 60, pp. 382-387.

Jianwu Zeng and Wei Qiao., "Short-Term Solar Power Prediction using an RBF Neural Network", IEEE Power and Energy Society General Meeting, 2011.

Juhi Joshi., "A comparative study of ANN and angstrom Prescott model in the context of solar radiation analysis", IPASJ-International Journal of Computer Science (IIJCS), 2(3), March 2014.

K. Chiteka, and C.C. Enweremadu, "Prediction of global horizontal solar irradiance in Zimbabwe using artificial neural networks," Journal of Cleaner Production, vol. 135, 2016, pp. 701-711, 2016.

Koca, A, Oztop, HF, Varol, Y & Koca, GO 2011, "Estimation of solar radiation using artificial neural networks with different input parameters for mediterranean region of Anatolia in turkey", Expert Systems with Applications, vol. 38, no. 7, pp. 8756-8762.

M. Shaddel, D. S. Javan, and P. Baghernia, "Estimation of hourly global solar irradiation on tilted absorbers from horizontal one using artificial neural network for case study of Mashhad," Renewable and Sustainable Energy Reviews, vol. 53, 59-67, 2016.

M. Vakilia, S-R. Sabbagh-Yazdi, K. Kalhorb, and S. Khosrojerdi, "Using artificial neural networks for prediction of global solar radiation in Tehran considering particulate matter air pollution," Energy Procedia, vol. 74, pp.1205-1212, 2015.

Mohammadi, K, Shamshirband, S, Tong, CW, Arif, M, Petković, D & Ch, S 2015, "A new hybrid support vector machine–wavelet transform approach for estimation of horizontal global solar radiation", Energy Conversion and Management, vol. 92, pp. 162-171.

Naveen Sharma, MK 2012, "Applications of artificial neural network in solar thermal systems: A review ", Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, pp. 188-194.

Ozgur Celik, Ahmet Teke, & Basak Yıldırım, H 2016, "The optimized artificial neural network model with Levenberg Marquardt algorithm for global solar radiation estimation in eastern mediterranean region of turkey", Journal of Cleaner Production, vol. 116, pp. 1-12.

Premalatha N, Dr. ValanArasu A., "Estimation of global solar radiation in India using artificial neural network", International Journal of Engineering Science & Advanced Technology, 2(6), pp.1715 – 1721, 2012.

Qazi, A, Fayaz, H, Wadi, A, Raj, RG, Rahim, N & Khan, WA 2015, "The artificial neural network for solar radiation prediction and designing solar systems: a systematic literature review", Journal of Cleaner Production, vol. 104, pp. 1-12.

Rajesh Kumar, Aggarwal RK and Sharma J D.," New Regression model to Estimate Global Solar Radiation Using Artificial Neural Network", Advances in Energy Engineering (AEE) ,1(3), pp.66 -73, 2013.

Renno, C, Petito, F, Gatto, A 2015, "Artificial neural network models for predicting the solar radiation as input of a concentrating photovoltaic system", Energy Conversion and Management, vol. 106, pp. 999-1012.

Shukla, R, Sumathy, K, Erickson, P & Gong, J 2013, "Recent advances in the solar water heating systems: A review", Renewable and Sustainable Energy Reviews, vol. 19, pp. 173-190.

Sivamadhavi V and R Samuel Selvaraj R.," Prediction `of monthly mean daily global solar radiation using Artificial Neural Network", J. Earth Syst. Sci. ,121(6), pp.1501–1510,2012.

Tamer Khatib, Azah Mohamed, Marwan Mahmoud and Sopian K., "An Assessment of Diffuse Solar Energy Models in Terms of Estimation Accuracy (Malaysia)", Energy Procedia, 14, pp.2066- 2074, 2012.

T. Khatib, A. Mohamed, K. Sopian, and M. Mahmoud, "Modeling of daily solar energy on a horizontal surface for five main sites in Malaysia," International Journal of Green Energy, vol. 8, issue 8, pp.795-819, 2011.