Coaxial and U-shaped Geothermal Probes Performance by EWS Software

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Abstract: Geothermal energy can be a useful supplement to traditional fossil fuels because it is resourceful, available, and reasonably priced. In terms of CO_2 emissions, water pollution [JFAS], and air pollution, this energy is less polluting than fossil fuels. Significant change in the construction sector increases the need for heating in buildings as well as the need for cooling. In the meantime, geothermal technology has advanced to access deeper subsurface layers and extract heat at higher temperatures. In this article, we present a geothermal installation that will provide heating and cooling for a detached home in Tlemcen city in Algeria. The coaxial cable's thermal behavior and double U borehole heat exchangers were examined in both the long and short terms using numerical simulations by EWS (ErdWärmeSonden) software. Two different types of ground (limestone and Gravel) with various thermal conductivity levels were taken into consideration when conducting the analysis. Thermal resistances of the borehole and infill material are also involved in this study. As a result, the more conductive ground type draws attention to the coaxial probe's higher yield.

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

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1. Introduction

Human activities have surged with the tremendous increase of the world population in the 21st century, and with it, the consumption of energy. Much of this energy is produced by burning fossil fuels (oil, gas, coal) [1]. However, 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 [2-5], wind [6], hydro, biomass and geothermal (Figure 1) unlike fossil fuels, provide unlimited sources of energy [7].

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 [7-8], EWS [9].

In this work, heating and cooling geothermal energy of a family house is studied. Indeed, underground heat can be operated through a heat transfer between soil and two type's exchangers; simple U and coaxial ones.

During the simulation, the circulating heat carrier fluid leads to the increase of temperature [10]. Parameters such as thermal conductivity and thermal borehole resistance are considered in the study of the performance of a borehole. Thermal borehole resistance describes heat transfer inside the entire borehole [11 - 13].

Thus, our goal is to predict the thermal behavior of coaxial and simple U heat exchangers [14] using the EWS software in long and short terms. The process of generating geothermal energy is presented below.

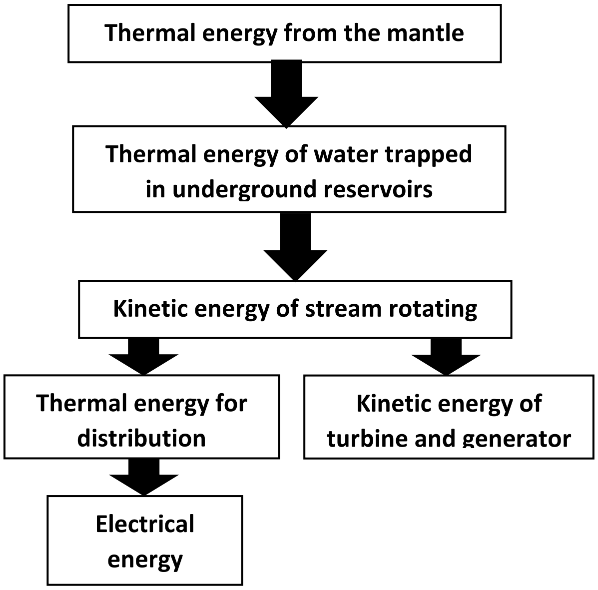

Figure1. Process of generating geothermal energy [15-16]

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 with 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, this system comprises a distribution system to direct the energy to the various transmitters of the room to be heated or cooled [17 - 18].

2.1. Soil temperature

Soil temperature refers to the warmth of the ground. It is a key factor in the environment, affecting various biological, physical, and chemical processes. The timing of the highest temperature below the Earth's surface changes with depth. [19]

2.2. Soil thermal conductivity

The magnitude of the conductive heat flux through the soil divided by the magnitude of the temperature gradient ($W.m^{-1}$ $°C^{-1}$) is known as the soil thermal conductivity (λ). It measures the soil's capacity to "conduct" heat in a similar way to how the hydraulic conductivity measures the soil's capacity to "conduct" water. [20]

2.2.1. Soil heat capacity

The amount of energy needed ($Jm^{-3}°C^{-1}$) to increase the temperature of a unit volume of soil by one degree is known as the soil specific heat capacity (C). Specific heat capacity rises exactly linearly as soil water content rises, in contrast to thermal conductivity [20]

2.2.2. Soil thermal diffusivity:

The volumetric heat capacity (m^2 s^{-1}) to thermal conductivity ratio is known as the soil thermal diffusivity. It serves as a predictor of how quickly a temperature change will be carried through the soil by conduction [20]

2.3. Utilization of geothermal energy in Algeria

There is a sizable geothermal potential in Algeria. The majority of geothermal resources have relatively low enthalpies, making them unsuitable for producing electricity, but they are still useful for direct heating. Algeria is the top country in Africa for the direct use of geothermal energy, with 54.64 MWt of installed thermal power and annual energy consumption of 1699.65 TJ [21]. According to [22], distribution of geothermal direct usage by African nations, Algeria is home to more than 39% of the continent's installed thermal capacity.

Balneology is Algeria's primary geothermal energy application, accounting for nearly 82% (44.37 MWt) of the country's total geothermal energy production.

Only 18% (10.28 MWt) of the total power used (54.64 MWt), for example, is used for other applications like space heating.

as shown in Figure 2, fish farming and heat pumps.

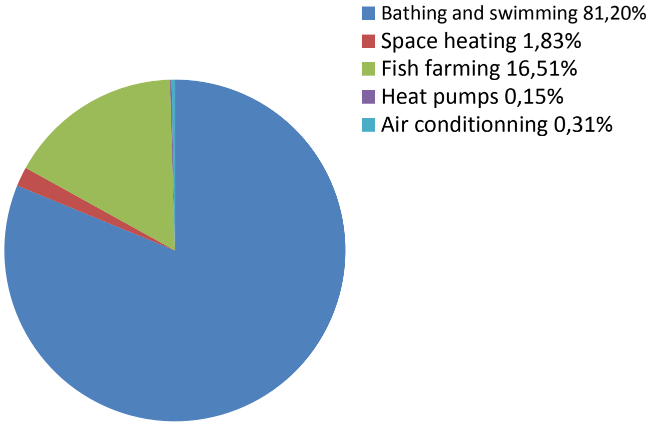

Figure 2: Distribution of total installed capacity of geothermal energy (MWt) in Algeria [22]

3. Presentation of the EWS software

Program EWS studies the behavior of borehole heat exchangers. Heat equation of the ground and the heat transfer from the boreholes are ironed out numerically.

EWS (ErdWärmeSonden, Geothermal probes) 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; the first method used the Crank-Nicholson difference method. This method is performed in the vicinity of the probe. The simulation of the ground temperatures is close to the boreholes (less than 3m) and the second technique represents an analytical response factor for the most distant layers of the earth. In this part, Eskilson is used. This model calculates the evolution temperature at the wall of wells subjected to constant heat extraction which starts at different times [13].

Short calculation time with a high level of precision is reached [12].

EWS takes, as well, in account the distribution of thermal flow of the earth as is presented in figure 3.

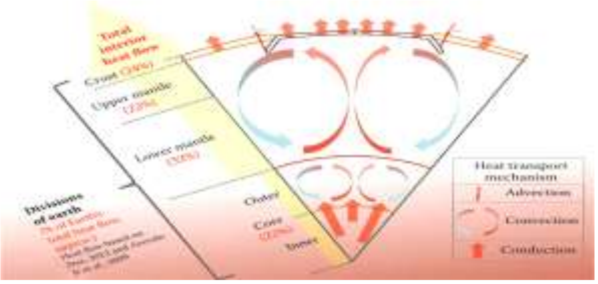

Figure 3: Structure of earth and thermal flow [23]

The 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 (properties of soil are also different) [9].

4. Simulation and Interpretation

4.1 Number of degree days for heating and / or cooling

Energy consumption is linked to the temperature difference between the interior and the exterior of the building. However, 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.

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

To perform this simulation, parameters influencing the thermal comfort of the occupants inside the individual house are firstly identified. Second, we calculate their energy needs in 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 ($D_d = 1052$).

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, ($D_d = 84$) [24].

Tlemcen is located at latitude 34.87833 and longitude -1.315. It is part of Algeria, an African and a Mediterranean nation. Algeria is situated in the middle of North Africa between 8 and 121° longitude east and 38-351° latitude north. The nation shares borders with Mali, Niger and Mauritania in the south. The Mediterranean Sea is in the north. Tunisia and Libya are in the east and Morocco in the west (Figure 4). Algeria, with a landmass of 2.381.741 km^2, has overtaken it as the largest nation in Africa [25-26].

Figure 4: Tlemcen city in Algeria

4.2 Description of the study habitat

Figure 5 shows the architectural plan of the study habitat. This house is a living area of 126 m² designed on the ground floor plus a floor. The ground floor has one Hall, one kitchen, one living room, one 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 W/m²K, the thickness concrete slab house is 20 cm and thermal transmittance coefficient of this zone is equal to U=4 W/m².K), single glazed window (U=2.5 W/m²K) and interior doors are made of wood (U=2.5 W/m².K), exterior doors are iron (U=5.8 W/m².K). The living space consists of 839.16 m^3 is (V_h=839.16 m^3).

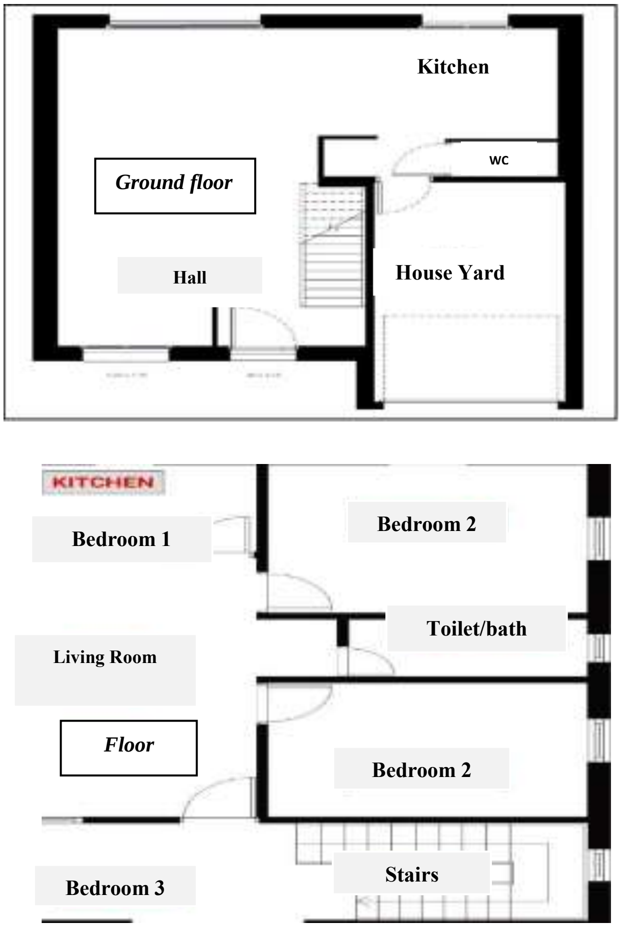

Figure 5. Architectural plan of an individual house

The losses of each element of the home are listed, taking into account the area of each room S (m²), as well as the various coefficients of thermal transmission U (W/m²K) of the construction elements. The total thermal conductance which represents the sum of habitat losses is calculated by $P = \sum U.S = 2246.08$ W/K, The volume loss coefficient G is given by: G = 2.68 W/m^3K.

4.3 Modeling and Simulation of Coaxial and Simple U geothermal probes

Our analysis was carried out through the EWS software. Comparison of thermal performance for coaxial and simple U heat exchangers in the term (one year of simulation) and 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 the Tlemcen region. Properties of soil types are summarized in table 1.

Table 1. Properties of soil types.

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

Water is chosen as the heat transfer fluid. All characteristics of the heat transfer fluid are given in Table 2.

Table 2. Characteristics of the heat transfer fluid.

Thermal conductivity λ (W/m.K)	0.572
Fluid density ρ (Kg/m^3)	1000
Specific heat capacity of the fluid Cp (J/Kg.K)	4204
Kinematic viscosity of the fluid ν (m²/s)	0.0000015
Mass flow rate in the boreholes m_f (Kg/s)	0.079

Table 3 shows Energy requirements of the studied house. Monthly energy requirements for heating and cooling are calculated according to the following equation:

$$C = 24\, G\, V_h\, D_d \qquad (2)$$

Where: G is volume loss coefficient.

V_h is The habitable volume [m^3]

And D_d is Degree day.

Table 3. Energy requirements of the studied house.

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

Tables 4 and 5 present characteristics of coaxial drilling and U shape tube respectively.

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

Table 4. Characteristics of coaxial drilling.

Description	**Value**
Inner diameter of the borehole pipe Di (mm)	0.103
H : borehole length	20
OUTER PIPE (1)	
Probe diameter D_1 (mm)	63
w_1 : wall thickness of the outer 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

U single borehole contains U shape tube as follows:

Table 5. Characteristics of U shape tube

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

Following figures 6 and 7 and by comparing the thermal behavior of the two geothermal probes, average temperature of fluid varies as it passes through the probes.

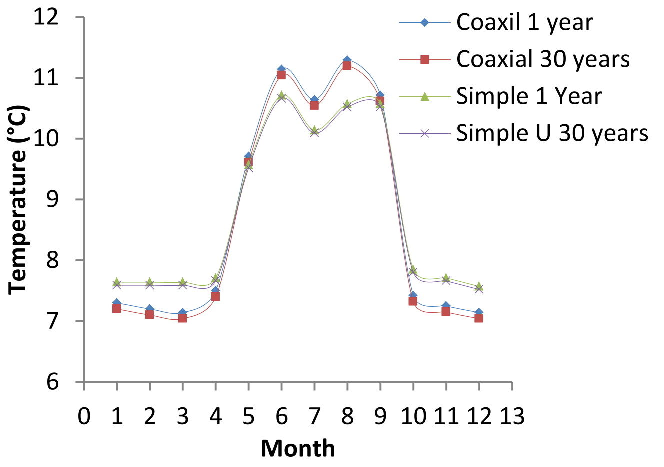

Figure 6. Comparison between coolant's average temperature for coaxial and single U boreholes ($\lambda_{Limestone}$ = 2.75 W/m.K)

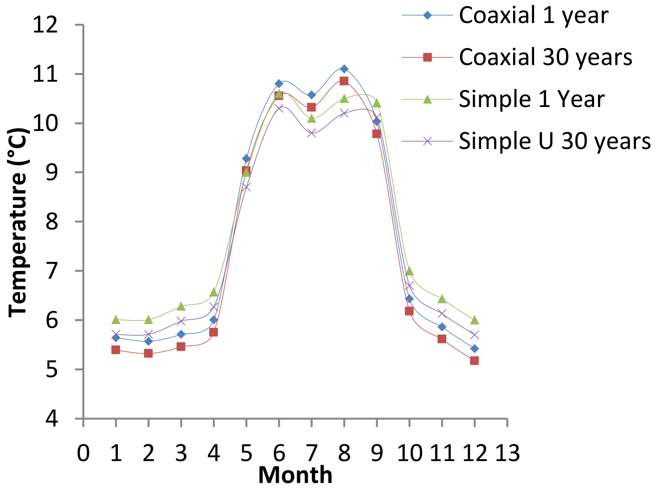

Figure 7: Comparison between fluid's average temperature for coaxial and single U boreholes (λ_{Gravel} = 0.8 W/m.K).

Thermal resistance of drilling of coaxial and single U boreholes is given in table 6.

Table 6. Thermal resistance of drilling Rb

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

Short term analysis:
The average temperature of the coolant in the heating mode is higher than the average temperature in the coaxial drilling mode. This is shown in the thermal conductivity study for Limestone where λ = 2.75W/mK and for Gravel where λ =0.8W/mK. This is because the Rb of the single drilling U is lower than the Rb of a coaxial drilling unit.
When the drilling fluid is cooled in the cooling mode, it is higher than the temperature of the simple drilling fluid during the months of June, July, and August. The reason for this is that the various factors affecting the ground such as solar radiation and air temperature are higher during these months. This means that the single U heat exchanger has better thermal performance compared to the coaxial drilling units.
The thermal resistance of the drilling Rb is also lower than the coaxial drilling Rb.

Long term analysis:
The investigation revealed a modest reduction in the fluid's average temperature (20 - 21). The temperature reduction is 0.05°C for U-single drilling and 0.1°C for coaxial drilling. According to the ground investigation, there is a slight decrease in temperature for U single drilling (0.3°C) and coaxial drilling (0.25°C). When thermal conductivity is included, the values for limestone and gravel are 2.75w/m.K and 0.8w/m.K, respectively. This indicates that the drilling temperature gradually declines with each heat extraction until it reaches a point where it stops dropping.

4.4 Influence of thermal conductivity of the soil for coaxial and single U heat exchangers

Figure (8) and Figure (9) show the impact of thermal conductivity of soil [27-29] in the case of coaxial and single U heat exchangers.

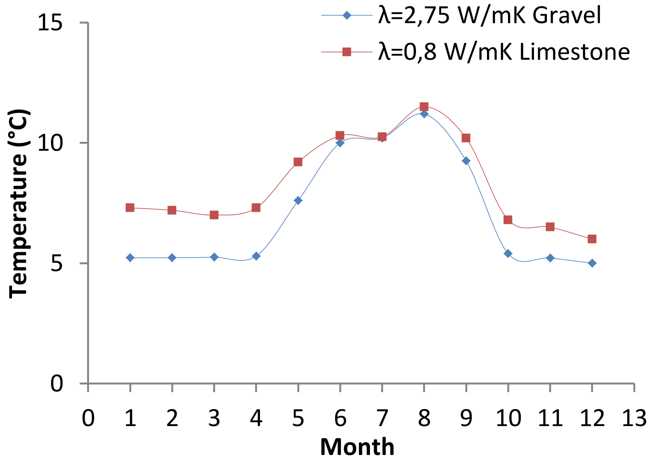

Figure 8. Influence of thermal soil's conductivity λ (limestone and gravel) for coaxial drilling.

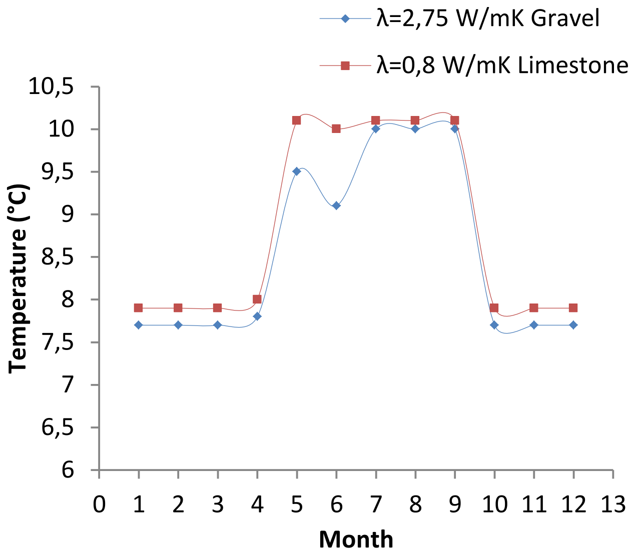

Figure 9. Influence of thermal soil's conductivity λ (limestone and gravel) for U single borehole.

For both gravel and limestone soil, the average fluid temperature is found. Regardless of the heat exchanger utilized, there is a difference between the limestone case and the gravel case of around 1-2.5°C. The soil's thermal conductivity (λ) affects how the borehole operates. When soil thermal conductivity is increased, thermal efficiency is enhanced.

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

A comparison has been made between two types of filler material that differ in their heat conductivity. Cement grout-gravel (λ=1.35 W/m.K) is the first, while cement grout-bentonite (λ=2.95 W/m.K) is the second. Studying the thermal behavior of two borehole types coaxial and U-tube is made feasible by this comparison.

According to figures (10) and (11), the average fluid temperature for coaxial drilling filling material (cement-bentonite, λ = 2.95 W/m.K) is 0.15°C, and for filling material (cement-gravel, λ = 1.35 W/m.K), it is 0.82°C. Furthermore, for U simple drilling, the fluid's average temperature differs between 0.13°C and 0.4°C between the cases of cement-gravel (λ = 1.35 W/m.K) and cement-bentonite (λ = 2.95 W/m.K).

Because of the structure's long-lasting stability, the filler material with a higher thermal conductivity often displays superior thermal behavior [30]. Lower drilling resistance and the optimal thermal behavior are associated with the stability of the probes in the borehole. The smaller the drilling resistance and the better the thermal behavior, the more stable the probes are in the borehole.

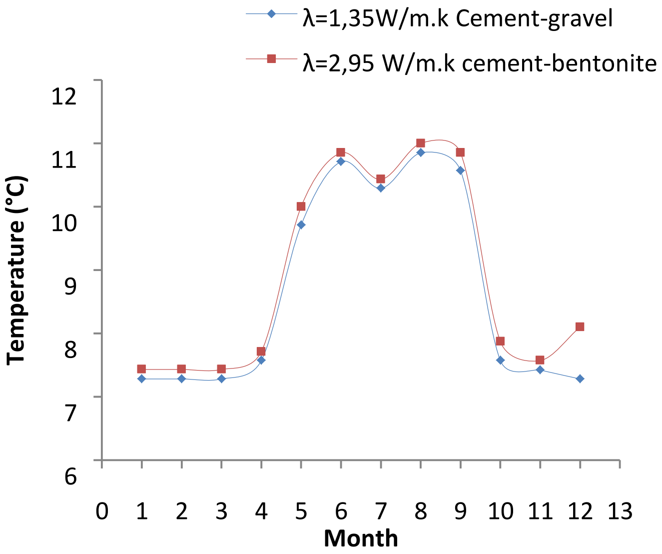

Figure 10. Influence of thermal conductivity of filling material at fluid's average temperature for coaxial borehole.

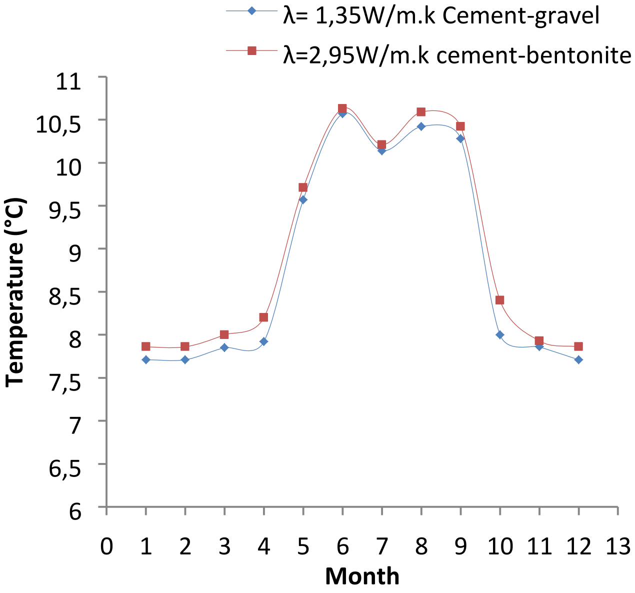

Figure 11. Influence of thermal conductivity of filling material at fluid's average temperature for single U borehole.

5. Conclusion

The energy performance of vertical heat exchangers of single U and coaxial boreholes 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 thermal performance is better too, due the higher capacity of heat transfer of fluid.

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

Furthermore, the knowledge obtained from this study highlights the considerable ability of geothermal energy to improve living conditions and comfort for the people of Tlemcen and Algeria. This promotes a move towards a more sustainable and robust energy environment, strengthening the commitment to environmental preservation and sustainability within the community's academic and social structures. Moreover, this study adds a crucial perspective to scholarly discussions on sustainable and energy-efficient climate control alternatives in similar areas.

Nomenclature:

Cp : Specific heat capacity of the fluid (J/(kgK)
Di : Inner diameter of the borehole pipe (m).
H : Borehole length or borehole depth (m).
m_f: Mass flow rate in the boreholes (kg/s).
R_b : Thermal borehole resistance (Km/W).
S : Area (m^2).
P **:** Total Thermal conductance (W/K).
U: Thermal Conductance at ground level per unit area (W/m^2K).
w_i : Thickness of the wall of a coaxial borehole's inner and outer pipe (m).
λ : Heat conductivity (W/mK).
ρ: Fluid density ρ (Kg/m^3).
ν : kinematic viscosity of the borehole fluid (m^2/s).

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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