



COAXIAL AND U-SHAPED GEOTHERMAL PROBES PERFORMANCE BY THE EWS SOFTWARE

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Abstract

In this article, we present a geothermal installation designed to ensure the heating and cooling of a detached house located in Tlemcen city at Algeria country. The thermal behavior of the coaxial and double U borehole heat exchangers was investigated using numerical simulations by EWS (ErdWäemeSonden) software, in both long and short-terms. The analysis was conducted considering two different types of ground with different thermal conductivity values. As result, the more conductive ground type highlights the higher yield of the coaxial probe.

Key words : Geothermal energy, EWS Software, Heating, Cooling, borehole.

1. Introduction

With the tremendous increase of the world population in the 21st century, human activities have surged , and with it, the consumption of energy. Much of this energy is produced by burning fossil fuels (oil, gas, coal). However, the problems inherent to the use of fossil fuels, such as their limited availability and their adverse effects on the environment (e.g.: gas emissions, depletion of the ozone layer...), have led humanity to seek energy resources other than hydrocarbons the following renewable energies: solar, wind, hydro, biomass and geothermal. Unlike fossil fuels, renewables provide unlimited sources of energy.

In this work, we will focus geothermal energy and more specifically the heating and cooling of a single family house by a geothermal heat pump. Indeed, the extractable amount of energy mainly depends on the thermal properties and the hydrogeological conditions of the ground as well as on the properties of the groudng material. Energy system simulations for design or performance evaluation of buildings and communities have gained significant importance in the last decades resulting in several dynamic simulation platforms such as Energy Plus [1- 2], EWS [3]. These simulation tools should comprise libraries containing every important building system element including accurate and computationally efficient borefield models.

During the simulation, by using a borehole exchange [4], the temperature development of the circulating heat carrier fluid is recorded. Parameters such as thermal conductivity, thermal borehole resistance [5] (which describes the heat transfer inside the entire borehole) are used to characterize the performance of a borehole [6 - 8].

Our goal is to predict the thermal behavior of coaxial and simple U heat exchangers [9] using the EWS software in long and short terms.

2. Geothermal Energy

A geothermal system allows the transfer of heat or cold from the basement in which circulates a heat transfer fluid. This fluid captures energy and moves it to be heated or cooled. Each geothermal installation can be associated to an energy exchange system in the basement (generally called a vertical or horizontal geothermal exchanger). Its role is to draw or inject energy into the basement and route it to the heat pump. In addition, the system comprises of a distribution system to direct the energy to the various transmitters of the room to be heated or cooled [10 - 11].

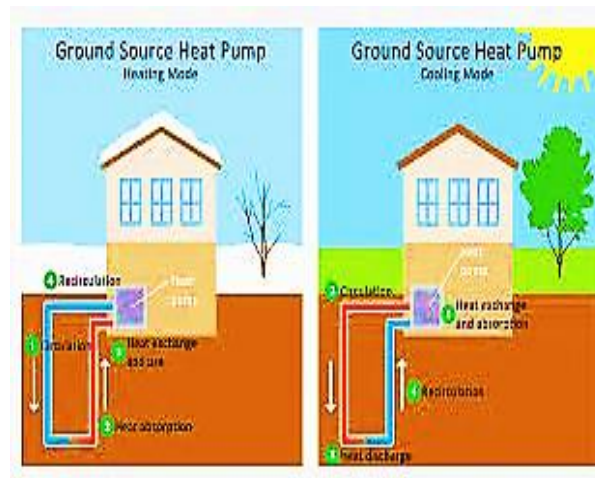


Figure1: General principal diagram of a heat pump

3. Presentation of the EWS software

The program EWS calculates the behavior of borehole heat exchangers. This is done by solving numerically the heat equation of the ground and the heat transfer from the boreholes.

The EWS (engl. Borehole Heat Exchanger) program can be used to calculate feed and return temperatures as well as capacities of borehole heat exchangers on a monthly basis over a period of up to 200 years. It is also possible to simulate the geothermal probes with direct or free cooling. This makes it possible to dimension individual borehole heat exchanger and BHE fields in accordance with the local situation. The software allows the acquisition of all relevant influencing parameters such as probe type, backfilling, probe arrangement, load profile, geology, etc.

The program is based on a mathematical model that is a mixture of two methods. First, a numerical simulation performed in the vicinity of the probe (The Crank-Nicholson-method is used for the simulation of the ground temperatures close to the boreholes ($< 3\text{m}$)) and second, an analytical response factor for the most distant layers of the earth (Eskelsen method is used when heat extraction rate and the regeneration of the earth is solved by the superposition of an optional number of constant heat extraction rates which start at different times.).

Short calculation time with a high level of precision is reached [2].

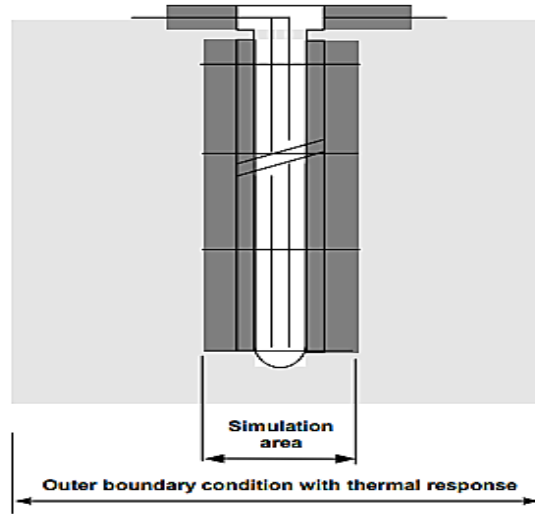


Figure 2: simulation zone and the external boundary condition.

EWS program calculates the inlet and outlet temperatures, while the heat extraction rate of the probes can be chosen freely. There can be up to a maximum of 10 layers of soil with different types of soil materials (The properties of soil are also different) [3].

4. Simulation and Interpretations

4.1 Number of degree days for heating and / or cooling

Energy consumption is linked to the temperature difference between the interior and exterior of the building. However, the temperature varies from one place to another. In this work, the concept of "Degree Day" to determine the quantity of heat consumed over a given period is used

The temperature differences existing between the interior and the exterior of the building, day after day is added up [4].

$$D_d = \text{Number of days heated (or cooled)} \times (T_{\text{inside average}} - T_{\text{outside average}}) \quad (1)$$

To perform this simulation, the parameters that influence the thermal comfort of the occupants inside the building (individual house) are firstly identified. Second, we calculate their energy needs are calculated (heating and / or cooling). It is important to note that the climate of Tlemcen is characterized by a much longer heating period (from October to May). The number of D_d for the comfort temperature calculated for each day, is 1052 ($D_d = 1052$) (Handbook, Beata Kępińska, MEERI PAS, Poland 2015).

In addition, Tlemcen is characterized by a short cooling period (from June to September) with the number of D_d for the comfort temperature of 84, ($D_d = 84$) [5].

Tlemcen is located at latitude 34.87833 and longitude -1.315. It is part of Algeria located in Africa (in the northern hemisphere).

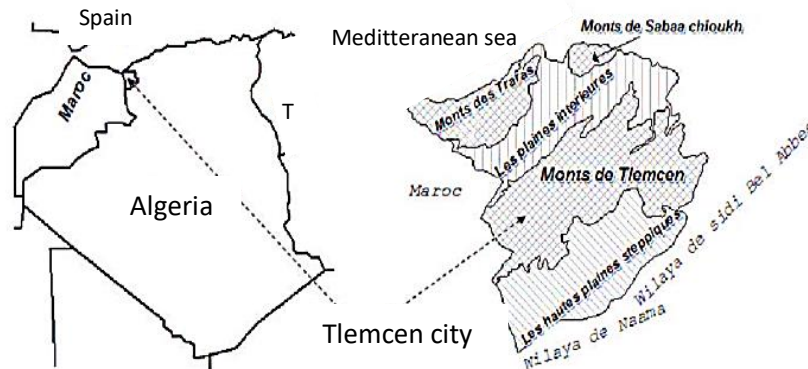
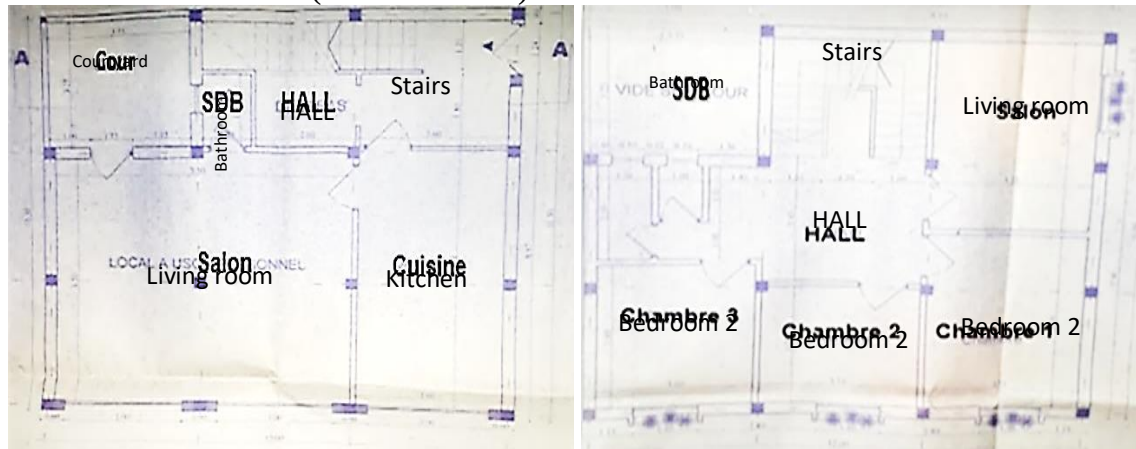


Figure 3: Tlemcen city [Google Map]

4.2 Description of the study habitat:

The architectural plan of the study habitat is a living area of 126 m² designed on the ground floor plus a floor. The ground floor has a Hall, a kitchen, a living room, a bathroom, and a small courtyard. The first floor contains a living room, 3 bedrooms, a hall, and a bathroom. The exterior walls are made of brick and have a double-walled layer of 30 cm, the interior walls are made of brick and have a thickness of 15 cm (the thermal transmittance coefficient of the walls is : $U = 3.5 \text{ W/m}^2\text{K}$, the thickness concrete slab house is 20 cm and thermal transmittance coefficient of this zone is equal to $U=4 \text{ W/m}^2\text{K}$), single glazed window ($U=2.5 \text{ W/m}^2\text{K}$) and interior doors are made of wood ($U = 2.5 \text{ W/m}^2\text{K}$), exterior doors are iron ($U = 5.8 \text{ W/m}^2\text{K}$). The living space consists of 839.16 m³ is ($V_h = 839.16 \text{ m}^3$).



Ground floor 1st Floor

Figure 3: House plan

The losses of each element of the habitat are listed, taking into account the area of each room $S \text{ (m}^2\text{)}$, as well as the various coefficients of thermal transmission $U \text{ (W/m}^2\text{K)}$ of the construction elements. The total thermal conductance which represents the sum of habitat losses is calculated by $P = \sum U \cdot S = 2246.08 \text{ W/}^\circ\text{K}$, The volume loss coefficient G is given by : $G = 2.68 \text{ W / m}^3\text{K}$.

4.3 Modeling and Simulation of Coaxial and Simple U geothermal probes

Our analysis was carried out through the EWS software. The comparison of the thermal performance of coaxial and simple U heat exchangers in the short term (one year of simulation) and in the long term (30 years of simulations) is studied. The two types of soils used are : Limestone and gravel, these are the most common types of soil used in Tlemcen region.

Soil type	Soil properties		
	λ (W/m.K)	ρ (Kg/m ³)	c_p (J/Kg.K)
Limestone	2.75	2400	1350
Gravel	0.8	2000	800

Table 1: Properties of soil types.

Water is chosen as the heat transfer fluid.

Thermal conductivity λ (W/m.K)	0.572
Fluid density ρ (Kg/m ³)	1000
Specific heat of the fluid c_p (J/Kg.K)	4204
Kinematic viscosity of the fluid ν (m ² /s)	0.0000015
mass flow rate, mass flow rate in the boreholes m_f (Kg/s)	0.079

Table 2: Characteristics of the heat transfer fluid.

The monthly energy needs for heating and cooling are calculated by the equation :

$$C = 24 G V_h Dd$$

Month	MWh Heating Requirements	MWh Cooling Requirements
January	1,039	0
February	0.723	0
March	0.788	0
April	0.677	0
May	0.491	0
June	0	0.162
July	0	0.043
August	0	0.103
September	0	0.146
October	0.505	0
November	0.634	0
December	0.820	0

Table 3: Energy requirements of the studied house.

The coaxial borehole is of a concentric shape made up of two inner and outer tubes, the inner tube contains the rising fluid (hot fluid) and the outer tube contains the falling fluid (cold one).

Description	Value
Inner diameter of the borehole pipe D_i (mm)	0.103
H : borehole length	20
OUTER PIPE (1)	
Probe diameter D_1 (mm)	63
w_2 : wall thickness of the inner pipe of a coaxial borehole (mm)	2.9
INNER PIPE (2)	
D2 probe diameter (mm)	32
w_2 : wall thickness of the inner pipe of a coaxial borehole (mm)	3
Heat conductivity λ (W/ mK)	0.44

Table 4: Characteristics of coaxial drilling.

U single borehole contains U shape tube as follows:

Description	Value
Inner diameter of the borehole pipe D_i (mm)	32
borehole length, borehole depth H (m)	20
Pipe diameter (m)	0.115
Probe wall thickness w (mm)	3
Heat conductivity λ (W/m.K)	0.44

Table 5: Characteristics of U shape tube

From the following results, the average temperature of the heat transfer fluid changes as it travels through the probes (by comparing the thermal behavior of the two geothermal probes).

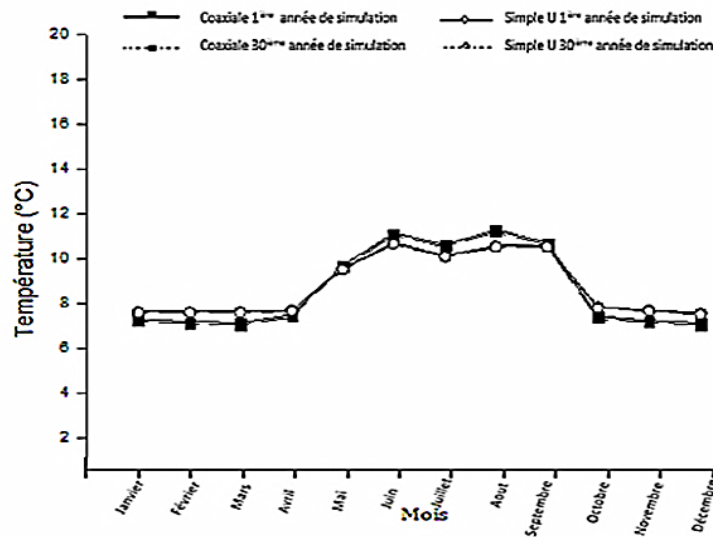


Figure 4: Comparison between the average temperature of the coolant of, coaxial and single U the boreholes ($\lambda_{\text{Limestone}} = 2.75$ W/m.K)

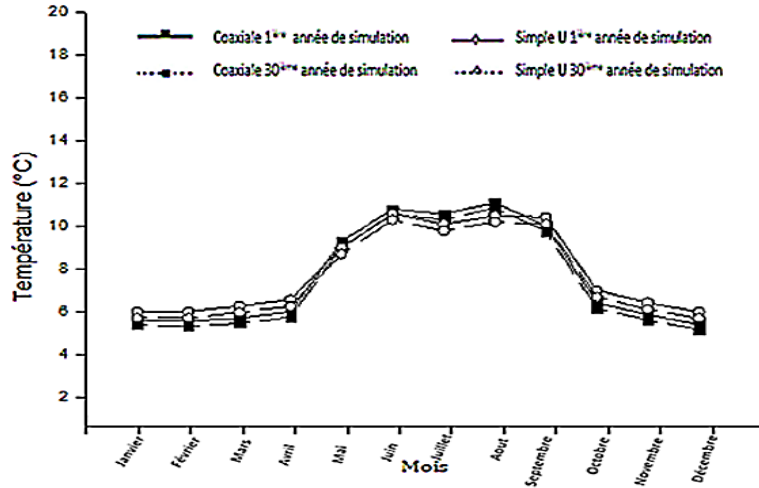


Figure 5: Comparison between the average temperature of the heat transfer fluid from coaxial and single U the boreholes ($\lambda_{\text{Gravel}} = 0.8 \text{ W/m.K}$).

Using the EWS software, the thermal resistance of drilling of coaxial and single U boreholes is as follows:

The drilling	Coaxial	Simple U
Rb (m.K/W)	0.259	0.211

Table 6: Thermal resistance of drilling Rb

Short term analysis:

In heating mode, the average temperature of the coolant of the single borehole U is higher than that of the coaxial borehole for both the thermal conductivity of the ground ($\lambda = 2.75 \text{ W/m.K}$ (Limestone)) and $\lambda = 0.8 \text{ W/m.K}$ (Gravel)). This is due to the thermal resistance Rb of single drilling U lower than coaxial drilling.

In cooling mode, the average temperature of the coaxial drilling fluid is higher than the temperature of the simple U drilling fluid in the months (June, July, August). This is due to the fact that the deferent influences on the ground (solar radiation, air temperature) are higher in this period. As a result, the U single heat exchanger characterizes better thermal performance. In addition the average temperature of coolant is higher than that of coaxial drilling due to the thermal resistance of drilling Rb which is weaker.

Long term analysis :

It noticed a small decrease in the temperature average of the heat transfer fluid [12 - 13]. A value of 0.1°C is observed for coaxial drilling and a value of 0.05°C is observed for U single drilling. In the other hand, the study of the ground deals with a decrease of 0.25°C for coaxial drilling and of 0.3°C for U single drilling in considering thermal conductivity of the ground in the case of limestone is " $\lambda = 2.75 \text{ W/mK}$; and in the case of the gravel " $\lambda = 0.8 \text{ W/mK}$ we obtain a decrease of 0.25°C for coaxial drilling and of 0.3°C for U single drilling This means that the drilling temperature is decreased with each heat extraction. As a result, the soil temperature decreases slightly over time until it reaches a level below which the temperature no longer drops.

4.4 Influence of the thermal conductivity of the soil on the thermal behavior of coaxial and single U heat exchangers:

Figure (6) and Figure (7) show the impact of the thermal conductivity of the soil on the thermal behavior [14-16] of the two coaxial heat exchangers.

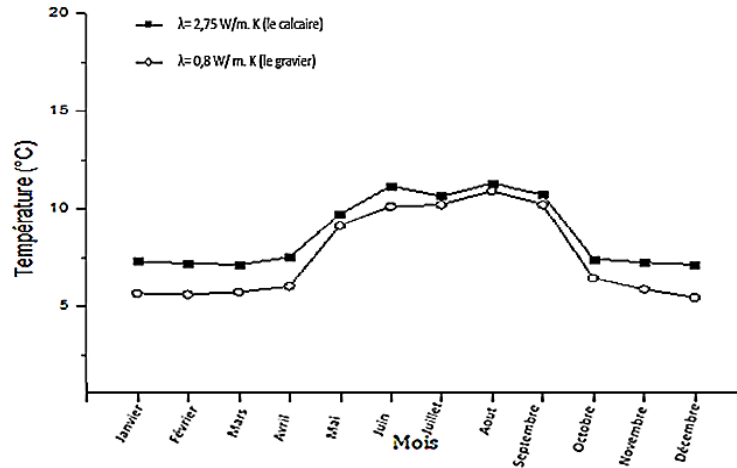


Figure 6: Comparison of the thermal influence of two types of thermal conductivity λ [W/m.K] of limestone and gravel on coaxial drilling.

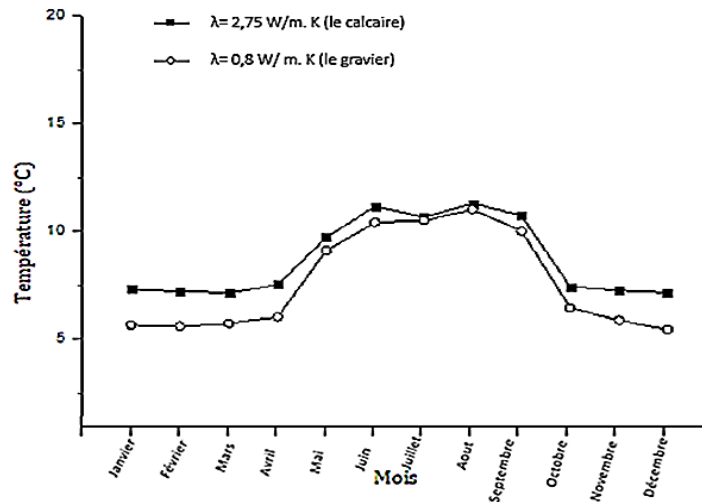


Figure 7: Comparison of the thermal influence of two types of thermal conductivity λ [W/m.K] of limestone and gravel on the U single borehole.

The average temperature of the heat transfer fluid is obtained for both Limestone soil and gravel soil. It is observed a difference of approximately 1 to 2.5°C between Gravel case and limestone case whatever the heat exchanger one uses. Consequently, the thermal conductivity λ [W/m.K] of the soil has a great influence on the thermal behavior of the boreholes. It is noticed that when the thermal conductivity of the soil is higher, the thermal efficiency of the boreholes is better.

4.5 Influence of the filling material on the thermal behavior of coaxial and U-tube heat exchangers:

We have compared two types of filling material with different thermal conductivities have been compared. The first is a cement-gravel grout ($\lambda = 1.35 \text{ W/m.K}$) and second of cement grout-bentonite of $\lambda = 2.95 \text{ W/m.K}$. This comparison makes it possible to study the thermal behavior of the two coaxial and U-tube boreholes.

Figures (8) and (9) show that the average temperature of the heat transfer fluid in the case of filling material (cement-bentonite $\lambda = 2.95 \text{ W/m.K}$) of coaxial drilling is 0.15°C and in the case of filling material (Cement-gravel $\lambda = 1.35 \text{ W/m.K}$) is 0.82°C . More over for U simple drilling the average temperature of the heat transfer fluid in the case (Cement-Bentonite $\lambda = 2.95 \text{ W/m.K}$) varies from approximately 0.13°C to 0.4°C than in the case (Cement-gravel $\lambda = 1.35 \text{ W/m.K}$).

As a result, the higher thermal conductivity filler material exhibits generally, better thermal behavior due to the durable stability of the structure [17]. More stable probes are in the borehole, the lower the drilling resistance, and the better thermal behavior is obtained.

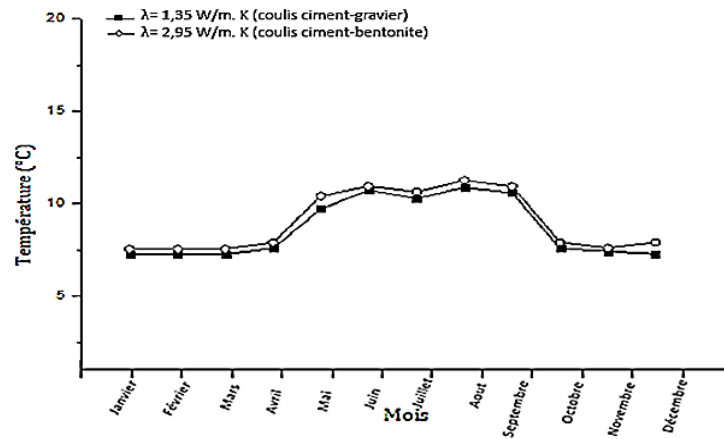


Figure 8: Influence of the thermal conductivity of the filling material at the average temperature of the heat transfer fluid in the coaxial borehole.

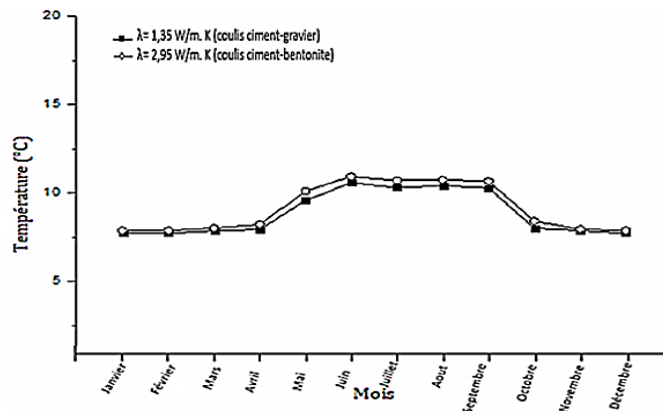


Figure 9: Influence of the thermal conductivity of the filling material at the average temperature of the heat transfer fluid in the single U borehole.

Conclusion:

The energy performance of vertical heat exchangers of single U and coaxial borehole using the software EWS has been analysed for short and long terms.

The results of the numerical study showed that: the thermal efficiency of the boreholes is better when the thermal conductivity of the soil is higher. The thermal performance of the heat exchanger depends significantly on the thermal resistance of the borehole, the infill material and the thermal conductivity of the soil. The coaxial pipes' configuration provides better thermal performance due to the higher thermal capacitance of the heat-carrier fluid and the lower borehole thermal resistance.

The higher thermal conductivity filler material exhibits generally, better thermal behavior due to the durable stability of the structure.

The use of geothermal energy, will not only stimulate the industrial sector, but also will improve the quality of life of citizens, the economy, and the environment in our country.

Nomenclature :

C_p : specific heat capacity of the fluid [J/(kgK)]

D_i : Inner diameter of the borehole pipe (m).

H : borehole length, borehole depth (m)

m_f : mass flow rate, mass flow rate in the boreholes [kg/s]

R_b : Thermal borehole resistance (from the fluid to the borehole radius) [Km/W]

S : area (m²)

P : Total Thermal conductance (W/K).

U : Thermal Conductance at ground level per unit area (W/m²K).

w_i : wall thickness of the inner pipe of a coaxial borehole [m]

λ : Heat conductivity (W/mK)

ρ : Fluid density ρ (Kg/m³)

ν : kinematic viscosity of the borehole fluid [m²/s].

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