RESEARCH ARTICLE

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The Readiness Investigation of The Ground Soil Temperature for Underground Heat Exchange Systems Installation in Hot Climates

Mohammed H. Ali, Zoltan Kurjak, and Janos Beke

ABSTRACT

This present article investigates the possibility of the use of ground soil of hot climates for the investiture of it for cooling and heating aims by using it as an underground heat exchange. The study region is Al-Najaf city, 168.83 km south of Baghdad the capital of Iraq. This heat exchange represents one of the sustainable energy types which depends on the difference between the ambient air and ground soil temperature, which can lead to reducing the exhaustion of fossil fuels. To measure the soil temperatures during all the months of the year, A hole drilled to a depth of 5 meters, seven thermocouples has been installed at each depth (0.5, 1, 2, 3, 4, and 5 m), and at the ground surface. The new experiment result of variation of the soil temperature with depth and during the year has been compared and evaluated in order to estimate the possibility of using Earth to Air Heat Exchanger (EAHE) for heating or cooling purposes along the year. The result shows that the average temperature difference between the ground surface and ground soil temperature during the months increasing as the underground depth increases. The results have let it a perfect referral for the priorities of the use that location at equal to or more than 3 m depth for cooling during summer months (the temperature differences reach to 16.17 ºC) rather than heating during winter months (the temperature differences reach to 10.76 ºC). The less than 3 m depths can use it for precooling and preheating purposes because it is directly affected by the ambient temperature, which reduces the possibility of using it in a better way. The most significant results were the important negative temperature variances for testing location that becomes an emboldening factor in designing and researching other factors for the build clean, cheap, and efficient ground source heat exchange systems.

Keywords: EAHE, heat exchange, ground temperature distribution, ground soil temperature.

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I. INTRODUCTION

Heat transfer enhancement has significant attention in the last two decades due to the rapid development in industrial and global warming. Thus, it is imperative and urgent to find alternative sources to replace or at least reduce the widespread use of fossil fuels and their impact on the atmosphere, given the importance of energy for the life of our society. Not only does the word alternative energy source mean it is an efficient option, but it is synonymous with renewable energy. In theory, this type of energy is inexhaustible and can be found and used equally well on Earth. Air conditioning has been commonly used in recent times for industrial development and occupants' comfort. Vapour compression machines can do this effectively, but due to the degradation of the ozone layer and global warming by chlorofluorocarbons (CFCs) and the need to minimize high-grade energy consumption, various alternative techniques are currently being explored [1], [2].

During the year, the soil at a depth of 2-3 m below the Earth's surface has almost a constant temperature profile considerably lower than the ambient air temperature in dry arid areas throughout the summer. Underground soil is distinguished by its high thermal inertia, which decreases the effect of temperature variations on the soil's surface. This temperature differential can be used for the pre-cooling of hot ambient air in summer using the heat exchanger of the earth-air pipe, and then the cooled air can be guided to heat rejection in thermal systems [3]-[5], [7].

The ground source's heat exchanger is characterized by easy construction, low energy consumption, less maintenance, and minimal environmental impact [8] compared to traditional heating, boiler cooling, or cooling systems. Goswami and Biseli [9] performed Earth-air heat exchanger experiments. They stated that efficiency could be improved by reducing the pipe diameter and air flow rate, thereby increasing the pipe length and buried depth. It was proposed that several parallel pipes may be sufficient for optimum efficiency to be achieved. It was also found that a higher drop in temperature was generated by the smaller pipe diameter, while it used more fan power. Fard et al. [10] evaluated Earth-air heat exchanger devices' efficiency across different parameters such as burial depth, pipe length, air velocity, and pipe material. After 72 experimental tests, it was concluded that all parameters were directly related to efficiency, excluding pipe content. The coefficient of cooling output (COP) was higher than of COP heating (5.5 versus 3.5). Bisoniya et al. [6] measured the hot/dry summer conditions of the EAHE system and concluded that the drop in air temperature was significant relative to the rest of the segment in the initial length of the pipe. Top and minimum air temperature decreases were observed at 2 m/s and 5 m/s at 12.9 °C and 11.3 °C, respectively.

Niu et al. [11] studied the recovery of Earth-air heat exchanger soil temperature and cooling power in intermittent and continuous mode. They concluded that the cooling power of EAHE had decreased by 240W within four days of continuous service, although it could be recovered in intermittent mode during the non-working time. Dehghan [12] has studied different design configurations to use a spiral ground heat exchanger for a ground source heat pump (GSHP). As a practical design for the GSHP system, he suggested the configuration of nine spiral ground heat exchangers, each separated by a distance of 6 m with a pitch length and the main diameter of 0.1 and 0.45 m, respectively. Bi et al. [13] have studied the temperature distribution of the GSHP spiral ground heat exchanger. The findings showed substantial temperature differences between the inside and outside of the coil, the top and bottom of the coil. Zhu et al. [14] reviewed the integration of GSHP with various thermal energy storage (TES) systems, such as ice storage, solar collector, soil storage, and phase-shifting material. They calculated that the COP of the GSHP-TES system is within the range of 2–6.5, while the energy savings range ranges between 13 and 32%, depending on the type of thermal energy storage unit. Inalli and Esen [15] studied the thermal efficiency of the horizontal GSHP system. The horizontal earth heat exchanger COP was recorded as 2.66 and 2.81 at depths of 1 m and 2 m, respectively.

Recently, Liu et al. [16] have been working with the vertical earth to air heat exchanger system at various soil depths and flow rates. The findings showed that this system had an outlet air temperature in summer, varying from 22.4 °C to 24.4 °C and from 16.0 °C to 18.0 °C in winter. The exact air temperature of the profile along the entire tube showed that the difference in air temperature in the deep soil below 5 m was more significant than that of the inlet up to 5 m twice that amount. Its recovery rate for the soil temperature at different depths is approximately equal to the respective rate of change at the same depth during operation. The proposed scheme measured its energy repayment duration at 8.2 years and its mitigation potential and gross CO2 emissions. Due to the economic life of 20 years, carbon credits were estimated at 7170.42 kg and $203.43, respectively. It also assessed the monetary repayment duration to be 17.5 years. The above findings demonstrate feasibility and effectiveness.

The heat flow rate is behaving through a material is proportional to the contact area, to a temperature difference and distance of heat flow. For a one dimensional, Fourier's equation expresses the rate steady state heat flow [17]:

$$Q = -\frac{k}{d} A \, \Delta T \tag{1}$$

where: Q is the heat flow rate (W), k is the thermal conductivity (W/m-K), A is a contact area (m^2), d is the heat flow distance (m), ΔT is a temperature difference (K).

Based on the literature and the reviews studies [18]-[20], the Earth's vertical temperature profile is a significant factor in considering it as a renewable energy source and in designing Earth to air or water heat exchange techniques.

The objective of this study is to investigate the possibility uses of ground soil of the hot climate, by conducting an experimental study and measurement of Earth's vertical temperature profile at different underground depth (0.5, 1, 2, 3, 4, and 5 m) and compared it with the dominant surface temperatures during the seasons of the year. This region located in Al-Najaf, Iraq, as this city does not have any studies on its soil temperature yet and thus this study will provide a new reading of the possibility of using a ground heat exchanger in it, as well as most regions of the Middle East owing limit of experimental studies and benchmarks, this provides an opportunity to know the possibilities which this ground soil can be used for engineering applications and energy saving as a one of renewable energy sources with steady long term and efficient in this region, such as Ground Heat Pump systems installation in order to cooling and heating a building and/or use it to cooling the photovoltaic panel to enhance its efficiency. This includes the temperature differences test of ground soil and its trends at specific depths and compared with the prevailing temperatures of surface ground during the seasons of the year.

II. Set-up and Measurement Method

The experiment was carried out at Al-Najaf city, 168.83 km south of Iraq's capital Baghdad, north of Al-Najaf, on the famous river's South-West side, the Euphrates, as shown in Fig. 1. A hole has been drilled to a depth of 5 meters to measure the soil temperature during all the months of the year. Six thermocouples (K-type) were inserted inside the hole at different depths (0.5, 1, 2, 3, 4, and 5 m depth) in order to use it to measure ground soil and seventh thermocouple use it to measure the ground surface temperatures for documenting and comparing their daily temperature at different periods (every ten minutes) in 2019, with the goal of more accurately identifying and assessing the possibilities of underground uses. Data were collected via "TEMPERATURE RECORDER, Model: TM500," daily, 144 times a day.

The ground surface temperatures are subtracted from ground soil at the specified depths (0.5, 1, 2, 3, 4, and 5 m depth) and this temperatures differences used to estimate the probability of using ground heat exchanger heating/cooling systems at every specified depth in the region study and

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regions with comparable climates to reduce the cost of power and to address the need for complex mechanisms for that purpose. The system test is illustrated in Fig. 2.

Fig. 1. Al-Najaf city shows the location of the study area.

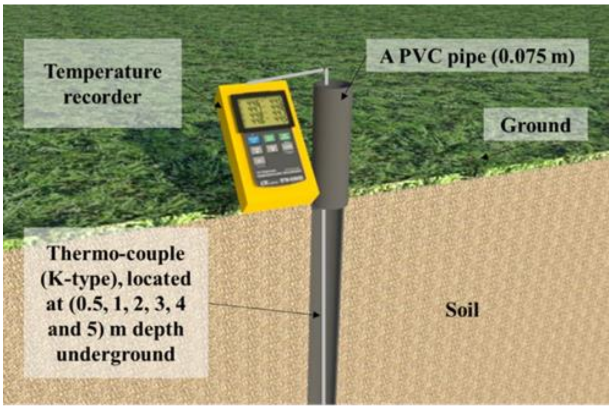

Fig. 2. The system test design.

III. Results and Discussion

The experiment results were recorded daily during the year 2019 using seven thermocouples located at each specified depth and ground surface. The new experimental results of the soil temperature at every depth during all months of the year has been compared and evaluated. As it was the temperature difference between ambient and ground soil temperatures that plays a significant in the heat exchange processes, the records of ground surface were subtracted from all temperature's records by ground soil thermocouples at each depth, the purpose of that to determine these one's differences that were adopted through any following studies and analysis. Especially, use it in design of earth to air heat exchanger for heating or cooling purposes along the year. All these records were averaged for each monthly time reading, every month's average, maximum and minimum temperature of the ground surface at the study location were recorded during all the months of the year as presented in Table 1. The recorded temperature of the surface shows that the lowest average temperature was recorded in January at 11.45 °C, while the highest average temperature was recorded in July at 41.58 °C.

TABLE I: The month's average, maximum, and minimum temperature of the ground surface

Month	Ground Surface Temperature (°C)		
	Maximum	Average	Minimum
January	22.02	11.45	0.81
February	21.92	12.74	0.00
March	31.31	19.82	10.61
April	40.30	25.59	14.04
May	37.24	32.94	20.10
June	50.40	37.49	24.64
July	44.22	41.58	29.19
August	50.90	40.75	28.58
September	40.64	37.00	25.55
October	39.19	27.93	16.46
November	33.03	20.15	8.18
December	30.40	15.28	3.74

Table II presents every month's average, maximum, and minimum ground soil recorded temperatures at different depths (0.5, 1, 2, 3, 4, and 5 m) during all the months of the year and the standard deviation. The recorded temperatures were varying significantly as the depth change and during the different months of the year as well as standard deviation. It was observed that shallow depths are affected by the ground surface temperature, while this effect decreases as the depth increases reaching to 5 m depth. The standard deviation between the recorded temperatures was varying between 1.45 and 3.9 as a maximum deviation and observed that it's decreases as depth increasing.

Fig. 3 illustrates the month's average underground temperature at different depths (0.5, 1, 2, 3, 4, and 5 mm) during all the months of the year. The figure's overall trend shows that there is a significant variation in soil temperature during the year at a depth of (0.5-1.0) m. However, this temperature variation decreases as the depth increase. Moreover, there was an insignificant effect on average underground temperature with the increasing depth.

The month's average temperature differences between the ground surface and the ground soil at different depths during all months of the year are presented in Table III. The highest negative average temperature differences were -16.17 °C in July (summer) at 5 m depth which can be used for cooling purposes, while the lowest positive average temperature differences were +10.76 °C in January (winter time) at same depth.

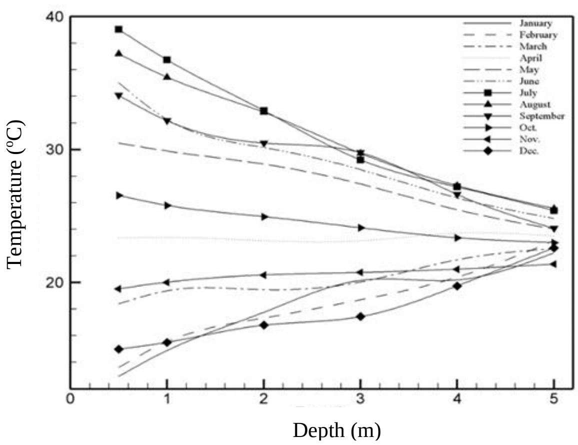

Fig. 3. The month's average underground temperature at different depths.

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TABLE II: THE MONTH'S AVERAGE SOIL TEMPERATURE AT SPECIFIED DEPTH AND THE STANDARD DEVIATION

Month	Depth (m)	Temperature (°C)	
		Average	Standard Deviation
January	0.50	12.92	3.90
	1.00	14.87	3.55
	2.00	17.74	3.41
	3.00	20.15	3.25
	4.00	20.18	3.02
	5.00	22.21	2.75
February	0.50	13.61	2.83
	1.00	15.54	2.56
	2.00	17.33	2.29
	3.00	18.70	2.02
	4.00	20.40	1.75
	5.00	23.14	1.62
March	0.50	18.39	2.39
	1.00	19.38	2.18
	2.00	19.45	1.97
	3.00	20.04	1.76
	4.00	21.71	1.56
	5.00	22.56	1.45
April	0.50	23.34	2.86
	1.00	23.38	2.59
	2.00	23.14	2.33
	3.00	23.13	2.07
	4.00	23.70	1.81
	5.00	23.50	1.68
May	0.50	30.49	3.28
	1.00	29.89	3.08
	2.00	28.91	2.88
	3.00	27.41	2.70
	4.00	25.47	2.53
	5.00	24.02	2.45
June	0.50	35.02	2.80
	1.00	32.26	2.55
	2.00	30.15	2.30
	3.00	28.49	2.05
	4.00	26.36	1.81
	5.00	24.82	1.69
July	0.50	39.04	3.19
	1.00	36.75	3.02
	2.00	32.93	2.85
	3.00	29.22	2.69
	4.00	27.18	2.54
	5.00	25.41	1.99
August	0.50	37.20	3.19
	1.00	35.44	3.01
	2.00	32.80	2.83
	3.00	29.72	2.67
	4.00	27.28	2.52
	5.00	25.57	2.45
September	0.50	34.08	2.80
	1.00	32.17	2.55
	2.00	30.48	2.30
	3.00	29.76	2.06
	4.00	26.62	1.82
	5.00	24.06	1.70
October	0.50	26.54	3.38
	1.00	25.80	3.19
	2.00	24.95	3.00
	3.00	24.11	2.82
	4.00	23.36	2.65
	5.00	23.00	2.57
November	0.50	19.52	2.73
	1.00	20.01	2.48
	2.00	20.56	2.23
	3.00	20.75	1.98
	4.00	21.00	1.74
	5.00	21.37	1.63
December	0.50	14.97	3.01
	1.00	15.49	2.80
	2.00	16.78	2.61
	3.00	17.42	2.43
	4.00	19.73	2.26
	5.00	22.59	2.17

TABLE III: THE TEMPERATURE DIFFERENCE BETWEEN THE MONTH'S AVERAGE SURFACE AND THE GROUND SOIL TEMPERATURES

Month	Temperature (°C)			
	Depth (m)	Maximum	Average	Minimum
January	0.50	-9.10	1.47	12.11
	1.00	-7.15	3.42	14.06
	2.00	-4.28	6.29	16.93
	3.00	-1.87	8.70	19.34
	4.00	-1.84	8.73	19.37
	5.00	0.19	10.76	21.40
February	0.50	-8.31	0.87	13.61
	1.00	-6.38	2.80	15.54
	2.00	-4.59	4.59	17.33
	3.00	-3.22	5.96	18.70
	4.00	-1.52	7.66	20.40
	5.00	1.22	10.40	23.14
March	0.50	-12.92	-1.43	7.79
	1.00	-11.93	-0.44	8.78
	2.00	-11.86	-0.37	8.85
	3.00	-11.27	0.22	9.44
	4.00	-9.60	1.89	11.11
	5.00	-8.75	2.74	11.96
April	0.50	-16.96	-2.25	9.30
	1.00	-16.92	-2.21	9.34
	2.00	-17.16	-2.45	9.10
	3.00	-17.17	-2.46	9.09
	4.00	-16.60	-1.89	9.66
	5.00	-16.80	-2.09	9.46
May	0.50	-6.75	-2.45	10.39
	1.00	-7.35	-3.05	9.79
	2.00	-8.33	-4.03	8.81
	3.00	-9.83	-5.53	7.31
	4.00	-11.77	-7.47	5.37
	5.00	-13.22	-8.92	3.92
June	0.50	-15.38	-2.47	10.38
	1.00	-18.14	-5.23	7.62
	2.00	-20.25	-7.34	5.51
	3.00	-21.91	-9.00	3.85
	4.00	-24.04	-11.13	1.72
	5.00	-25.58	-12.67	0.18
July	0.50	-5.18	-2.54	9.85
	1.00	-7.47	-4.83	7.56
	2.00	-11.29	-8.65	3.74
	3.00	-15.00	-12.36	0.03
	4.00	-17.04	-14.40	-2.01
	5.00	-18.81	-16.17	-3.78
August	0.50	-13.70	-3.55	8.62
	1.00	-15.46	-5.31	6.86
	2.00	-18.10	-7.95	4.22
	3.00	-21.18	-11.03	1.14
	4.00	-23.62	-13.47	-1.30
	5.00	-25.33	-15.18	-3.01
September	0.50	-6.56	-2.92	8.53
	1.00	-8.47	-4.83	6.62
	2.00	-10.16	-6.52	4.93
	3.00	-10.88	-7.24	4.21
	4.00	-14.02	-10.38	1.07
	5.00	-16.58	-12.94	-1.49
October	0.50	-12.65	-1.39	10.08
	1.00	-13.39	-2.13	9.34
	2.00	-14.24	-2.98	8.49
	3.00	-15.08	-3.82	7.65
	4.00	-15.83	-4.57	6.90
	5.00	-16.19	-4.93	6.54
November	0.50	-13.51	-0.63	11.34
	1.00	-13.02	-0.14	11.83
	2.00	-12.47	0.41	12.38
	3.00	-12.28	0.60	12.57
	4.00	-12.03	0.85	12.82
	5.00	-11.66	1.22	13.19
December	0.50	-15.43	-0.31	11.23
	1.00	-14.91	0.21	11.75
	2.00	-13.62	1.50	13.04
	3.00	-12.98	2.14	13.68
	4.00	-10.67	4.45	15.99
	5.00	-7.81	7.31	18.85

Fig. 4 shows the temperature differences between the average ground surface and the ground soil temperatures at different depths during all months of the year. The figure's general trend demonstrates that the temperature difference during the months increasing as the underground depth increases. This means that the soil at shallow depths is affected by the ambient temperature, and it is directly proportional to it, that its temperature increases with the increase in the ambient temperature in the summer and decreases when the ambient temperature decreases in the winter season. This effect decreases as the depth increases, thus the temperature differences between the ambient and the soil increases, indicating the possibility of using these depths in installing a heat exchanger for cooling in the summer and for heating in the winter season depending on these differences. On the contrary, at shallow depths, it can be used for precooling and preheating due to low differences.

These experiment results have let it a perfect referral for the priorities of the use that location at equal to or more than 3 m depth for cooling during summer months rather than heating during winter months because the temperature differences in the summer months preferable than the temperature differences in the winter months. The less than 3 m depths can be use it for precooling and preheating purposes because it is directly affected by the air temperature, which reduces the possibility of using it in a better way. The most significant results were the important negative temperature variances for testing location that becomes an emboldening factor in designing and researching other factors for the build of clean, cheap, and efficient ground source heat exchange systems.

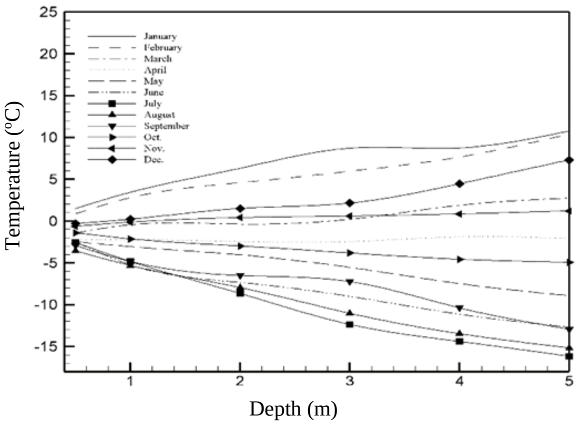

Fig. 4. The average temperature difference between the underground surface the surface.

IV. Conclusions

The current research focused on analyzing the applicability of using an EAHE in hot climates, especially in Al-Najaf, Iraq. As the temperature there reaches up to an average of 41 °C during the summer season. The temperature of the ground surface has been recorded during all the months as well as the ground soil temperature at different depths (0.5, 1, 2, 3, 4, 5 m). The ground surface temperatures result shows that the average temperature was varied with the different months and the highest month's average temperature was in July at 41.58 °C and the lowest month's average temperature was in January at 11.45 °C. The average ground soil temperatures were varied with the different months and the different underground depths. According to the results obtained and the discussion that took place around it, the conclusions will be as follows:

1) The recorded temperatures are varying significantly as the depth change and during the different months of the year. The shallow depths are affected by the ambient, while this effect decreases as the depth increases reaching to 5 m depth.
2) The standard deviation between the recorded temperatures was varying between 1.45 and 3.9 as a maximum deviation and observed that it's decreases as depth increasing.
3) There is a significant variation in soil temperature during the year at a depth of (0.5-1) m. However, this temperature variation decreases as the depth increase. Moreover, there was an insignificant effect on average underground temperature with the increasing depth.
4) The highest negative average temperature differences were -16.17 °C in July (summer) at 5 m depth which can be used for cooling purposes, while the lowest positive average temperature differences were +10.76 °C in January (winter time) at the same depth.
5) The soil at shallow depths is affected by the ambient temperature and it is directly proportional to it, that its temperature increases with the increase in the ambient temperature in the summer and decreases when the ambient temperature decreases in the winter season. This effect decreases as the depth increases. Thus, the temperature differences between the ambient and the soil increases, indicating the possibility of using these depths in installing a heat exchanger for cooling in the summer and heating in the winter season depending on these differences. On the contrary, at shallow depths (less than 3 m depths), it can be used for precooling and preheating due to low differences.
6) Perfect referral for the priorities of the use that location at equal to or more than 3 m depth for cooling during the summer months rather than heating during the winter months.
7) The most significant results were the important negative temperature variances for testing location that becomes an emboldening factor in designing and researching other factors for the build of clean, cheap, and efficient ground source heat exchange systems. But the economic analysis should also be carried out to understand better the techno-economic feasibility of using this thermal application method in hot climates.

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