

## Original article

## Earth-to-air heat exchangers cooling evaluation for different climates of Iran



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## ABSTRACT

Earth-pipe-air heat exchangers (EPAHEs) are viable alternatives or supplements to conventional central heating or cooling systems. In present study, to reduce the cooling load of a sample residential building; usage and potential energy conservation of a four-pipe EPAHE were studied for different climates of Iran. The evaluation of the EPAHE was based on a three-dimensional transient computational model and validated by experimental data of another research. For this purpose four cities of Iran, by different climates (Temperate, Steppe, Desert, and Snow) were selected according to climate classification map of Wladimir Köppen, and the inlet/outlet temperature of working fluid (air) for each pipe, the monthly average energy conservation, and the maximum cooling load of the building with and without the EPAHE for these cities were compared in July.

As a result, the average energy conservation by the EPAHE is significantly different in selected cities with different climates. The energy conservation shows better when the city soil, is silt in comparison with loam and clay. Also in some cases, using of EPAHE shows a negative effect on the air-conditioning of buildings. The model was developed by the FLUENT simulation program.

## Introduction

Ground temperature remains almost constant from a certain depth in the ground throughout the year (1–8 m for dry light soils and 20 m for moistened heavy sandy soils) [1]. This temperature is lower than the ambient air temperature in the warm seasons and higher than the ambient air temperature in the cold seasons, and due to this property of the earth, it proves to be a good energy source for heating and cooling applications. One of the common ways to recover ground energy for heating and cooling of buildings is a Ground-coupled heat pump (G-CHP). However, recently it has been explored that natural air cooling or heating systems, that use earth as a source of energy for heating and cooling of ambient air have good efficiencies. These heat exchangers (EPAHEs) consist of a simple system of buried pipes through which the outside air circulates and ground energy transferred to air during this circulation. The air stream can then flow into the house directly or can enter an air-conditioning system to be conditioned further. This simple way of harnessing ground energy has directed the researchers towards evaluating the performance and applications of EPAHEs. A number of analytical and numerical models have, therefore, been developed to predict the behavior of earth-pipe-air heat exchangers. The results of some analytical and numerical models have also been compared with measured data from experimental investigations. Some early studies presented two-dimensional models such as Schiller [2] which has been carried out a numerical axisymmetric model for a single pipe with heat

conduction around the pipe and temperature dependent soil thermal properties. For instance, Santamouris and Lefas [3] and Rodriguez et al. [4] developed single pipe one-dimensional models. However, most of the early studies concern relatively simple often one-dimensional single pipe models. A more practical study was conducted by Bansal et al. [5] in which they evaluated a large earth-air-pipe system meant to provide a whole building complex at one hospital in India with thermal comfort. Mihalakakou et al. [6] proposed a transient axisymmetric model for a single pipe in which the temperature gradient beneath the ground was taken into account. Then the model was adapted to predict the several parallel pipes behavior by using the method of superposition [7]. Mihalakakou et al. [8] proposed a parametrical model in order to evaluate the impact of design parameters (pipe length, pipe radius, the velocity of the air inside the tube and depth of the buried pipe below earth surface) on the performance of the EPAHE. Santamouris et al. [9] developed a method to investigate how much the heating and cooling load of a building would be reduced by means of an EPAHE. Another study was conducted by Gauthier et al. [10] in which a transient fully three-dimensional numerical model was presented for predicting the thermal behavior of soil heat exchanger storage systems (SHESs) aimed at reducing the energy consumption of greenhouses. Hollmuller [11] introduced an analytical solution for air-to-earth heat exchanger with external adiabatic or isothermal boundary condition. Kumar et al. [12] evaluate the conservation potential of earth-pipe-air system, used directly to heat and cool a building with no air conditioning. Pfaffertott

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**Nomenclature**

$\dot{m}$	mass flow rate of air through the pipe (kg/s)
$c_p$	specific heat capacity of air (J/kg.K)
$d_{\text{pipe}}$	diameter of the pipe (m)
$v$	mean velocity of air through the pipe (m/s)
$Q_{\text{total for one month}}$	total monthly heating or cooling from the EPAHE system (J)
$\dot{Q}$	heat transfer to the working fluid per second (W)
$T_{\text{in}}$	temperature at the inlet of earth-pipe-air heat exchanger (K)
$T_{\text{out}}$	temperature at the exit of earth-pipe-air heat exchanger (K)
EPAHE	earth-pipe-air heat exchanger
$t$	time (s)

$C_v$	specific heat capacity of soil (J/m <sup>3</sup> K)
$\omega$	frequency of the temperature wave (1/s)
$\Delta T(t)$	inlet/outlet temperature difference (K)
$A_0$	amplitude of the temperature wave (K)
$d$	damping depth (m)
$z$	depth beneath the earth (m)
$T_a$	mean annual ground surface temperature (K)
$\alpha$	thermal diffusivity (m <sup>2</sup> /s)
$\lambda$	thermal conductivity (W.m/K)
BSa	arid-steppe-cold
BWh	arid-desert-hot
Csa	temperate-dry summer-hot summer
Dsa	cold (snow)-dry summer-hot summer

[13] appraised three different earth-pipe-air heat exchangers for cooling and heating of buildings and employed a general method for comparison of the EPAHEs. Another study was carried out by Ajmi et al. [14], dealing with the cooling potential of earth-air heat exchangers for buildings in a desert climate. The ground heat exchanger for ground-coupled heat pump applications in alternative operation modes over a short time period was addressed by Cui et al. [15]. They developed a finite element numerical model to simulate the ground heat exchanger. Tittlein et al. [16] proposed a new numerical method of an earth-pipe-air heat exchanger. The problem of conduction was solved using response factors method in order to reduce computational time. Zhang and Haghghat [17] conducted numerical experiments using computational fluid dynamics (CFD) to investigate the airflow, and thermal behavior in the large ducts as large cross-sectional area ETAHEs found more energy efficient than the conventional small ones. Bansal et al. [18] presented a transient and implicit model based on computational fluid dynamics for predicting of the thermal performance and cooling capacity of earth-air-pipe heat exchanger systems. They elaborated on the air velocity inside the pipes and material of buried pipes. Ascione et al. [19] evaluated the energy performances achievable using an earth-to-air heat exchanger for an air-conditioned building for winter and summer in different climates of Italy by means of dynamic building energy performance simulation codes. In their studies, the energy requirements of the systems have been analyzed for different Italian climates, as a function of the main boundary conditions (such as the typology of soil, tube material, tube length and depth and etc.) Xamán et al. [22] investigated a numerical study for prediction of the thermal performance of an Earth-to-Air Heat Exchanger (EAHE) in México for three cities. The effect of thermal insulation at the outlet section of the

EAHE is investigated in their study. The numerical study of the pseudo-transient thermal behavior of an earth-to-air heat exchanger (EAHE) for three cities in México is also presented by Xamán et al. [23]. The climate conditions correspond to the coldest day in winter and the warmest day of summer for extreme weather (Juárez city, Chihuahua), mild weather (México city, D.F.) and hot weather (Mérida, Yucatán). Mathur et al. [24] conducted a CFD analysis of EATHE (earth air tunnel heat exchanger) system under transient conditions for intermittent operation. Earth air tunnel heat exchanger thermal performance has been investigated under transient conditions for three different soil conditions considering three operating modes. Serageldin et al. [25] evaluated the thermal performance of Earth-air heat exchanger in Egyptian conditions. They discussed experimental results, mathematical model and computational fluid dynamics in their study.

In present study application and effectiveness of Earth-Pipe-Air heat exchanger, used for summer cooling, was evaluated for different climates of Iran, which is a multi-climate country. For the purpose of this evaluation, a three-dimensional, transient model based on computational fluid dynamics was developed and validated by experimental data of another research [18]. Then heat transferred to working fluid (air), which represent the effectiveness of the EPAHE, was compared to each other for four cities of Iran.

Earth tubes used for either partial or full cooling and/or heating of facility ventilation air. However, in the present study, we wish to evaluate and compare the energy conservation potential of EPAHEs indifferent climates of Iran. It is considered that the total energy, which is transferred to the air by EPAHE, can increase the efficiency of the air-conditioning system.

What makes present study particular is that; we performed a 3D

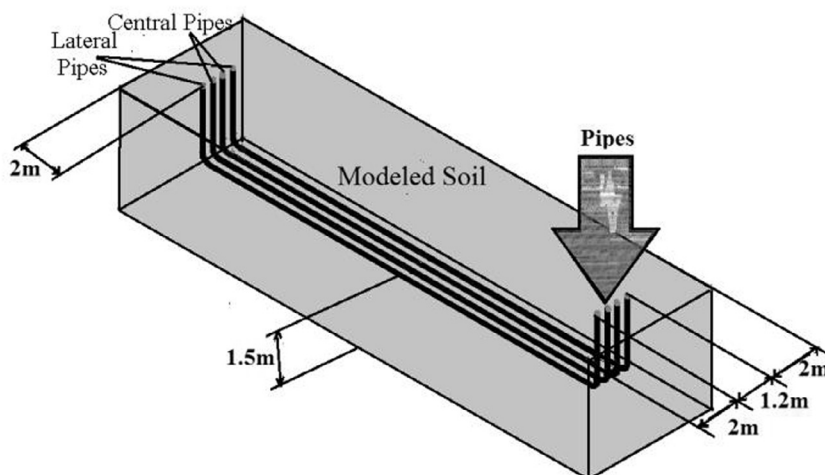


Fig. 1. Schematic illustration of modeled EPAHE.

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