Artificial Neural Network Modeling of the Thermal Performance of a Novel Solar Air Absorber Plate

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Abstract

Solar air collectors are usually used for support space heating and drying agricultural products. Artificial surface geometry applied on the absorber plate is the very efficient method to improve thermal performance of solar air collector. The thermal efficiency of solar air collector is generally poor due to low heat transfer co-efficient between the absorber plate and the air flowing in the collector. In the literature for increasing the thermal efficiency; trapeze, zigzag, sinusoidal, finned, obstacles, corrugated, roughness, ribs, expanded etc. different surface geometry absorber plate were used. In this study, a novel absorber plate was designed and manufactured in order to improve the thermal efficiency of the solar air collector. Thermal performance of solar air collector with conical absorber plate (Conic Type) of has been experimentally investigated and the collector with flat absorber plate (Flat Type) is used for comparison.

Experimental measurements are carried out under sunny weather conditions. Global radiation value is measured with a pyranometer on the collector. Temperatures of three points on the absorber plates and collectors input-output air temperatures are recorded at regular intervals. Air flow rate at the collector output is measured by using hotwire type anemometer. As a result of all these measurements, thermal efficiency is determined. Experiments are performed for air flow rate that is 0.06 kg/s. The average thermal efficiencies obtained are 31.5% and 45.1% for both Flat Type and Conic Type respectively for 0.06 kg/s. The average outlet temperatures obtained are 24.8 °C and 27.5 °C for both Flat Type and Conic Type respectively for 0.06 kg/s. According to the data obtained in the experiments, a model of artificial neural network (ANN) of the collector is created considering five inputs and two outputs data. The collector inlet air temperature, global radiation and temperatures of the absorber are evaluated as input parameters however the collector outlet air temperature and the thermal efficiency values of the collector are evaluated as output parameters. By training a ANN with a part of the experimental data, the output parameters are estimated corresponding to different inputs data. In conclusion, the collector thermal performance is significantly improved by conical obstacles on the absorber plate and the ANN model can easily be implemented to predict thermal efficiency and outlet temperature of the solar air collectors.

Keywords: Solar air collector, conical obstacles, thermal efficiency, artificial neural network, modelling.

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1. Introduction

Solar air collectors are usually used for supporting space heating and drying agricultural products. Despite solar air collectors have simple structure and have a long life, thermal efficiencies are low. Many absorber plate geometry studies in the literature are performed to increase the thermal efficiency. Benli performed an experimental study to evaluate thermal performance of solar air collectors with different shape absorber plates. His experimental results show that the efficiency of air collector increases significantly depending on the surface geometry of the absorber plates [1]. Özgen et al. investigated experimentally the effect on efficiency by inserting an absorbing plate made of aluminum cans into the double-pass channel in a flat-plate solar air collector. They concluded that this method substantially improves the collector efficiency by increasing the air velocity and enhancing the heat transfer coefficient between the absorber plate and air [2]. Akpınar and Koçyiğit investigated thermal performance of solar air collector having different obstacles on absorber plates. They found that thermal efficiency of the collector with obstacles is significantly better than that of without obstacles [3]. Esen experimentally investigated energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates. He reported that obstacles on the absorber plates increased thermal efficiency [4]. Benli studied on the determination of thermal performance of two different types of solar air collectors with the using of ANN. The results of this study showed that the ANN can be used to predict the thermal performance of solar air collectors as an accurate method [5]. Esen et al. used ANN and wavelet neural network approaches for modeling a solar air collector. They concluded that wavelet neural network model can be used for estimating the some parameters of solar air heaters with reasonable accuracy [6].

In this study, thermal performance of absorber plate with conical obstacles of solar air collector has been experimentally investigated. Flat plate collector absorber is used for comparison. According to the data obtained in the experiments, a model of ANN of collector is established considering five inputs and two outputs data. The input variables of neural network model are the collector inlet air temperature, the global radiation and the temperatures of the absorber plate. The collector outlet air temperature and the thermal efficiency values of the collector constitute the output parameters. By training an artificial neural network with a part of the experimental data, the output parameters are estimated corresponding to different inputs data.

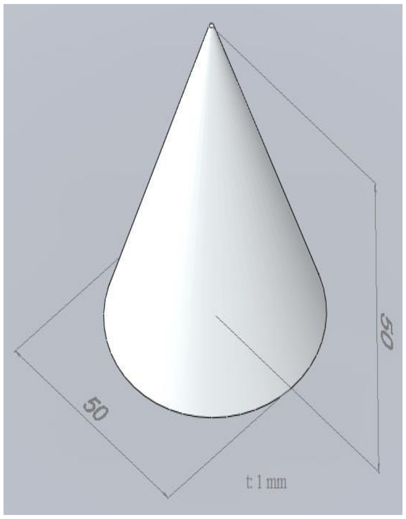
2. Materials and Method

The experimental setup of the solar air collectors is shown in Figure 1. The system consists of collector box, absorber plate, insulation, transparent cover, air circulation fans and test devices. The main properties of the solar air collectors are given in Table 1. Cross sectional view of the conical obstacle and solar absorber plate with conical obstacles is presented in Figure 2.

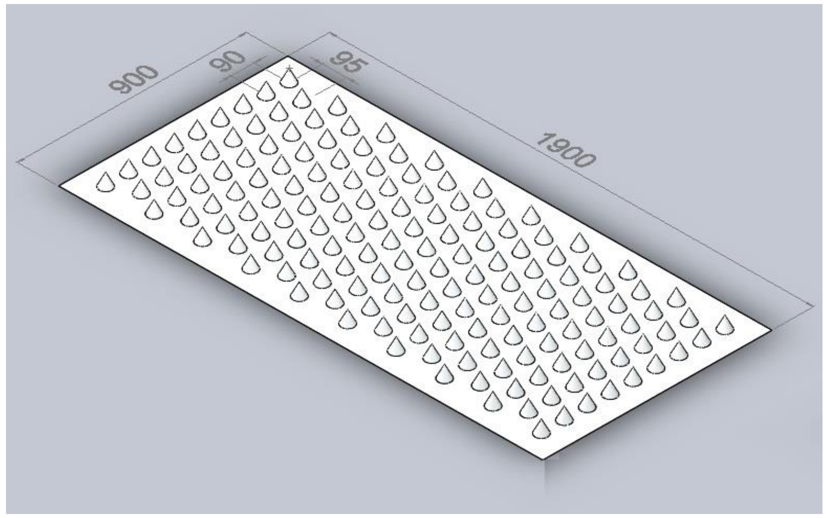
Table 1. Properties of collectors.

Collector Components	Technical Specifications
Collector type	Active type, single pass.
Collector box	Steel sheet of 0.8 mm thickness and 1000x2000x200 mm in dimensions.
Insulation	50 mm glass wool was used for back and side insulation.
Absorber Plate	Aluminum. 900x1900x1 mm in dimensions.
Transparent cover	Low iron tempered solar glass (3.2 mm thickness), solar energy transmittance is 90.7%.
Absorber paint	Selective solar paint. The emissivity of paint is between 0.20 to 0.49 and absorptivity of paint is between 0.88-0.94.
Fans	35 W, 225 m^3/h, cross fans

Figure 1. Experimental setup of the solar air collectors (Flat Type on the left and Conic Type on the right)



(a)



(b)

Figure 2. Conical obstacle (a) and absorber plate with conical obstacles (b)

The Conic Type absorber plate is designed as shown in Figure 2. In the absorber plate manufacturing, aluminum is used in the 1 mm thick. Conical obstacles are designed as 50 mm height and base diameter. 172 cone nets are cut off at laser cutting machine. Cone nets are formed as cone and soldered with oxy-lpg. 172 circles in 50 mm diameter cut off by laser cutting machine. Conical obstacle rows are made transversely to each other. Manufactured conical obstacles are soldered with oxy-lpg to the absorber plate.

The experiment was held in the 38°55'N-27°50'E coordinates in Manisa/Turkey in November 2014. After installation of the experimental system, all tests began at 09.00 a.m. and ended at 15.00 p.m. under the sunny weather conditions. Surface temperatures are measured at three points on the diagonal of the absorber plate. The total solar radiation incident is measured by using pyranometer mounted adjacent to the glazing cover. Air velocity is measured by a hot wire anemometer placed at the collector output. The collector outlet and ambient temperatures are measured by using pt1000 temperature probes. Slope of the collector is set to be 23^o. All data are recorded at the time intervals of 5 minutes. Figure of the absorber plate with conical obstacles and schematic demonstration of the measurement points is given in Figure 3. The following parameters are measured in the experimental setup.

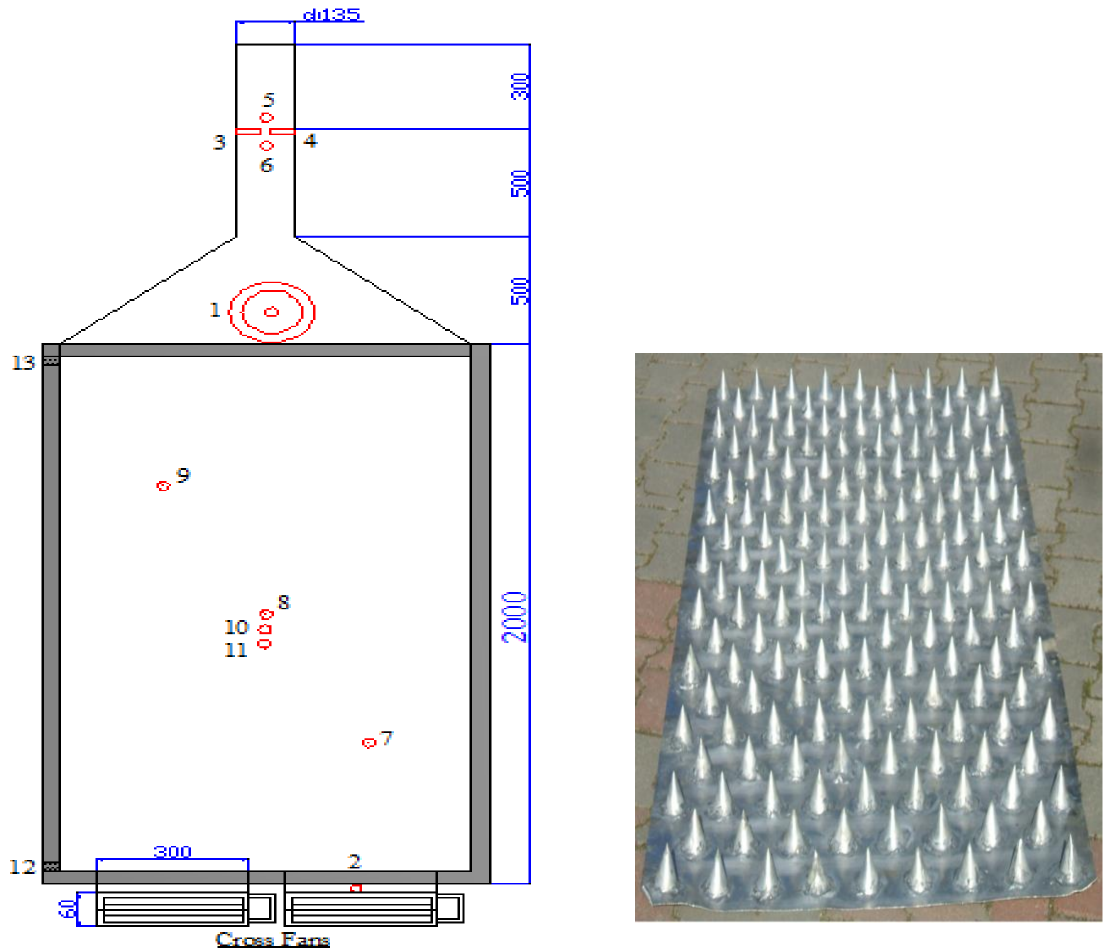
Measurement Points:

1. Solar irradiance (I)
2. Collector inlet temperature (T_i)

3-4. Average output velocity of the air from the collector $\left((V_3 + V_4)/2\right)$

5-6. Average output temperature of the air from the collector $\left((T_5 + T_6)/2\right)$

7-8-9. Average surface temperature of the absorber plate $\left((T_7 + T_8 + T_9)/3\right)$



(a) (b)

Figure 3. Measurement points (a) and absorber plate with conical obstacles (b)

The mass flow rate is controlled and equalized by electric dimmer connected with fans. The velocity of the air is measured by hotwire type anemometer with precision of ±0.2 m/s. Inlet and outlet air temperatures are measured by T-type thermocouples with precision of ±0.5 °C. PT1000 type temperature probes with precision of ±0.15 °C are used to measure surface temperatures of the glazing, absorber plate and back surface of the collector box. The global solar radiation incident on the glazing is measured by a pyranometer with accuracy of ± 2%. Mass flow rate and thermal efficiency of the collector are calculated based on the above experimental measurements. The total uncertainties belong to mass flow rate and thermal efficiencies are %2.4 and %1.05, respectively.

3. Thermal Efficiency Analysis

The useful energy in the solar air collector can be determined as follows

$$Q_u = \dot{m} c_p \left(T_o - T_i\right) \tag{3.1}$$

where $\dot{m}$ is the mass flow rate of the air, c_p is the specific heat of the air, T_o and T_i are the collector inlet and outlet temperatures, respectively. The mass flow rate of the air can be written as

$$\dot{m} = \rho A_k V \tag{3.2}$$

Where ρ is the density of the air, A_k is the cross sectional area at the collector outlet and V is the air velocity. Thermal efficiency of the collector is defined as the ratio of the useful energy and the total solar radiation incident as

$$\eta = \frac{Q_u}{I A_c} \tag{3.3}$$

where A_c is the surface area of the collector.

4. Modelling of the Solar Air collector by Using Artificial Neural Networks

Artificial neural networks (ANN) can be defined as a method inspired by the operating system of the human brain. ANN is composed of interconnected many neural cells and usually arranged in layers [7]. ANN has a wide range of applications such as image recognition, prediction and classification. The ANN is formed in three layers called the input layer, hidden layer, and output layer as shown in Figure 4.

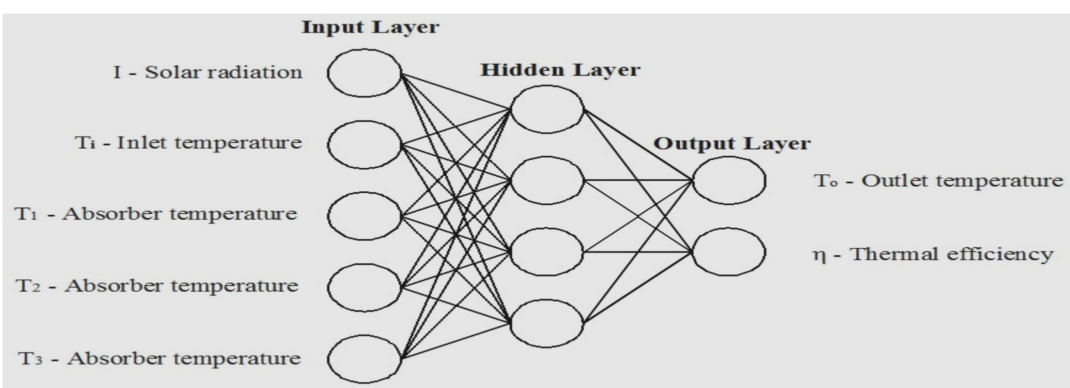


Figure 4. The structure of the ANN

The solar air heater collector system is modeled by ANN has five inputs and two outputs. The absorber plate surface temperatures (T_1, T_2 and T_3), solar radiation incident (I) and inlet temperature (T_i) are considered as input variables. The collector thermal efficiency (η) and outlet temperature (T_o) are evaluated as output variables. Matlab 7.12 platform was used to train and test of the ANN. The information set contains 72 data patterns of input and output information of which 48 patterns were used for training of the ANN and the rest were evaluated in the test procedure. The structure of the ANN and training parameters are given in Table 2.

Table 2. The structure of the ANN and training parameters

	ANN
The number of layers	3
The number of neuron on the layers	8-8,10-2
The initial weights and biases	Random
Activation Functions	Tangent Sigmoid
Learning Rule	Back propagation
Learning Rate	0.8
Mean-Squared Error	1e-06

The forecasting accuracy of the ANN was determined by the using of root mean square error (RMSE) and the coefficient of multiple determinations (R^2) as follows:

$$RMSE = \sqrt{\frac{\sum_{m=1}^{n}\left(y_{pre,m} - t_{mea,m}\right)^2}{n}} \tag{4.1}$$

$$R^2 = 1 - \frac{\sum_{m=1}^{n}\left(y_{pre,m} - t_{mea,m}\right)^2}{\sum_{m=1}^{n}\left(t_{mea,m}\right)^2} \tag{4.2}$$

where n is the total number of the data patterns, y_{pre} is the predicted value and t_{mea} indicates the true value.

5. Results and Discussions

In this study, thermal performance of absorber plate with conical obstacle and flat plate absorber plate are investigated experimentally and thermal efficiency and collector air output temperature were predicted by ANN. The minimum, maximum and average values of the experimental results are given in Table 3. Subscript 1 and 2 identify flat type and conic type absorber plate, respectively.

Table 3. Experimental data

Values	I (W/m^2)	T_i (°C)	T_{o1} (°C)	T_{1a} (°C)	T_{1b} (°C)	T_{1c} (°C)	T_{o2} (°C)	T_{2a} (°C)	T_{2b} (°C)	T_{2c} (°C)	η_1 (%)	η_2 (%)
Min.	391.4	10.3	14.2	19.6	29.2	29.5	15.9	15.2	21.3	26.9	21.8	36.2
Max.	809.7	23.4	29.8	45.4	63.1	58.7	32.6	35.9	45.0	51.2	35.9	50.0
Avg.	676.5	18.8	24.8	37.7	53.1	49.5	27.5	29.4	38.0	43.9	21.8	36.2

Experimental and predicted outlet temperature values of the collector with flat absorber plate are shown in Figure 5.

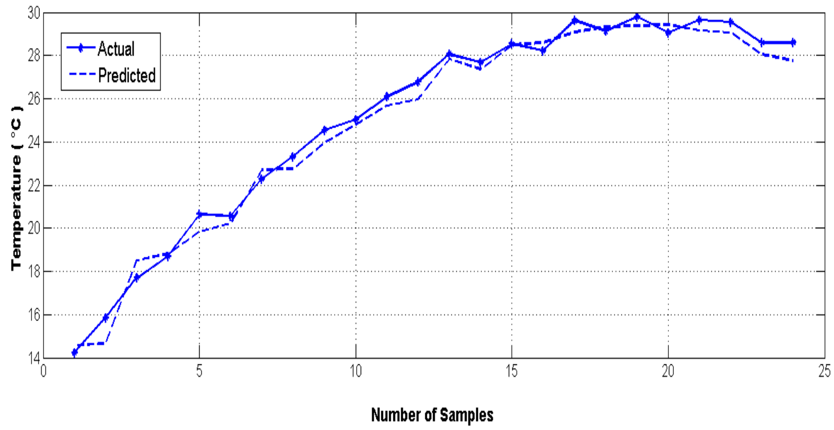


Figure 5. Outlet temperature graph of the flat absorber plate

Experimental and predicted thermal efficiency values of the collector with flat absorber plate are shown in Figure 6.

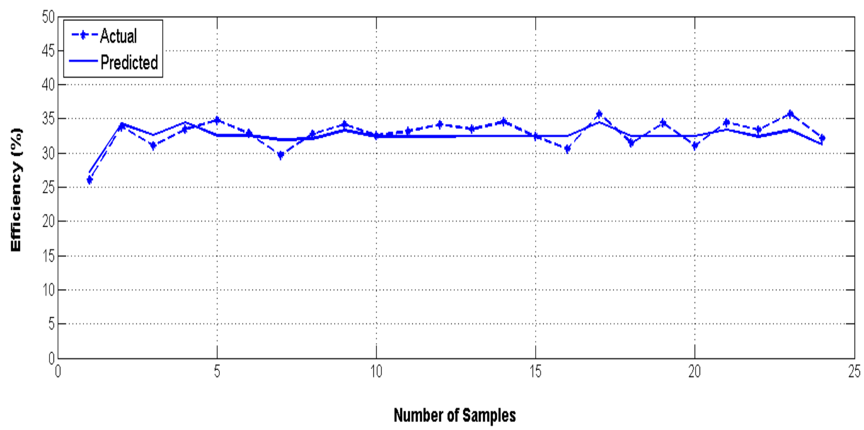


Figure 6. Thermal efficiency graph of the flat absorber plate.

The predicted and experimental outlet temperatures of the absorber plate with conical obstacle are given in Figure 7.

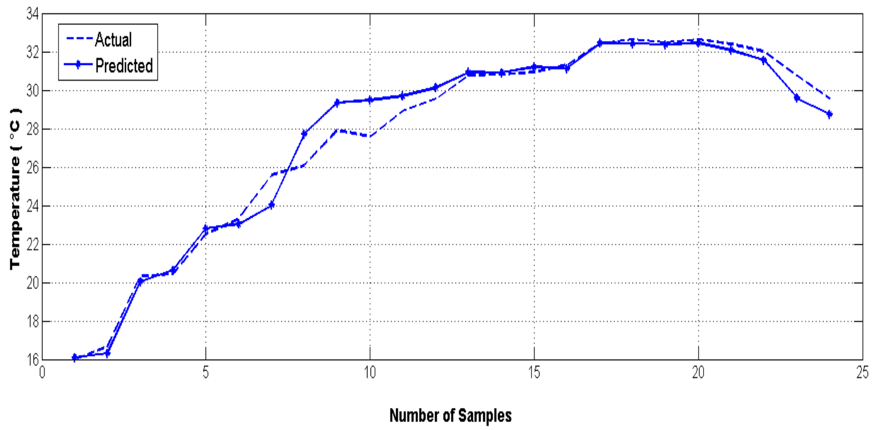


Figure 7. Outlet temperature graph of the absorber plate with conical obstacle

The predicted and experimental thermal efficiency values of the absorber plate with conical obstacle in Figure 8.

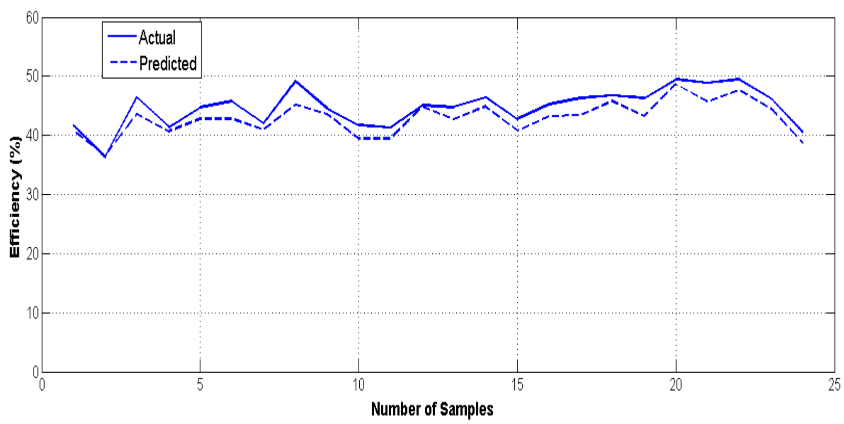


Figure 8. Predicted and experimental outlet thermal efficiency values of the absorber plate with conical obstacle

6. Conclusions

In this paper, thermal performance of solar air collector absorber plate with conical obstacle and flat absorber plate are experimentally investigated. The average outlet temperatures obtained are 24.8 °C and 27.5 °C for both Flat Type and Conic Type respectively for 0.06 kg/s. The average thermal efficiencies obtained are 31.5% and 45.1% for both Flat Type and Conic Type respectively for 0.06 kg/s. According to the data obtained in the experiments, a model of artificial neural network of collector is created considering five inputs and two outputs data. The input variables of neural network model are the collector inlet air temperature, the global radiation and the temperatures of the absorber plate. The collector outlet air temperature and the thermal efficiency values of the collector constitute the output parameters. By training an artificial neural network with a part of the experimental data, the output parameters are estimated corresponding to different inputs data. Different parameters to improve the ability to predict the Artificial Neural Networks have been tried on training time. The test values were tested with the parameters that give the closest result according to the training values. The predicted values by the ANN model are very close to the experimental ones. The thermal efficiency prediction has a 98% percent accuracy rate with the ANN on the modeling of the collector with a flat absorber plate according to the R^2 method. The thermal efficiency prediction has a 99% percent accuracy rate with the ANN modeling of the collector with a conic absorber plate according to the R^2 method. It is clear that ANN model successfully predicts the thermal efficiency. The ANN model can easily be implemented to predict thermal performance of the solar air collector.

In conclusion, the collector thermal performance is significantly improved by conical obstacles on the absorber plate and the ANN model can easily be implemented to predict thermal efficiency and outlet temperature of the solar air collectors.

Acknowledgment

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