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Finite volume and response surface methodology based performance prediction and optimization of a hybrid earth to air tunnel heat exchanger

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ABSTRACT

In the present investigation, finite volume method is applied for the thermal performance prediction of a hybrid earth to air tunnel heat exchanger whereas process parameters are optimized using response surface methodology. A commercial CFD based software-ANSYS Fluent is used to simulate the heat exchanger. RNG k–ε turbulence model was selected to carry out a two-dimensional simulation modelling. Moreover, response surface methodology is applied to analyse the results of finite volume method and to optimize the process parameters of hybrid earth to air tunnel heat exchanger (HEAHX). The numerical results obtained from HEAHX are compared with that of individual EAHX. It is found that performance of HEAHX is about three times higher than as compared to individual EAHX. In addition, the theoretical results of present study are validated with theoretical results obtained from previous works and a good agreement is achieved. The maximum difference between the outlet and inlet air temperatures of hybrid and individual earth to air heat exchangers at the optimum value of input parameters are found to be 49.83 K and 14.4 K, respectively.

1. Introduction

The present energy scenario indicates that the renewable resources are depleting day by day. With the increasing population and living standards, the geothermal energy is widely used in various thermal applications such as space heating/cooling. For achieving indoor thermal comfort using less energy has been an important issue and also a great challenge for our researchers. Several passive measures are used to substitute for or to complement traditional heating, ventilating and air-conditioning (HVAC) systems [1]. In recent times, air conditioning is widely employed not only for industrial purpose but also for the comfort of occupants and numerous alternative techniques are being currently explored [2,3], one such alternative technique is earth air tunnel heat exchanger. In an EAHX system, pipes are buried under the ground at a certain depth which can extract the thermal energy from the soil into the air and that extracted air serves the purpose for space heating during winters and cooling during summers, respectively. The performance of an EAHX has been investigated by several researchers all over the world [4–12].

An earth–air tunnel heat exchange system uses underground soil as a heat source or sink and air as the medium of heat exchange [13]. Outdoor air is drawn into the earth–air tubes before being supplied to the building, rather than being introduced into the building directly as shown in Fig. 1. When air passes through the earth–air tubes, heat is transferred between the soil and ventilation air. Due to the delayed thermal response of soil, the temperature of the soil at a sufficient depth is lower than ambient temperature in summer but higher in winter [14,15]. As a result, the air is pre-cooled by the soil in summer and pre-heated in winter. The outlet air from the earth air tunnel heat exchanger can directly be used for space heating/cooling applications inside the buildings.

Most of the studies have described that the earth-to-air tunnel heat exchangers (EAHX) coupled with buildings is an effective technique for space air conditioning [16,17]. An earth-to-air tunnel heat exchanger system suitably meets heating and cooling energy demands of a building [18]. The performance of soil is based upon the seasonally varying inlet temperature, and the earth's temperature as well as moisture distribution inside the ground [19,20].

Abbreviations: ANN, artificial neural network; ANOVA, analysis-of-variance; EAHX, earth air tunnel heat exchanger; FVM, finite volume method; HEAHX, hybrid earth air tunnel heat exchanger; RSM, response surface methodology.

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Nomenclature

I	solar radiation intensity (W/m^2)
k	thermal conductivity of soil (W/m K)
T_a	ambient air temperature (K)
T_i	inlet air temperature (K)
T_o	outlet air temperature (K)
v	air velocity (m/s)

Jacovides et al. studied several statistical characteristics of the soil temperatures at the surface, at various depths and for grass covered areas [21]. A study has been investigated for single pipe carrying warm fluid buried in medium wet sand, initial soil moisture concentration, temperature and fluid-tube interface temperature using FEM [22]. Bojic et al. evaluated the technical and economic performance of an earth air tunnel heat exchanger which consists of pipes buried in soil coupled to the system for heating or cooling of a building that uses 100% fresh air as cooling or heating medium during summer and winter, respectively, using mathematical modelling [23].

The effectiveness of an earth–air tunnel ventilation system is related to the air temperature at the outlet of tunnel. Because both the outdoor air and soil temperatures could be harmonic functions of time, the air temperature at the tunnel outlet can also be represented as a time-harmonic function but probably with different time-averaged temperature [24]. Krarti et al. developed a simple model to predict the air temperature variation along the earth–air tube [25]. Deglin et al. described a 3D non-steady-state heat flow model for studying the influence of type of soil, air speed and characteristics of the pipes on the efficiency of heat exchange between the soil and the air flowing through the pipe [26]. Shukla et al. developed a thermal model for green houses using earth air tube systems for heating [27]. Thiers and Peuportier [28] obtained a technical solution for an earth air tunnel heat exchanger to reduce energy consumption while providing a satisfactory thermal comfort level in buildings.

The paper describes the development of an artificial neural network based Heat Convection (ANN-HC) algorithm to predict local average Nusselt number along duct surface. The various transient models based on computational fluid dynamics have been developed to predict thermal performance and heating capacity of an earth air tunnel heat exchanger system [29,30]. The developed models were validated against experimental investigations. These investigations proposed one and two-dimensional transient analytical models to estimate the performance of earth air tunnel heat exchangers, installed at different depths, used for building cooling/heating [9,10].

The main objective of the present study is to investigate the performance of an earth to air tunnel heat exchanger coupled with conventional single pass solar air heater, called as hybrid earth to air heat exchanger. The effects of various input parameters on output responses were analysed using response surface method (RSM). ANSYS is used to investigate the performance of proposed hybrid earth to air tunnel heat exchanger. To validate the proposed theoretical models, comparisons between the already available data from the previous studies are performed. Moreover, a theoretical study is expanded out to find the potential advantages that are associated with this air heating system.

2. Computational modelling of hybrid earth air tunnel heat exchanger (HEAHX)

2.1. Description of CFD model

The schematic of the numerical model of HEAHX used for CFD simulation is shown in Fig. 2. For simulation purpose, both components of hybrid earth to air heat exchanger were simulated individually using a commercial software ANSYS-Fluent. The computational domains of earth to air tunnel heat exchanger and conventional solar air heater are shown in Fig. 3, which are further integrated to form a hybrid earth to air tunnel heat exchanger. The final performance of HEAHX is obtained, based on the integrated results of earth to air heat exchanger and conventional solar air heater. In the working operation of HEAHX, the exit air from EAHX is fed to the inlet of the conventional solar air heater. The computational domain of EAHX consists of a pipe of diameter 0.1 m and length 30 m, which is placed inside a soil cylinder having external diameter 1 m. Whereas the length and the width of the solar air heater is assumed to be 2 m and 0.5 m, respectively. The computational domain of conventional single pass solar air heater consists of one glass cover and one well insulated absorber plate. The single pass of the air is provided between the glass cover and the absorber plate. Both, EAHX and single pass solar air heater are operated at various input air velocities, ranging from 1 to 3 m/s. Table 1

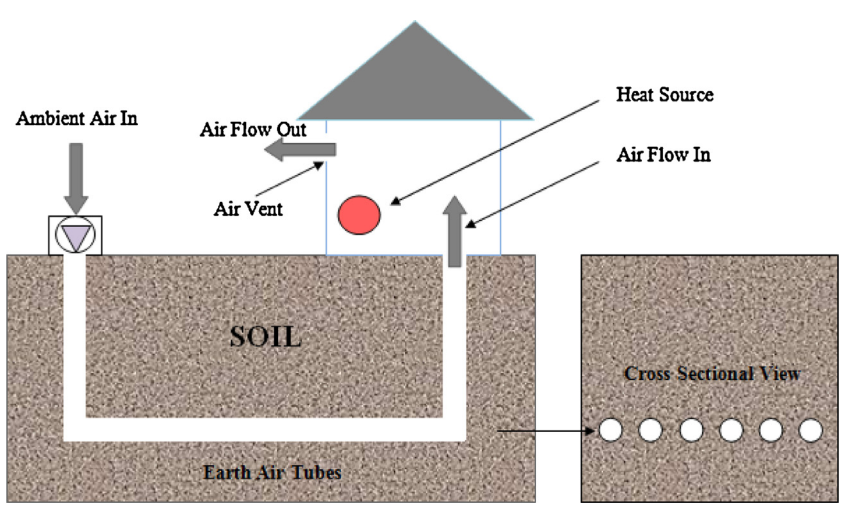

Fig. 1. Schematic view of a building combined with an earth–air tube heat exchanger system.