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Determination of thermal performance calculation of two different types solar air collectors with the use of artificial neural networks

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ABSTRACT

In this study, two different surface shaped solar air collectors are constructed and examined experimentally; corrugated and trapeze shaped. Experiments are carried out between 09.00 and 17.00 in October under the prevailing weather conditions of Elazığ, Turkey. Thermal performances belonging to experimental systems are calculated by using data obtained from experiments. A feed-forward neural network based on back propagation algorithm was developed to predict thermal performances of solar air collectors. The measured data and calculated performance values are used at the design of Levenberg–Marquardt (LM). Calculated values of thermal performances are compared to predicted values. It is concluded that, ANN can be used for prediction of thermal performances of solar air collectors as an accurate method in this system.

1. Introduction

A solar thermal collector is designed to collect heat by absorbing sunlight. The term is applied to solar hot water panels, but may also be used to denote more complex installations such as solar parabolic, solar towers, or simpler installations such as solar air heat. The more complex collectors are generally used in solar power plants where solar heat is used to generate electricity by heating water to produce steam which drives a turbine connected to an electrical generator. The simpler collectors are typically used for supplemental space heating in residential and commercial buildings. A collector is a device for converting the energy in solar radiation into a more usable or storable form. The energy in sunlight is in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths. The solar energy striking the Earth's surface depends on weather conditions, as well as location and orientation of the surface. In general solar collectors are separated into two sections with respect to type of heat transfer fluid: liquid collector and solar air collector (SAC), [1].

Solar air collectors which heat air directly, fall into two categories: glazed and unglazed. They are also used for pre-heating make-up air in commercial and industrial HVAC systems. Glazed systems have a transparent top sheet as well as insulated side and back panels to minimize heat loss to ambient air. The absorber plates in modern panels can have an absorptivity of more than 93%. Air typically passes along the front or back of the absorber plate while scrubbing heat directly from it. Heated air can then be distributed directly for applications such as space heating and drying, or may be stored for later use. Unglazed systems, or transpired air systems, consist of an absorber plate which air passes across or through as it scrubs heat from the absorber. These systems are typically used for pre-heating make-up air in commercial buildings. These technologies are among the most efficient, dependable, and economical solar technologies available. Payback for glazed solar air heating panels can be less than 9–15 years depending on the fuel being replaced. The main disadvantage of a SAC is that the heat transfer coefficient between the absorber plate and air stream is poor, which results in a lower thermal efficiency of the collector. One of the effective ways to augment the convective heat transfer rate is to increase the heat transfer surface area and the turbulence inside the channel by using fins or corrugated surfaces. Thermal performance of solar air collectors depends on material, collector length, collector depth, type of absorber plate, glass cover plate and wind speed. Performance improvement can be achieved using diverse materials, various shapes and different dimensions and layouts. Many studies have been carried out on this topic [2–6].

In the last decade, the use of artificial intelligence methods in mechanical engineering is increasing gradually. ANN has been becoming increasingly popular in thermal engineering applications. Several studies have been introduced about using ANN in thermal applications [7–15].

In this study the thermal performance of two different types of solar air collectors, called corrugated and trapeze are examined experimentally under prevailing weather conditions in Elazığ,

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Nomenclature

A_c	collector surface area (m^2)	R^2	fraction of variance
ANN	artificial neural network	SSE	sum squared errors
C_p	specific heat (J kg^{-1} K^{-1})	T	temperature (°C)
I	global solar irradiance (W m^{-2})		
LM	Levenberg–Marquardt learning algorithm	*Subscript*	
$\dot{m}$	mass flow rate (kg s^{-1})	a	*air*
MRE	mean relative errors	in	*inlet*
n	number of independent data patterns	out	*outlet*
RMSE	root mean square error	pre	predicted

Turkey. Thirty three data are obtained from each experimental system for ANN models. Thus, totally 66 data are performed. Each of data includes eight parameters, but only three parameters are used to calculate thermal performances. Thus ANN models have been developed using measured and calculated data from experiments. Proposed Levenberg–Marquardt LM learning algorithm is used to predict the thermal performances of solar air collectors. Predicted and measured values of thermal performances are compared. Comparing errors are evaluated via statistical analysis according to model type and data groups.

2. Experimental study

Two different types of solar air collectors are constructed by using same properties of galvanize materials. A schematic view of used SAC systems is shown in Fig. 1. The detailed specifications of solar air collectors are described in Table 1. Type-I named as corrugated solar air collector, type-II named as trapeze solar air collector. The air flow is provided as seen in Fig. 1. Experiments are carried out between 09.00 and 17.00 on October 15, 2009 under Elazığ weather conditions (38:41°N latitude; 39:14°E longitude). Two collectors were placed facing south and a slope angle of 37° with the respect to horizontal line. Each of the two collectors had 0.7 m width and 1.7 m length. The collection surfaces area of solar radiation were 1.8663 m^2 in type-I, 1.3125 m^2 in type-II. The absorbing surfaces in two collectors were formed by a dull black-painted galvanized sheet with 0.4 mm thick. A single glazing of 4 mm glass was used in two collectors. In order to minimize energy losses from the bottom of the collectors, all collectors had the backs and sides insulated with a 70 and 50 mm of glass wool insulation, respectively. The air was provided by a radial fan with a maximum $\dot{m} = 0.036$ kg s^{-1} mass flow rate [6]. Change of collector efficiency for two types and others (reverse corrugated, reverse trapeze, flat) in $\dot{m} = 0.036$ kg s^{-1} is given in Fig. 2. During the experiments, the inlet and outlet air temperatures of the solar air collector, mass flow rate of air, ambient temperature, surface temperature of collectors and solar radiation density are measured.

The experiments were conducted from September 2009 to December 2009. The experiments were carried out at the same time periods between 9.00 and 17.00 of the days for a variety of mass flow rates. The air flow through the collectors were supplied by a radial fan and adjusted via a sliding valve located at the air inlet. The flow rate was kept constant for both collectors.

The experiments were carried out for $\dot{m} = 0.036$ kg s^{-1} mass flow rate. The sliding valve at the radial fan caused the changes in these rates. The air flow was provided by a centrifugal fan 0.75 kW and 1500 rpm. The air flow rate was measured by a flow meters placed at the outlet of the collectors in a vertical position. The collectors were tested according to the ASHARE 93–97 standards [16]. The incident solar radiation was measured with a Kipp and Zonen piranometer. The collectors were instrumented with T-type thermocouples for measuring temperatures of flowing air at inlet and outlet of the collectors, and the ambient temperature. The thermocouple, which measured the ambient temperature, was kept in a shelter to protect the sensor from direct sunlight. A flow meter with an electronic transducer was used to measure the wind velocity and wind direction. All the sensors used in the collector test were continuously monitored and output signals were recorded in a 20-channel data acquisition system. During the measurements of the parameters, the uncertainties occurred were presented in Table 2. Considering to relative uncertainties in the individual factors denoted by x_n, uncertainty estimation was made using the following equation [17].

$$W = [(X_1)^2 + (X_2)^2, \ldots, +(X_n)^2]^{1/2} \quad (1)$$

3. Calculation of solar air collector performance

Calculation of the solar collector efficiency according to the first law is defined as the ratio of the energy gain to the solar radiation incident on the collector plane [4].

$$\eta_I = \frac{\dot{Q}_c}{\dot{Q}_s} \quad (2)$$

where $\dot{Q}_c$ is the rate of heat transfer to a working fluid in the solar collector, and $\dot{Q}_c$ the solar energy absorbed by the solar collector surface and is given in Eq. (3)

$$\dot{Q}_s = I_T(\tau\alpha)A_c \quad (3)$$

where I_T is the rate of incidence of radiation per unit area of the tilted collector surface. A_c the collector area, and $\tau\alpha$ the effective product transmittance–absorptance. $\tau\alpha$ represents the fraction of the solar radiation absorbed by the collectors and depends mainly on the transmittance of the transparent covers and on the absorbance of the absorbent. The effective product transmittance–absorptance can be evaluated by using (4).

$$(\tau\alpha) = \frac{\tau\alpha}{1-(1-\alpha)}\rho_G \quad (4)$$

Equation (2) is the result of a first law analysis of flat plate solar collectors because all energy fluxes are treated equally, regardless of their potential usefulness.

The absorption heat-transfer rate by the solar collectors $\dot{Q}_c$ can be estimated by using (5).

$$\dot{Q}_c = \dot{m}_a Cp_a(T_{a,out} - T_{a,in}) \quad (5)$$

4. Artificial neural networks

Artificial neural networks (ANN) try to mirror the brain functions in a computerized way by restoring the learning mechanism