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CFD ANALYSIS OF AN EARTH - PIPE - AIR HEAT EXCHANGER

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Abstract. *The thermal performance of a horizontal earth-pipe-air heat exchanger (EPAHE) was analyzed numerically using the Computational Fluid Dynamics (CFD) tool. In this way, it was analyzed the effects of pipe diameter, air flow velocities and different thermal properties of the soils in the thermal performance of the EPAHE system. The developed CFD model was simulated using commercial software and validated with numerical and experimental data. CFD analysis was executed using a steady-state three-dimensional numerical model with standard k-ε turbulence model. The results showed that the thermal performance of the EPAHE system was higher with a diameter of 0.1 m for the pipe, flow velocity of 2.5 m / s and with saturated sand soil.*

Keywords: *Energy efficiency, passive cooling, CFD, EPAHE.*

1. INTRODUCTION

The heating, ventilation and air conditioning systems (HVAC) are the main responsible for the high electric energy consumption in the buildings (Pérez-Lombard *et al.*, 2008). In this context, many countries support the development of new climate control technologies in buildings. Due to this, the use of earth-pipe-air heat exchangers (EPAHE) is a technique that has been studied by several researchers (Chen *et al.*, 2016; Soni *et al.*, 2015; Michopoulos *et al.*, 2009).

EPAHE are air conditioning systems, used to reduce the use of conventional air conditioners and consequently to reduce the electric energy consumption of buildings (Kaushal, 2017). EPAHE are generally composed by one or more underground pipes in which systems uses the thermal energy from soil as a source or heat sink, due a high thermal inertia that maintains its temperature approximately constant at certain depths (Olfman *et al.*, 2014).

The systems are used for heating and cooling of buildings, since the temperature of the soil in winter is higher than that of the external environment and lower in summer (Hollmuller *et al.*, 2014). EPAHE can use the external or internal air from the building as showed on Fig. 1 a, b, flowing through the underground pipes and performing heat exchange from soil until reaching the building environment.

To understand and analysis the thermal performance of the EPAHE systems a mathematical, numerical and experimental models were developed. A mathematical model developed for a horizontal EPAHE was based on a one-dimensional transient equation with an internal heat source (Kupiec *et al.*, 2015). Another transient analytical model elaborated to analyze the performance, and the influence of parameters for an EPAHE coupled to a wind tower (Benhammou *et al.*, 2015). A three-dimensional CFD (Computational Fluid Dynamics) numerical analysis analyzed three models of EPAHE geometry and different pipe materials (Selamat *et al.*, 2016). A comparison between different configurations of EPAHE and several soil was execute using CFD (Congedo *et al.*, 2012). Experimental measurements and numerical CFD analysis of a horizontal EPAHE proved to be feasible for thermal performance analysis (Flaga-Maryanczyk *et al.*, 2014).

In this way, the Ansys Fluent 18.0 (commercial software) was used to analyze the thermal performance of a horizontal EPAHE. The numerical simulations analyzed different parameters of EPAHE system as input velocities, pipe diameter and different thermal properties of the soils.

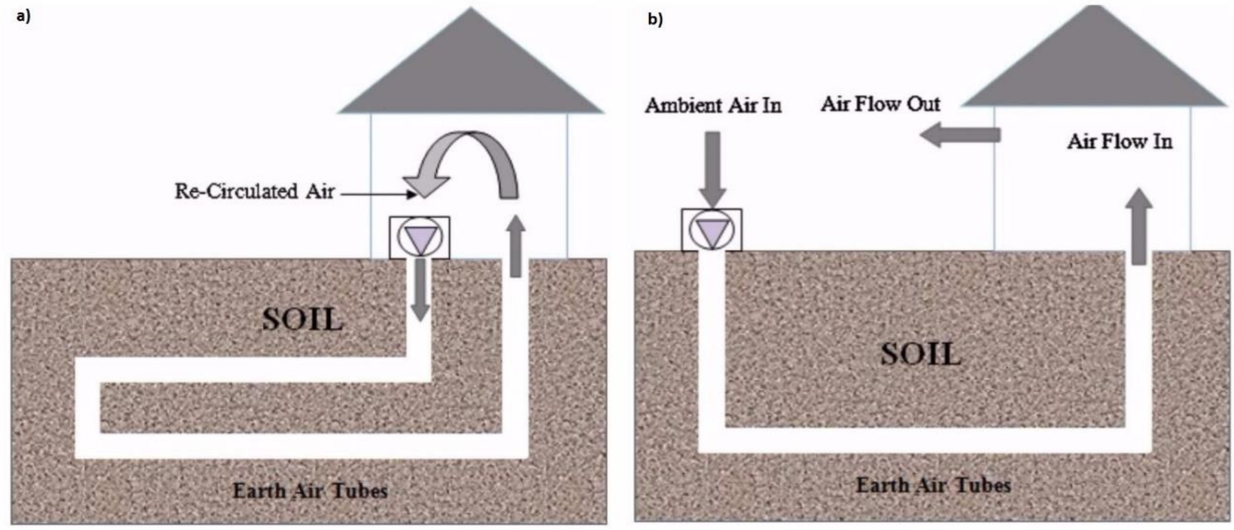

Figure 1. Building system coupled to a soil heat exchanger (Kaushal, 2017).

2. COMPUTATIONAL PROCEDURE

Three-dimensional steady state heat transfer in a EPAHE system have been analyzed through a model based on the studies of Mathur *et al.* (2015) and Misra *et al.* (2013). CFD simulations were performed using Ansys Fluent 18.0 software. Geometric modeling has been done using Solid Edge ST8 software and the 3-D mesh was prepared with Ansys Meshing. The EPAHE system domain has been separated into three parts: soil, tube and air. An unstructured quadrilateral mesh was utilized (Fig 2). As the temperatures and velocities gradients are larger in the pipe surface, the mesh has been more refined in this region and 4.601.788 elements and 5.006.767 nodes has been used in the domain.

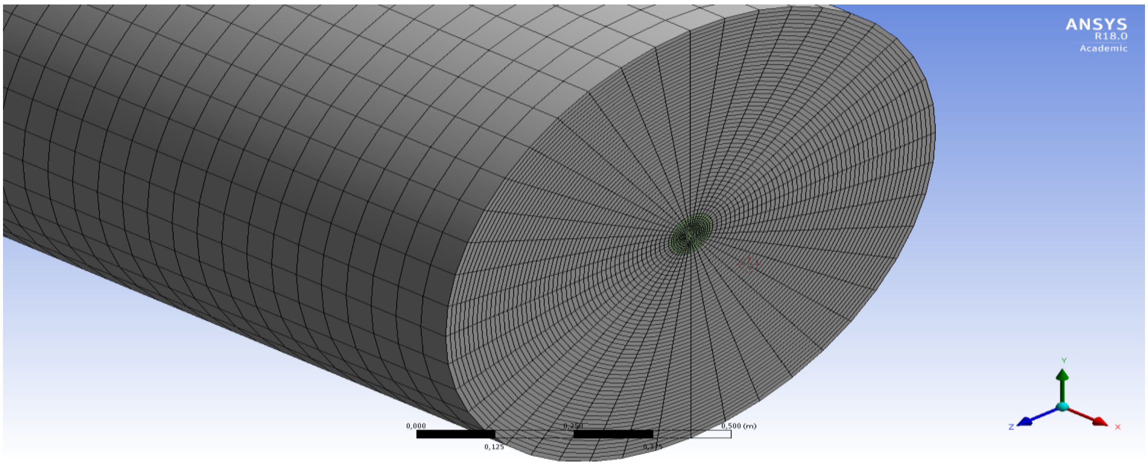

Figure 2. Mesh Model.

Air was considered incompressible and the soil treated as homogeneous in the model presented. Thermal properties of air, pipe and soil were assumed constant. For air flow analysis inside the tube, the standard k-ε turbulence model and standard wall functions were used. The convergence criteria adopted for the equations of continuity, momentum and the k-ε turbulence model were 10^{-3} and for the energy equation, of 10^{-6}.

2.1 Model Validation CFD

The CFD model developed has been validated through numerical and experimental work presented by Misra *et al.* (2013). Maximum temperature difference of 0.7 K has been verified in steady state condition, as shown in Fig. 3. However, in transient conditions, a temperature difference is practically imperceptible after 12 hr (Fig. 4).

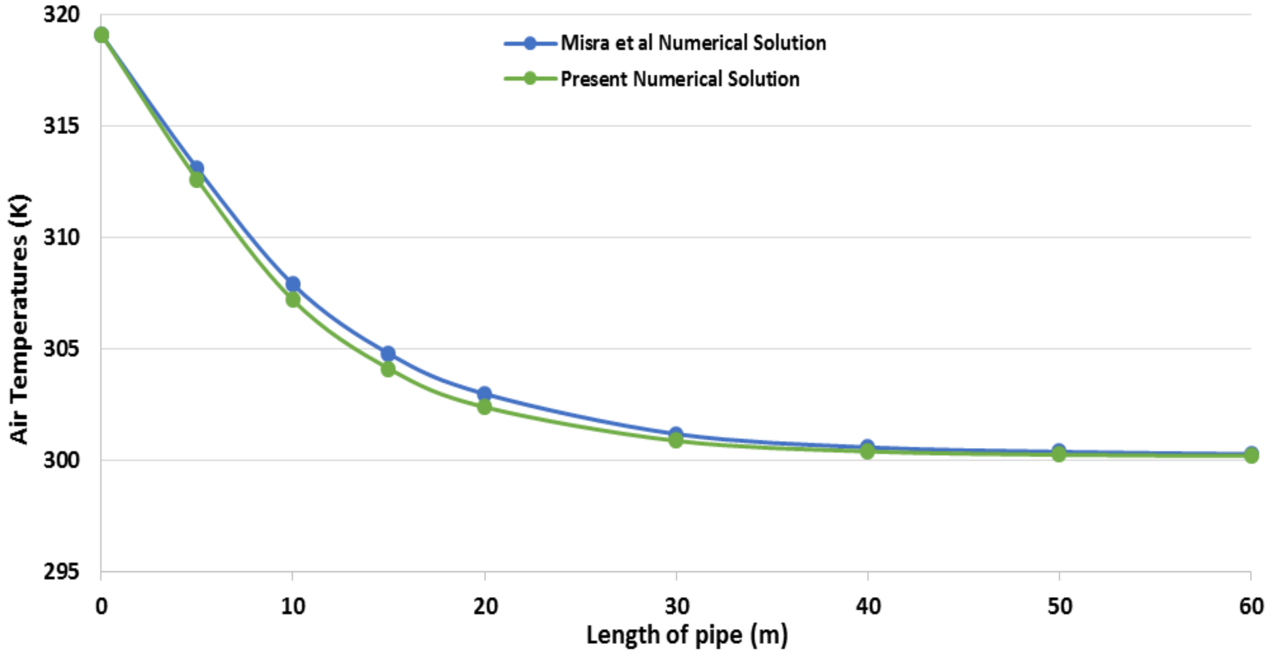

Figure 3. Validation in steady state.

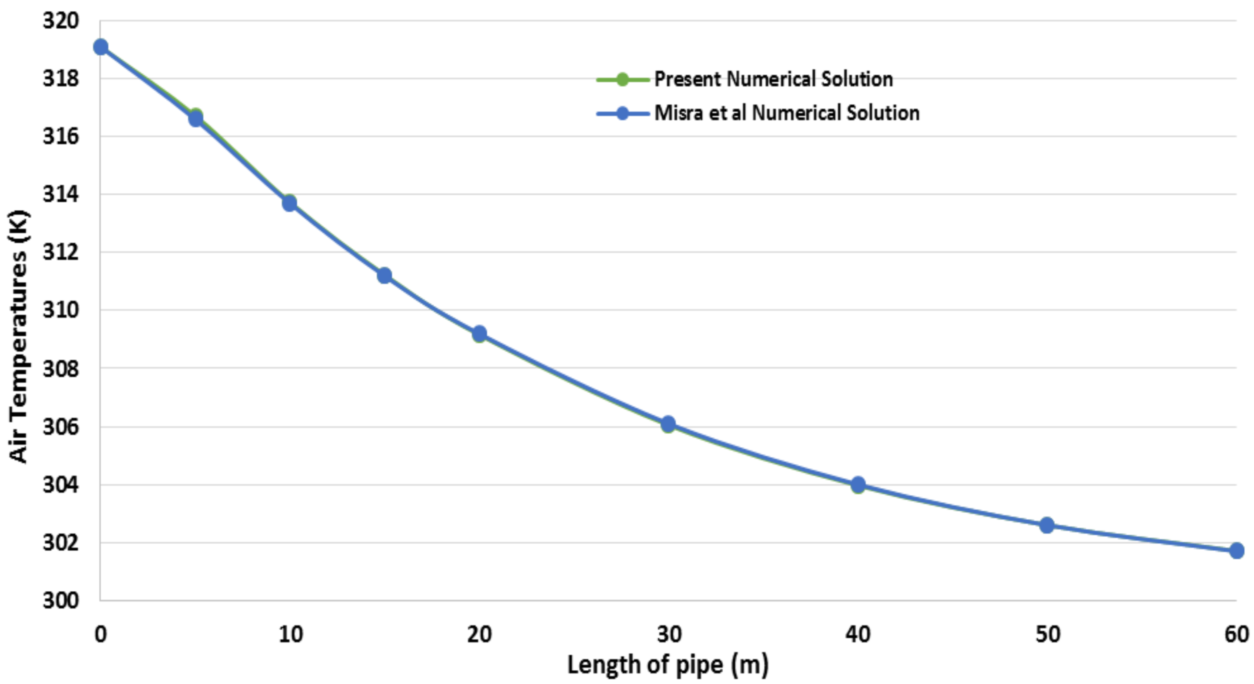

Figure 4. Transient validation (12 hours).

The geometric parameters and thermal properties used in the comparison are shown in the Tab. 1.

Table 1. Parameters used in the validation.

Parameters	Values
EPAHE	60 m
Pipe diameter	0.1 m
Surrounding soil diameter	1.1 m
Air density	1.225 kg m^{-3}
Air thermal conductivity	0.02 W m^{-1} K^{-1}
Air specific heat capacity	1006 J kg^{-1} K^{-1}
Soil density	2050 kg m^{-3}
Soil specific heat	1840 J kg^{-1} K^{-1}
Soil thermal conductivity	0.52 W m^{-1} K^{-1}
PVC pipe density	1380 kg m^{-3}
PVC thermal conductivity	1.16 W m^{-1} K^{-1}
PVC specific heat capacity	900 J kg^{-1} K^{-1}

2.1.1 Boundary conditions for the CFD model validation

- Air inlet: 5 m/s and 319.1 K have been utilized for inlet velocity and inlet temperature, respectively.
- Pipe and soil walls: the front and back surfaces were considered as adiabatic.
- Exterior surface of the soil: a constant temperature of 300.2 K was considered.
- Air outlet: pressure of 0 Pa has been used.

2.2 Simulation model

After the validation of the model, the thermal performance of a horizontal EPAHE has been obtained in which the input velocities, the diameter of the pipe and the different conductivities of soils have been verified.

2.2.1 Soils properties

Two soil types with different thermal properties were selected as shown in the Tab. 2. The sand and sandy silt, after 40% and 70% of saturation, respectively, have the thermal conductivity approximately constant up to 100%. Specific heat and density were considered constant.

Table 2. Soil properties (Santos and Mendes, 2005; 2006).

Soils	Thermal Conductivity	Specific heat	Density
Dry Sand	0,4 W m^{-1} K^{-1}	800 J kg^{-1} K^{-1}	1650 kg m^{-3}
Sand 40%	2,4 W m^{-1} K^{-1}	800 J kg^{-1} K^{-1}	1650 kg m^{-3}
Dry Sandy Silt	0,3 W m^{-1} K^{-1}	880 J kg^{-1} K^{-1}	1280 kg m^{-3}
Sandy Silt 70%	1,68 W m^{-1} K^{-1}	880 J kg^{-1} K^{-1}	1280 kg m^{-3}

2.2.2 Boundary conditions for analysis of the proposed model

- Air inlet: 2.5, 5 and 7.5 m/s and 308 K have been utilized for inlet velocities and inlet temperature, respectively, based on the temperature of an environment in a summer building.
- Pipe and soil surfaces: the front and back surfaces were considered as adiabatic.
- Air/pipe and pipe/soil interfaces: coupled interface conditions were used.
- Exterior surface of the soil: a constant temperature of 292.5 K obtained from Santos, *et al.* (2004) has been considered (Curitiba City)
- Air Outlet: 0 Pa has been used.

3. RESULTS AND DISCUSSIONS

The simulations were developed to determine the air temperature distribution along the steady-state EPAHE system. Differents thermal conductivities and inlet velocities are shown in Figs. 5, 6 and 7 for a diameter tube of 0.1 m and 0.15 m.

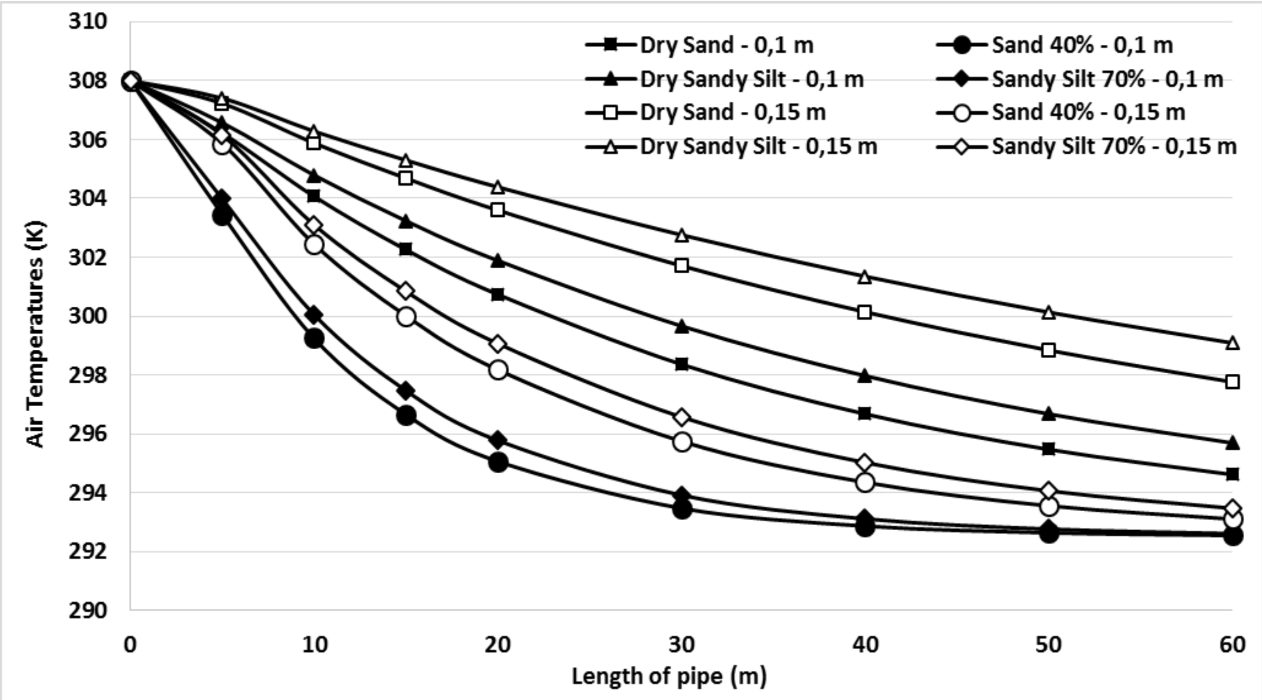

Figure 5. Temperature distribution for velocity of 2.5 m/s.

A better thermal performance was observed in the EPAHE system for sandy (40%) and sandy silt soil (70%) with a diameter of 0.1 m (Fig.5). It was observed that for a flow velocity of 2.5 m/s under these conditions, the temperature variation became imperceptible from 40 m. In this case, 15.45 K in the temperature drop has been verified. The worst thermal performance was verified for the dry sandy silt soil (2.5 m/s and 0.15 m) with a temperature drop of 8.9 K. due to lower thermal conductivity.

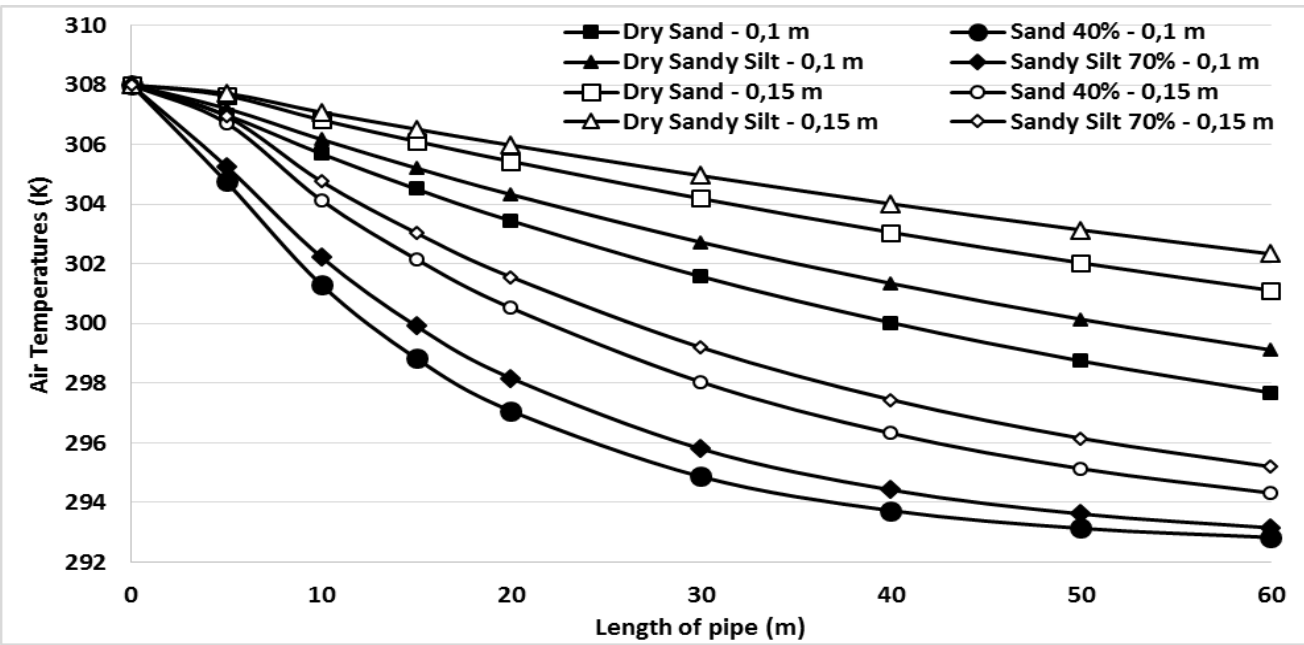

Figure 6. Temperature distribution for velocity of 5 m/s.

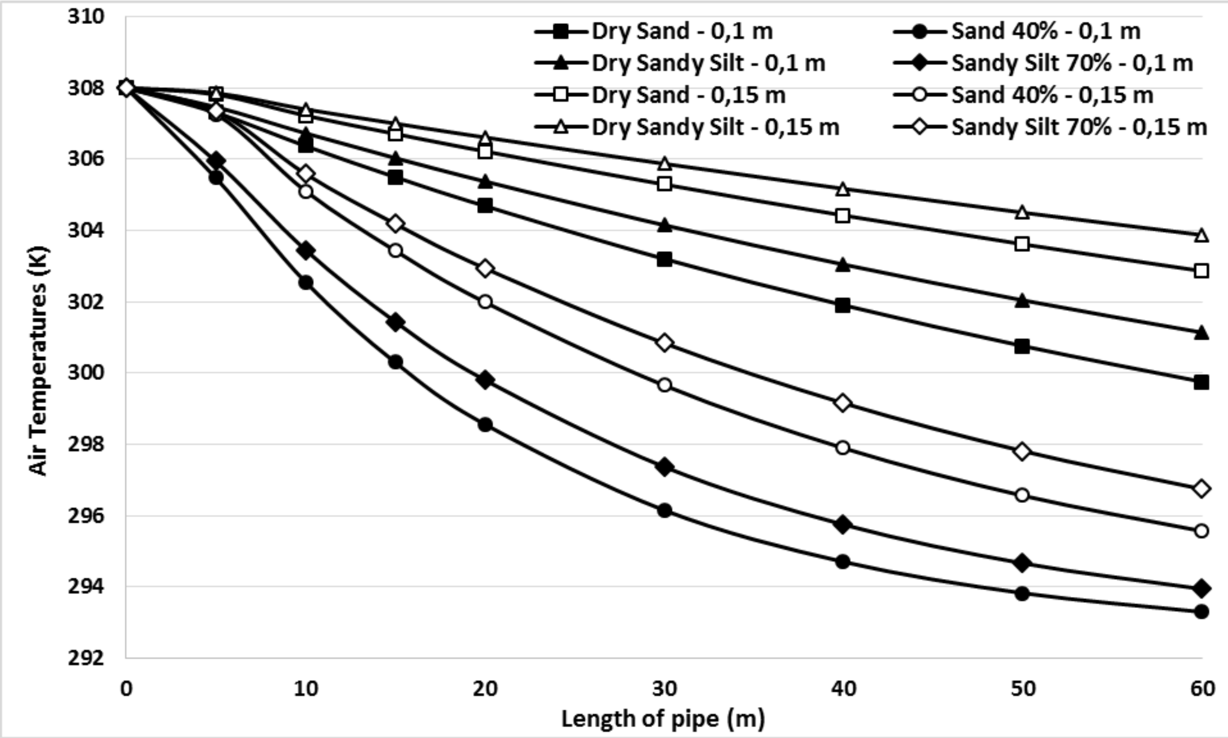

Figure 7. Temperature distribution for velocity of 7.5 m/s.

Figures 6 and 7 showed the same behavior of the Fig. 5 where the sandy (40%) and sandy silt soil (70%) presented the best performance. However, for a velocity of 5 m/s under these conditions, the temperature change becomes imperceptible from 50 m with a temperature drop of 15.1 K (Fig. 6). For the velocity of 7.5 m/s, the temperature drop of 14.7 K has been observed in this same region (Fig.7).

4. CONCLUSIONS

The paper presented a numerical analysis of the thermal performance of a horizontal EPAHE system. A numerical analysis was carried out to investigate the effects of pipe diameter, air flow velocities and thermal properties of the soils on the thermal performance of the EPAHE. The simulations showed that with a diameter of 0.15 m, the temperature drop was lower in relation to the smaller diameter (0.1 m). Regarding to air flow velocities, increasing the velocities, the EPAHE system thermal performance was also reduced. In the soils analysis, it was observed that the thermal conductivity is the most important factor for the thermal performance of the EPAHE system. Likewise, when sand (40 %) and sandy silt soil (70%) are utilized, a pipe with 0.1 m of diameter and 40 m of length provided the best behavior among the cases analyzed.

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