Modelling and Numerical Investigation of the thermal properties effect on the soil temperature in Adrar region.

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ABSTRACT

Geothermal energy is part in various clean sources in the world. The geothermal energy resources originate from the ground and its temperature varies according to depth and its thermal properties. This paper presents a numerical simulation of the soil temperature variation in different thermal properties depending on the nature of the soil. three different Specific heat capacity and thermal conductivity are used in this this simulation and have applied in Adrar city. Three soils A, B and C, each soil has characteristics that are different from the others are presented. The results showed that the soil C is considered the best soil in terms of results in the southern desert region that can be applied to help in ventilation, cooling homes in summer (22°C) and natural heating in winter (31°C). A is considered to be a soil with high thermal insulation and its results can be used for agricultural irrigation applications in desert areas in the summer season because its temperature stabilizes at 26 °C. As an economic vision, it can use the soil B in depth of 3 m to reduce costs, based on the convergence of the results of soil C in this depth, but it's remain less effective.

I. Introduction

In recent years, Algeria's approach has become clear towards renewable energies [1]. Algeria is one of the most fossil energy producing countries in Africa [2,3], after fall in oil prices on the world stock exchange [4], In response, the OPEC Organization of Petroleum reduced their oil production [5]. This enables Algeria to develop and establish renewable energy centrals [6], such as solar photovoltaic power [7], wind energy [8,9], and geothermal energy [10–13]. Underground energy is the most important clean energies used in recent years, which is under many studies [14]. The Earth's temperature varies according to the depth, area, and soil nature. Enrico Barbier, [15] presented a complete overview of geothermal energy technology. It is found that the average soil temperature near the gradient, within a slight kilometre, is about 30 ° C in one kilometre, but the minimum values of 10 ° C in one kilometre are recorded in the ancient continental. At specific depth, it can use for determining the rate in which heat was moving upward into a specific part of soil crust. A. A. Alabi et al [16], Studied earth temperature variability at depths of 2 cm to 200 cm in South West of Nigeria. The experimental work was achieved in the duration of time between January to December 2014. The findings showed that the temperature of Earth changed from 27.75 ° C at 200 cm and to 29.9 ° C at 2 cm deep. Tomoyoshi Hirota et al [17], proposed a new procedure for appreciating profound earth temperature by utilizing a transformation of the FRM. If the boundary conditions can be set, the FRM has the power to presage regular changes in external face temperature of the mind. The findings indicated that the coupling between HCE and FRM will be strong than the direct FRM only for non-sinusoidal forcing conditions. K. G. Cassman et al [18], evaluated the interacting effectiveness earth and its temperature, for checking the effectiveness of the water quantity in uniformly distributed soil by squeeze diaphragm stabilization, and for checking the kinetic of the number mineralization at different depths in the earth. The results confirm that in a Yolo soil, the kinetics of N mineralization is affected by; the depth, temperature Y moisture interaction, the quantal and distribution of earth moisture. The Yolo soil may do not be irregular in these esteem. The mastery to appreciate ground N availability strength be improved if these effects were evaluated for other soil types. Carlene A et al [19], determined the effect of earth temperature variation on buried pipe, with a maximal temperature between 40 to 55 °C; and validated the effectiveness of TIR films varying intensity with a classic Ldpe film on earth temperature. Al-Ajmi and his partners [20], Presented a theoretical simple EAHE model and built for the prevention of outdoor air temperature and cooling energy in an arid and dry environment. The result confirmed the system of Earthling air heat changer would ensure a reduction of 1,700 KW in daytime peak load with an internal temperature drop of 2.8 ° C in hot cycle (15 July). Faezeh Fazlikhani et al [21], present a numerical simulation with MATLAB to evaluate and check the power reducing energy of ground system air heat-exchanger at warm and phlegmatic climate in Iran. The findings showed that earth temperature swing decreases with depth until the set average annual temperature of 18,2 C in the lower depth of 13,2 meters in Yazd and 12,1 C in Hamadan is reached at 14 m depth. Zhongbing Liu et al [22], Presented an overall analysis of cooled air outfit conversion energy technologies, including theoretical, modeling and realistic studies in arid and hot climates. The advantage, disadvantage, economy and climates adaptabilities of various energies storage and conversion technology for clean air in houses are analysed and discussed. Bordoloi et al [23], Presented a review of the previous research on heat exchangers and explains the theoretical and practical research on the various forms of EAHE and analyzes the thermal efficiency effects. Ramkishore Singh et al [24], Review the latest innovations in the EATHE configurations over the last ten years with a particular focus on the layout sections of these technologies for the realization of fresh domestic climate as a reduced power consumption in cooling and heating operations in desert houses. The results showed that, regardless of long-term EATHE studies, economic analysis is limited in the literature and can not necessarily be applied. They proposed an elaborate economical work for stand-alone and hybrid earth to air tunnel system design was proposed to be outright for each layout and climatology type. Mohammad Habibi and Ali Hakkaki-Fard [25], presented a numerical simulation based on 3D model of horizontal Ground Heat Exchangers with CFD methods was developed by the authors. This simulation for evaluating the thermal efficiency and the first installation price of the horizontal GHEs. The results showed that the spiral and linear forms in simple and parallel arrangement have low initial installation prices respectively. Menhoudj et al [26], studied the energy efficiency of EAHEX model for houses in three different regions in Algeria (Oran, Bechar and Adrar). The experimental findings obtained were tested against those resulting from the Trnsys 16 simulation. Misra et al [27], The thermal performance of the EAHE was tested in two forms of soil; dry and wet soil during peak summer season. The results confirmed that for the same cooling efficiency the pipe length with wet EATHE system can be reduced by 12–14 m compared to dry EATHE system. Mohamed Salah Saadi and Rabah Gomri [28], Investigated seasonal thermal interference and dynamic heat flux for vertical coaxial borehole heat exchangers. The findings show that the soil resistance increases over time, with the result that the outlet temperature decreases over time, resulting in a reduction in the heat pump efficiency. That is why it is suggested that the device be coupled with a solar thermal soil recharge system and/or combined with an energy storage system. Elsayed Barakat et al [29], Three models of hybrid cooling systems have been developed and compared to other configurations of gas turbine inlet air-cooling systems. Recently, many researchers have conducted studies on the effect of the nature and quality of soils on geothermal energy [30–34].

This research aims at evaluating the impact of thermal properties and the nature of the material on earth temperature at different depths in order to increase the effectiveness of cooling in dry desert areas during the summer and heating in the cold winter period, a comparison with the performance of the three different types of soil, and thus suggest the most effective option by comparison with the performance of the three forms.

II. Mathematical model

The mathematical model used for the ground sub temperature was built on a theory of heat conduction transferring to earth as a semi infinite medium. The flux of one-dimensional soil heat, Qheat is described through:

$$Q_{heat} = \lambda_{heat} \times \frac{\partial T}{\partial z} \qquad (1)$$

Where : λ: is thermal conductivity (w/m.K)

T: Température. z: soil depth.

The Conservation of energy results in:

$$C_{heat} \times \frac{\partial T}{\partial t} = \frac{-\partial Q_{heat}}{\partial z} \qquad (2)$$

Where: C_heat: the soil heat capacity.

The Combination of Equation (1) and (2) gives the differential equation for soil heat flow:

$$C_{heat} \times \frac{\partial T}{\partial t} = \frac{\partial(\lambda_{heat} \times \frac{\partial T}{\partial z})}{\partial z} \qquad (3)$$

The soil thermal diffusivity as is given by:

$$a_{soil} = \frac{\lambda_{heat}}{C_{heat}} \qquad (4)$$

Than the equation (3) simplified to:

$$\frac{\partial T}{\partial t} = a_{soil} \times \frac{\partial^2 T}{\partial z^2} \qquad (5)$$

Then the conduction in the soil was given by reference [12]:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{a_{soil}} \times \frac{\partial T}{\partial t} = 0 \qquad (6)$$

$$T(0.t) = T_{mn} + A_s \times \cos(\omega(t - t_0)) \qquad (7)$$

$$T(\infty, t) = T_{mn} \qquad (8)$$

Where:

As: Amplitude of variation in temperature of the soil surface.

T_mn: Mean temperature per annum

t_0: Max surface temperature day.

$$\omega : \frac{22 \times \pi}{365} \qquad (9)$$

Optimum profundity of underground pipes is a parameter required in the investigation of air-earth exchangers. This parameter depends on the characteristics of the region under study. The temperature of the soil was calculated with equation (4), reported in reference [11].

$$T(z,t) = T_{mean} + A_s \times (\mathrm{Exp}^{-(z)\sqrt{\frac{\pi}{365 \times a_{soil}}}} \times \cos\{\omega \times (t - t_0) - (z/\sqrt{365 \times a_{soil}/\pi})\} \qquad (10)$$

III. Results and discussion:

The city of Adrar is characterized by many different types of soil, as it occupies an area of 439.700 km², which recognized with variable soils from one sub-region to another. In this study there are three different soils, a (sand soil), b (slit soil) and c (Clay soil). As shown in Figure .1. below:

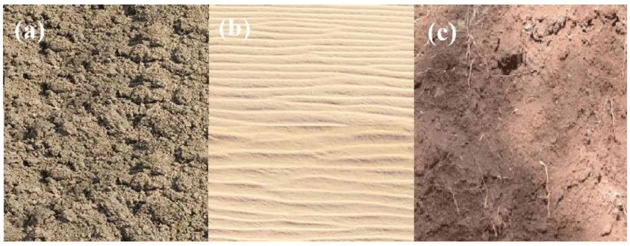

Figure 1. Soils proposed for use in simulation.

Before beginning to assess the effectiveness of soil thermal properties over underground temperatures, it must validate the mathematical model with an experimental study from the literature works.

III .1. Soil temperature Validation:

Our mathematical model was matched with an experimental study, the figure. 2. shows the validation of soil temperature against Al-Ajmi et al.[20], The comparison between our simulation work and experimental gives a good agreement, with a maximal and minimal errors of 7 and 0.3 %, respectively. The sub-surface soil parameters found from the experimental study in Kuwait were present in Table 1.

Table 1 Input parameters used in the simulation.

Validation parameters	Values
The annual mean terrestrial temperature (Tm)	27 °C
Annual amplitude of a surface temperature (As)	13.3 °C
Thermal diffusivity of the soil (a)	0.0038 m^2/h
Depth (z)	4 m

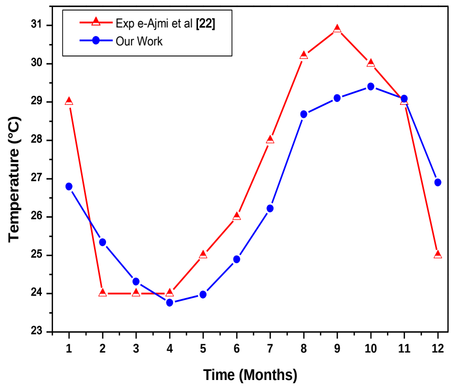

Figure 2. Results of validation against Al-Ajmi et al [22]

III .2. Soil temperature results:

This study was conducted on three samples of various soils in the Adrar region, each of which has certain characteristics as shown in Table 2. The three soils had different density, thermal conductivity and specific heat combinations resulting in a terms of their thermal diffusivity disparity. The values of thermal diffuseness for the 3 types of ground were given as 1.37×10-7, 6.22×10-7 and 9.69×10-7 m2/s. The Soil (A), has a very high thermal insulation property due to low of its thermal conductivity, high density and specific heat capacity, while soil (C) is characterized by the properties of the opposite of soil A, which allows it to early to heat transfer from and into the depth as the view point before the simulation. Whilst, the soil (B) is considered to have intermediate properties between Soil (A) and (B), and Soil, also, the calculation of thermal insulation was based on the results obtained in Table.2, through equation (4).

Table 2 Soils properties.

Soil	Soil A	Soil B	Soil (c)
Density	2050	1800	1500
Thermal conductivity	0.52	1.5	1.28
Specific heat capacity	1840	1340	880
Thermal diffusivity (m2/s)	1.37×10-7	6.22×10-7	9.69×10-7
Reference	Benhammou et al [35,36]	Menhoudj et al [26]	Mathur et al [37]

- **Variation temperature in Soil A:**

Soil A is characterized by high density and low thermal conductivity, which allows for heat insulation between the outer surface with ambient temperature and underground temperature. The figure. 3, illustrates the Monthly soil temperature variation in different depths. The changes in the earth temperature at different depthless of 1, 2, 3 and 5 meters during one year. it's observed is that the temperature changes on the surface are large, the opposite, whenever it's reach the depth, the temperature stabilizes, also noticed is that the minimum temperature recorded in the month of July, the value of 26.19 and 26.29 temperatures in each of the depths of 3 and 5 meters, respectively. This will contribute to the optimize of the upcoming studies concerned with geothermal energy. In depth of 5 m, it can be noticed that there a low variation of the soil temperature between 25.7 to 27 °C, during the year. The stability of soil temperature (A) in depth of 5 m, mainly due to its physical properties and in particular the thermal conductivity, which made the thermal transfer between the sub soil depth underground and the outdoor very weak. The comparison between 1 and 5 depths in Figure 3, it's noticed that there is a large temperature difference of up to 11 °C, and this is due to the storage of energy at the soil surface resulting from the ambient space.

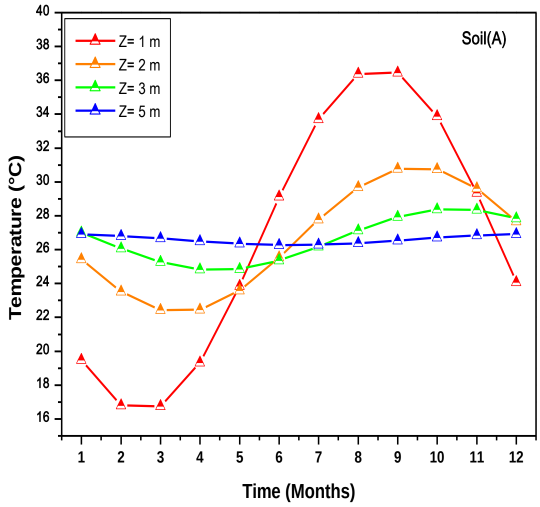

Figure 3. Monthly variation of Soil temperature (A).

- **Variation temperature in Soil B:**

Figure 04, shows the variation of the soil B temperatures during a year at different depths from 1 to 5 meters. Soil B consistency is medium regarding thermal properties in comparison to other soils, whether in terms of density or thermal insulation, the results have proven that changing the soil temperature B more than in the soil, and that is due to the high thermal insulation coefficient, which makes the depth of the soil more affected by the external heat of the surface, and this is confirmed by the graph curve, where ;it's noted that at a depth of 5 meters the temperature changes from a minimum degree of 23,45°C and High temperatures are estimated at 29,74°C in June and December, respectively.

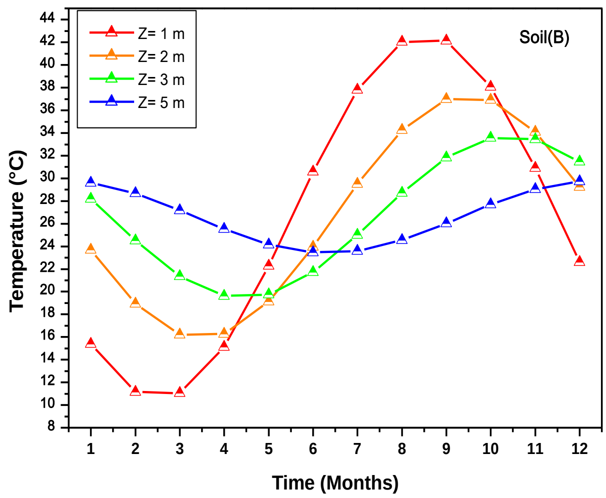

Figure 4. Monthly variation of Soil temperature (B).

- **Variation temperature in Soil C:**

Figure 05, shows the soil C temperature changes, which are characterized by a high thermal insulation value compared to each of the two previous soils. It is observed that the soil temperatures at a depth of 5 meters are variable throughout the year, and this is due to the different characteristics and the soil's influence in the outer environment. It is evident at a depth of 1 meter compared against the other type of ground, where this highest temperature in ground C reaches 43,44°C while in soil A and B it reaches 36.45 °C and 42.1°C, respectively. Also noticed is That's going to deepen of 5 meters, the soil temperature C changes from a minimum temperature of 21.89 °C to a high temperature of 31.3 °C in each of June and December, respectively.

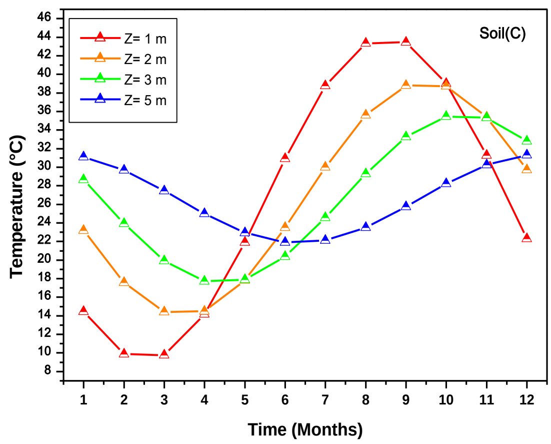

Figure 5. Monthly variation of Soil temperature (C).

- **Variation of Soils temperature in 5m of depth:**

Figure. 06, shows a numerical comparison of the monthly variation of temperature in the three soils of a depth of 5 m as best depth in terms of results and effectiveness extracted from the previously figures. It's observed from the figure. 06, that the soil A is more stable than both B and C. This is due to the thermal insulation strength of this type of Soil compared with the others, while its temperature is fixed at 26 °C throughout the year, and this is not useful for cooling or heating, but it allows it to be used to adjust the temperature of agricultural watering area, contrary to what is observed in soil B with a percentage less than soil C, it has been observed that the temperature of the soil depth is Low in the summer, which allows it to be used for cooling, and high in the winter, which allows us to use it for heating. The results confirm that soil C is the best choice in terms of temperature changes every month.

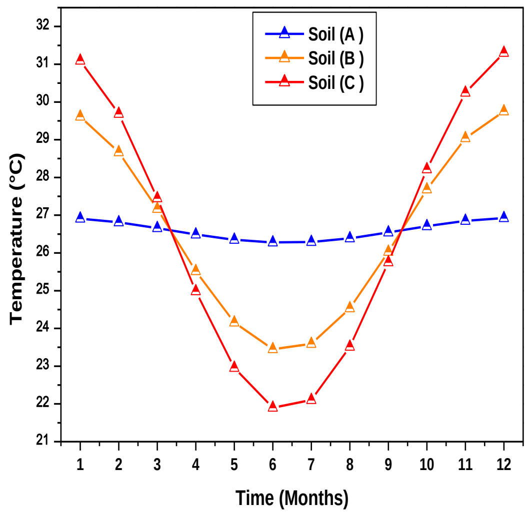

Figure 6. Monthly variation of Soils temperature in depth of 5m.

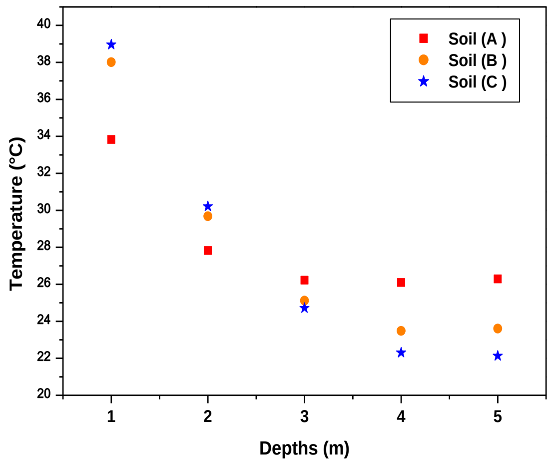

Figure 7. Vertical profile of three soils temperature in July month.

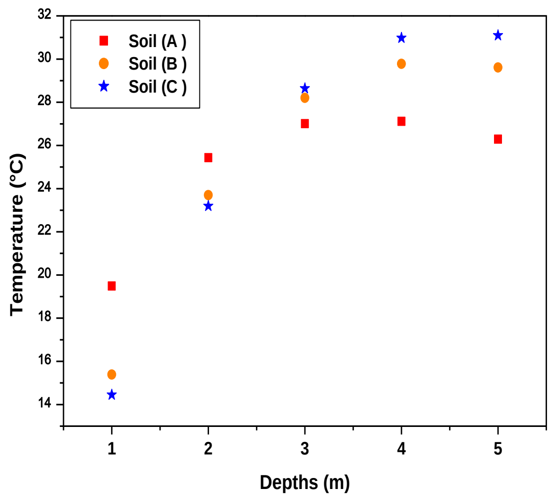

Figure 8. Vertical profile of three soils temperature in January month.

Figures 7 and 8 represent the three soil temperature changes in both July and January months, respectively. It is noted that during the July month period, soil A changes from 34 °C in a depth of 1 m to 26°C in a depth of 5 m with an average change of -1.5 °C/m while in soil B and C, it changes from 38°C, 39°C to 24°C and 22°C with an average change of -2.88°C and -3.36°C degrees per meter, respectively. It is also noticed in the January month period is that the average change of the T° of ground A is about 1.36 °C/m temperatures per meter in the depth of the ground while in each of the soil B and C 2.84°C by m and 3.32°C by m into the earth through the results. Also it can consider the depth of 3 m as an economic depth in terms of the cost of operating and the convergence of results between both the soil B and C.

IV. Conclusion:

Geothermal energy is very important in many countries of the world which are used in many applications, in desert areas where the temperature is high used to reduce electrical consumption by reducing the temperature and changing the internal air with fresh air, while it is used in cold areas for natural heating. Through our study of three types of existing soils that have different properties, whether thermal or mechanical, it's noted that these characteristics have a great role in changing the results and through this study can be relied upon in extracting the results for geothermal energy applications, this study was done on three soils A, B and C, each soil has characteristics that are different from the others. Through the results, it can extract some points that are as follows:

- Soil A is considered to be a soil with high thermal insulation and its results can be used for agricultural irrigation applications in desert areas in the summer season because its temperature stabilizes at 26 degrees Celsius.
- Soil C is considered the best soil in terms of results in the southern desert region that can be applied to help in ventilation, cooling homes in summer (22°C) and natural heating in winter (31°C).
- In the case of soil B, it can have used this type at a depth of 3 m to reduce costs and also because its results in this depth are very close to the results of soil B, but remain less effective.

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