Measurement 116 (2018) 412–421

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Comparisons of novel modeling techniques to analyze thermal performance of unglazed transpired solar collectors

Saliha Erenturk[a], Koksal Erenturk[b,*]

[a] Ataturk University, College of Eng., Department of Chemical Eng., Erzurum, Turkey
[b] Ataturk University, College of Eng., Department of Electrical&Electronics Eng., Erzurum, Turkey

ARTICLE INFO

Keywords:
Solar heating
Neural network applications
Fuzzy neural networks
Unglazed transpired collectors
Grey modeling
ANFIS

ABSTRACT

In order to evaluate different modeling techniques for Unglazed Transpired Collectors (UTC), not only mathematical modeling method for UTC based on heat transfer expressions to estimate the various heat transfer coefficients for the UTC components and empirical relationship, but also grey modeling (GM) approach, Artificial Neural Networks (ANN) and Adaptive Network based Fuzzy Inference System (ANFIS) methods have been designed and introduced, in this study. Thermal performance experiments of UTC have been carried out on an optimized experimental setup. Firstly, obtained experimental results have been compared with the mathematical model. To constitute a common point, output temperature of the UTC has been selected as the output variable. Secondly, the GM(1,1) approach has been used to forecast the output temperature with higher accuracy with the aid of simple mathematical equations. Then, an ANN has been designed to estimate the output temperature using measured inputs variables. Next, ANFIS has been designed and used to predict the output temperature. Finally, obtained results have been compared and comparison results have been illustrated in both graphical and tabular form. GM(1,1) is the simplest method to forecast the output temperature with high accuracy, while ANFIS technique will be the best solution to predict the output temperature.

1. Introduction

More sustainable and energy efficient building design and construction plays an important role in engineering of curtain wall assemblies [1]. In terms of thermal energy losses or gains, building envelope including different passive insulation methods is one of the most suitable method to mitigate thermal compensation requirements. For this purpose, passive solar walls called as UTC have been received increasing attention. UTC based air heating systems (AHS) have been installed on building envelope and manufactured as profit-oriented products in most of the developed countries [2]. UTC based passive solar AHS is one of the recent technological research concept for the cold climates, especially. Solar chimney [3], solar room [4], and trombe wall [5,6] are some of the UTC based passive solar AHS. Hot air can be provided by using UTC system at the temperature range of 45–60 °C for almost 200 days of the year with the 2664 h/year sunshine period in Eastern region of Turkey [7].

UTC based passive solar air heating systems usually can be used for heating in winter. Despite the fact that the thermal load of envelope cannot be reduced with the usage of passive solar walls by controlling heat flux in summer, passive solar air heating technology can be taken into consideration as a special heating systems for Eastern region of Turkey because of the climate properties of the region.

In order to determine the required amount of heat generation while the UTC based air heating systems are working, being able to predict the future values will be useful for reducing the energy consumption. With reducing energy consumption in the building using UTC heating system, most of the required conditions for more sustainable, more economic, eco-friendly building systems design will be satisfied. For this reason, if one can estimate or predict future values of UTC systems based on its behavior modeling, this approach will carry the studies on UTC systems to a step forward. As aforementioned reasons, to reduce the energy consumption grey modeling, ANN, and ANFIS based modeling techniques have been used to predict the future values of UTC system for different atmospheric conditions, in this study.

In systems theory point of view, “black box” expression generally used to define if any system has an incomplete information. Conversely, if all of the required information are accessible and complete this type system is called as “white”. The meaning of “grey” can be used to express mixed characteristic neither black nor white. Generally, in real world applications, it is very hard to define the dynamic behavior of a complex system with a proper mathematical expression. Taking into

* Corresponding author.
E-mail address: erenturk@yahoo.com (K. Erenturk).

https://doi.org/10.1016/j.measurement.2017.11.033
Received 13 June 2017; Received in revised form 11 October 2017; Accepted 13 November 2017
Available online 21 November 2017
0263-2241/

consideration of a finite amount of available information, a new mathematical modeling technique based on grey modeling (GM) approach can be constituted to approximate the dynamic behavior of a system [8]. Therefore, in the literature, a great amount of published papers can be found for the applications of grey system in control and estimation [9–12].

Many different design parameters and factors that affect the performance of collectors are the climatic conditions, wind speed, cloud factor, perforation diameter, pitch of perforations, and etc. [13]. The determination of the output temperature of the collector is based on well-defined energy balance equations and rate equations. In addition to these equations, in order to get a correct model for climatic and atmospheric changes, most of the considered parameters should be switched from one state to another state. This switching requirement will complicate the analytical approach and correct modeling of the collectors using simple mathematical expressions. Instead of this analytical modeling method, ANN based mapping technique can be employed to determine the relationship between measured values and the output temperature of the collector. Since ANN has broad area of science applications such as: estimation, optimization, and data analysis in the field of energy [14–21], some of the researchers published many articles related with ANN.

AbdulHadi et al. [14] developed and validated a type of ANN with supervised learning model of solar cells against measured data. Yalcintas [15] reported a comparison method that uses ANN in its computations. Al-Shehri [16] presented an ANN architecture for predicting the electrical energy consumption in the residential sector and compared the results with the polynomial fit model. Bator and Sieniutycz [17] demonstrated the application of ANN to estimate hanging particulate concentrations in urban air, considering meteorological conditions. Yalcintas and Akkurt [18] introduced ANN methods to forecast energy usage in building. Ho et al. [19] carried out a predictive model for precise prediction of hydrogen parameters. Behera et al. [20] proposed and tested a neural model for the RPF-fired boiler to estimate the output variables such as mass flow rate of steam, pressure, and temperature with higher ability.

Neuro-fuzzy systems have been composed of merging fuzzy logic with an architectural structure of ANN [21]. ANFIS belongs to the family of integrated neuro-fuzzy system in which the fuzzy system is combined with a structure which is adaptive in nature. Amirinejad et al. [22] designed an ANFIS structure to reform Nafion and nanocomposite membranes were equipped by solution-casting method. However, ANFIS has not been used to estimate the output temperature of UTC air heating system based on the literature search. For this reason, as a novel estimator based on an ANFIS structure has also been designed and employed to predict the output temperature of UTC air heating system.

This paper introduces efficient estimation algorithms to predict the output temperature of UTC air heating system based on grey modeling, ANN, and ANFIS that can appreciably lessen the errors in measured data produced by atmospheric and climatic changes effects. As will be described later, not only quick response time and no cumulative prediction error but also no dependency on UTC parameters/characteristics and simplicity can be given attractive features of this estimation algorithm. The running performance evaluation of the proposed algorithm has been evaluated under different atmospheric and climatic conditions, with the inclusion of variations in the cloud factor, wind speed, relative humidity, and ambient temperature. Based on observed results, grey modeling approach has been found as the simplest method to predict the output temperature of UTC. However, the best prediction results have been observed with the ANFIS based method.

This paper organized as follows. Mathematical model and experimental setup details of the UTC air heating system have been described in Section 2. In Section 3, a brief introduction to the grey modeling approach has been presented. Design steps for both ANN and ANFIS based estimation algorithms have been given in Section 4. Both experimental and the simulation tests results of the realized estimators

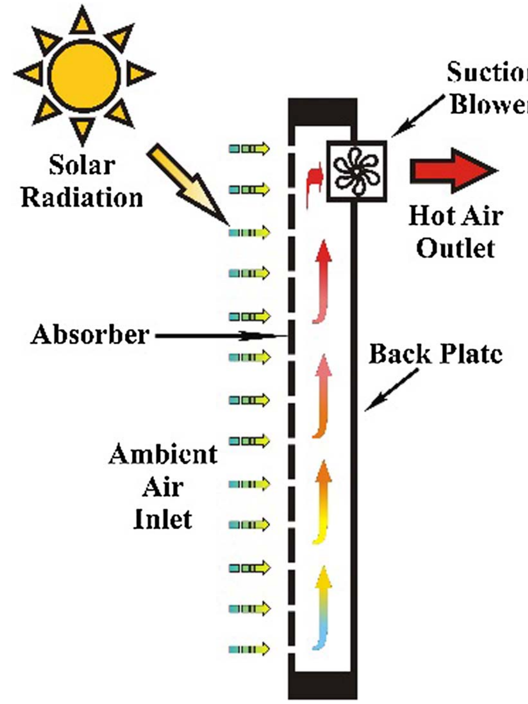

Fig. 1. Schematic diagram of the UTC air heating system.

Fig. 2. Experimental setup of the UTC air heating system.

have been demonstrated in Section 5. In Section 6, conclusions have been outlined, finally.

2. Experimental setup and mathematical model of UTC

Fig. 1 depicts the prototype UTC air heating system currently under development. The designed collector consists of an absorber with holes and a back plate (plenum). The plenum and absorber has been separated with an air gap, and formed as a closed-box. A suction blower has been inserted at the top point of the box and has been used for the necessary suction during experimental runs. All of the experimental runs have been conducted on July 2016.

As illustrated in Fig. 2, the experiments have been conducted on an experimental collector. The collector has been manufactured from an aluminum absorber and its surface has been coated with black paint. The solar radiation range is within 400–750 W/m^2 for the experiments, which quite compatible with the mean of solar radiation in Eastern region in Turkey. The measured airflow rates are in the range of 0.5–2.5 m/s. The UTC experiments have been performed for different atmospheric conditions. The thickness of the collector is 1.0 mm and