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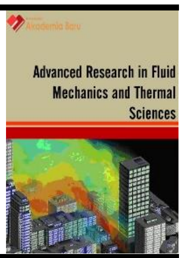

Experimental Study of Earth to Air Heat Exchanger Performance in arid regions. First step: in-situ Measurement of Ground Vertical Temperature Profile for Different Depths

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ABSTRACT

Ground vertical temperature profile at various depths is a major key in designing phase of the use of earth heating and cooling techniques for buildings, offices and greenhouses like earth to air heat exchanger (ETAHE), Earth-Air Tunnel (EAT), Ground Air Collector (GAC) and water Quanat. Annual undisturbed soil temperature is very important parameter to investigate earth to air potentials. The present experimental study was conducted in two different sites in South-west of Algeria, in the city of Bechar (arid region) starting from ground surface to 1.5 m depth. The obtained results show that at the ground surface temperature was 35.2 °C for both sites. At 1.5 m of depth, the temperature was 29.2 °C and 28 °C in site n°1 and n°2 respectively. Temperature values remain constant after 70 seconds. The study results serve as a benchmark for other studies and help researchers interested to study this renewable energy source.

Keywords:
Experimental study, Ground vertical temperature, arid regions, thermal comfort, temperature sensor

1. Introduction

The achievement of thermal comfort is a major key in designing buildings and offices especially in arid regions around the world. Air conditioning systems are the recent solution for this purpose but at which price. AC systems are responsible for 40 % of electrical energy consumption in Algerian building sector only [1]. With approximately 6 months of AC system use from May to September, the average electricity peak load for these months is 45% higher than the yearly regime [2].

Bechar city is situated in south west of Algeria. Classified as an arid region. Figure 1 is an experimental measured values in the shade of outside temperature between July and August (2018) where temperature get and sometimes exceed 44 °C and relative humidity doesn't exceed 21 %.Thermal discomfort is largely sensed by the occupants of the region.

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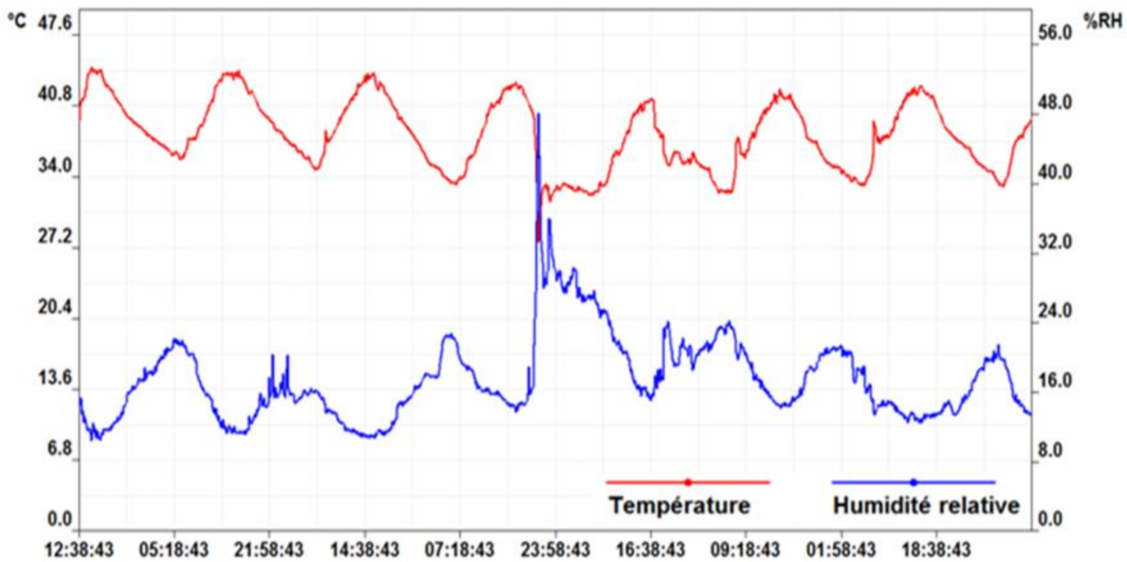


Fig. 1. Outside temperature and relative humidity measured in the region of Bechar

Renewable energies seem much promoted as a solution for providing thermal comfort and in the same time reducing energy consumption belt. The idea of using ground as a heat source or heat sink back to early times and precisely to 3000 B.C when Iranian architects integrate wind towers to underground water channel system called Quanat to reduce by few degrees and to add more humidity to air passing through this passages before injecting it in living spaces. The same idea was applied by Algerian desert inhabitants in the region of Adrar. The technic was called the Fougaraha and invented to provide water supply and precooling or ventilation for the houses [3]. In the same time, the people of Benni Abass (south of Bechar) build their own summer chamber under their basement to benefice from less few degrees in summer season in comparison with outside air (sometimes reach 50 °C) and serve as food storage in winter.

To benefice of ground cooling and heating potentials, earth to air heat exchanger ETAHE, ground air collector GAC, earth tunnel are several technics invented by researches and specialists. The basic of this technics is very sample; based on a heat transfer from the sub-soil covering a buried pipe or pipes to a medium (air or water) flowing inside it. The result is preheating in winter, and precooling in summer which decrease the need of AC systems.

The thermal potential of ground depends on climatic conditions of the region, moisture; composition of soil, etc. Ground temperature is a sinusoidal function of time described as follow [2]

$$T(z,t) = T_m + T_0.e^{[\left(-\frac{z}{\gamma}\right)\cos\left(\omega t-\frac{z}{\gamma}\right)]} \tag{1}$$

where $\gamma = \sqrt{\frac{2\alpha}{\omega}}$ and $\alpha = \frac{\lambda_{soil}}{\rho c_{p\ soil}}$

T_m: The mean annual ground temperature.
T_0: The temperature wave amplitude at the ground surface (z=0).
ω: The frequency of the annual temperature wave
λ_{soil} is soil thermal conductivity (W/m. °C), α is thermal diffusivity (m^2/s), C_{psol} is the specific heat (J/kg.°C), ρ is the density (kg/m^3).

Al-Ajmi *et al.,* [4] defined the soil temperature as

$$T(z,t) = T_m - A_s e^{\left(-z(\pi/8760\alpha)^{0.5}\right)} * cos\left[\frac{2\pi}{8760}\left(t - t_0 - \frac{z}{2}\left(\frac{8760}{\pi\alpha}\right)^{0.5}\right)\right] \tag{2}$$

A_s is annual surface temperature amplitude (°C). t and t_0 are time of the year (hours) and phase constant (hours) respectively.
According to the authors, this model yields errors of no more than ±1.1 °C when the variables are determined from field measurements.

2. Site Ground Compositions and Properties

Vertical temperature profile of soil is affected directly by several factors (figure 2):

i. Soil nature and type: sandy soil, sandy loam soil, rocky soil, etc.
ii. Physical properties: composition of layers, nature of each layer (sand, rocks, etc), thickness of the layers, Moisture, etc.
iii. Thermal properties: Thermal inertia, thermal conductivity, etc.
iv. Climatic conditions of the regions: Solar radiation, air temperature and humidity, wind, precipitation.
v. Grounds surface cover: concrete, trees, etc.
vi. Human surface activity: this effect is very limited to the nature of the activity and could rise the temperature of ground subsurface 1 or 2 °C (transport, industry, agriculture, etc.).

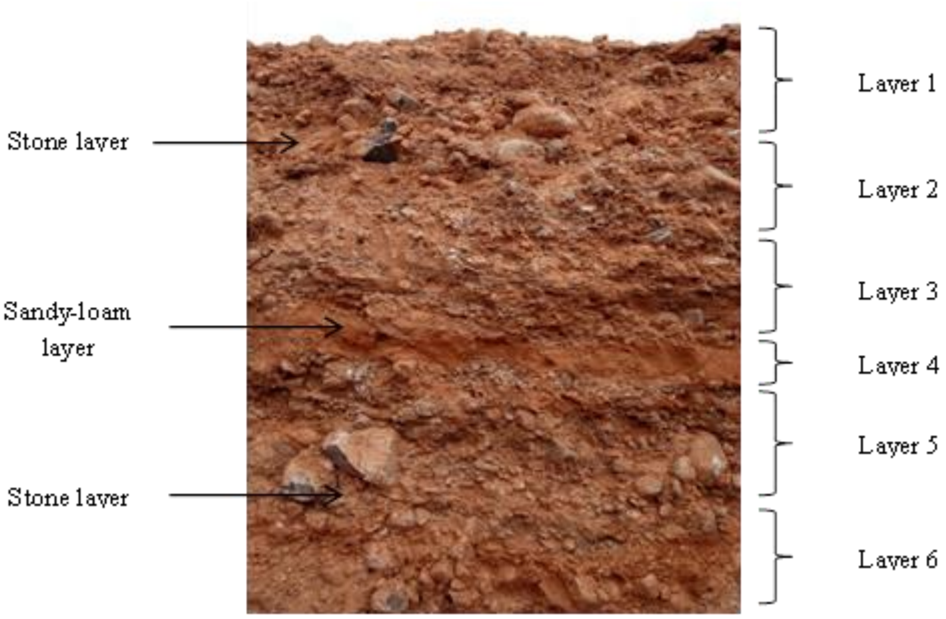


Fig. 2. Underground layers of the present study and composition

Underground temperature vertical distribution stays unchanged throughout the year and temperature increase by 30 °C each 1 km of depth [5].

Mihalakakou *et al.,* [6] present a complete model for the prediction of the daily and annual variation of ground surface temperature. Popiel *et al.,* [7] studied experimentally Poland underground temperature distributions between summers 1999 to spring 2001.

They divided the underground to 3 zones

i. Surface zone: (depth =1m), and directly affected by weather conditions.
ii. Shallow zone: (depth = 1- 20 m) where the ground temperature is almost constant.
iii. Deep zone: (depth = under 20 m) where the ground temperature variation is very slowly rising with depth according to the geothermal gradient.

Ground vertical temperature profile is a major key in designing earth to air or water heat exchanging technics based on renewable energy [8-27] and due to the leak of experimental studies and benchmarks for specialists and researchers especially for arid regions, we conduct an experimental study and in-situ measurement for ground vertical temperature profile.

3. Experimental Set-up

The experiment was carried out in two different sites in Bechar (South-West) of Algeria. The studies were carried out at +905 m altitude. Thermal sensors are used in this study. The time difference was less than 1 hour between the 2 sites to have a real time measurement. Climatic conditions were approximately the same (T, RH, etc.) where outside temperature was in the range of 38 °C .Based on soil layer rigidity, the depth step was selected. For example, 10 cm was the first site depth step due to the rigidity of soil and 5 cm for site n° 2 (agriculture site) until the depth reach 100 cm were 10 cm step because of temperature variation was negligible. The temperature sensors presented in figure 3 penetrate 10 cm inside soil layer and temperature measurements were taken each 10 seconds to eliminate the air temperature rising effect inside the sensor hall. It is observed that soil temperature stabilized after 70 seconds.

Fig. 3. Temperature sensor with 10 cm inside soil layer

3.1 Site n°1

The site is located in the north of the city of Bechar (figure 4) at 40 km from the centre of the city. The coordinate of the site are: 31.853821, -1.928988. This site was chosen for industrial activities which gives an idea about the soil nature. The soil in site n°1 is composed of several layers characterized by rigidity and bigger layer thicknesses in comparison with the soil in site n°2. This characteristic leads us to choose 10 cm step for depth.

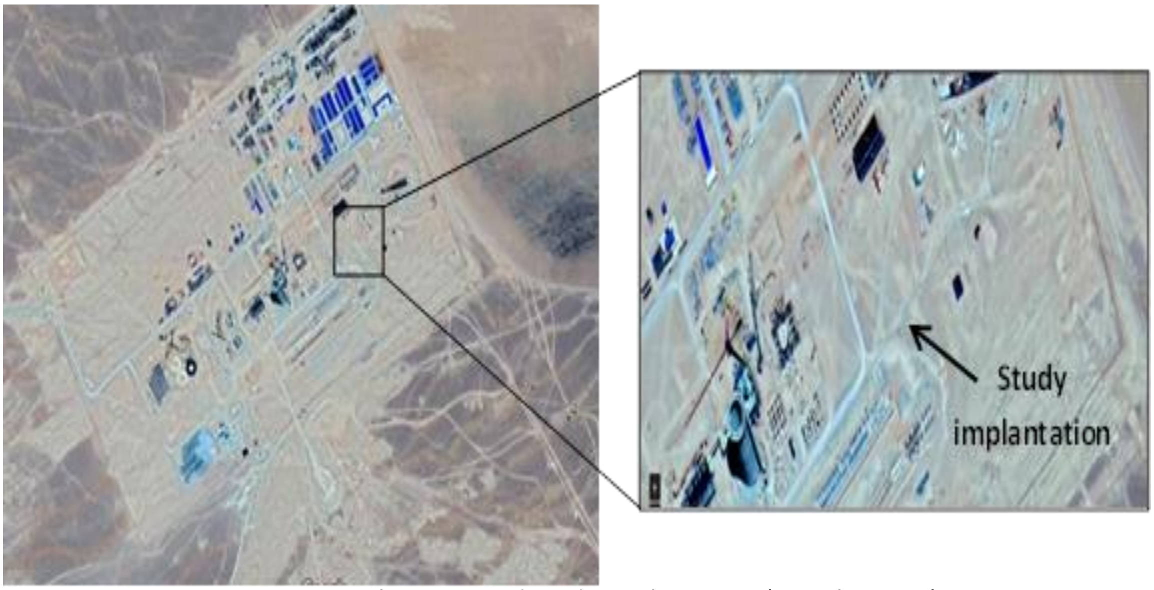


Fig. 4. Site n°1 location and study implantation (Google Maps)

3.2 Site n°2

The site is classified as agriculture zone activity (figure 5) located in the North-east of the city (31.644862, -2.167570). The soil layers were thin which allows as choosing 5 cm step. We remark the presence of plants roots and some layers contain some quantity of moisture which contributes in soil temperature rising in these specific layers.

Fig. 5. Site n°2 location and study implantation (Google Maps).

4. Results and Discussion

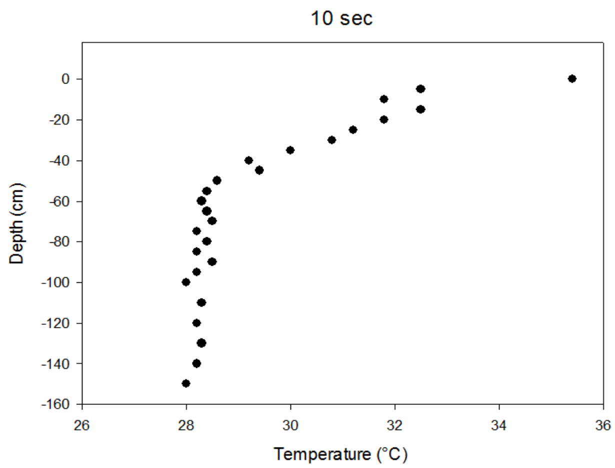
The results analysis of temperature vertical profile shows some few differences between the two sites according to

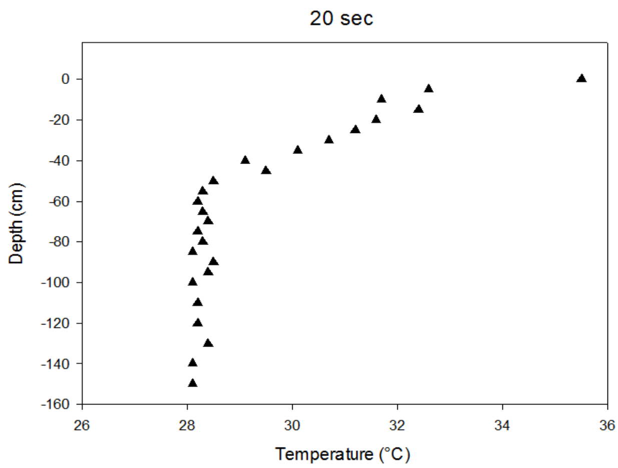
i. The nature and the composition of soil which site n°1 is a stone soil with different layers and site 2 is an agriculture zone.
ii. Geographical and geological properties of the two sites
iii. Human activity in both sites.

Ground vertical temperature profiles for the two sites progress is demonstrated every 10 seconds until it become stable after 70 sec. the results are presented in table 1 and 2. The graphs (figure 6 and figure 7) clarified the vertical temperature for different depth values.

Table 1
Temperature measurements for site n°1

Description		Site n°1		Time			13:16 (pm)
Location		North Bechar		Step			10 cm
Coordinates		31.853821, -1.928988		Sensor penetration inside soil			10 cm
Date		13/09/2018		zone activity			Industry
Step	10 s	20 s	30 s	40 s	50 s	60 s	70 s
0	35,1	35,2	35,3	35,2	35,3	35,2	35,2
10	34,7	34,6	34,5	34,6	35,0	35,1	35,2
20	33,1	32,7	31,8	30,8	30,9	29,7	29,5
30	29,7	29,6	29,5	29,6	29,5	29,4	29,3
40	29,7	29,6	29,7	29,6	29,5	29,4	28,9
50	29,6	29,5	29,6	29,7	29,7	29,6	29,5
60	31,7	31,8	31,9	31,7	31,8	31,7	31,6
70	29,5	29,6	29,5	28,9	28,8	28,7	28,5
80	26,7	26,6	26,5	26,6	26,7	26,6	26,5
90	27,5	27,4	27,3	27,4	27,3	27,2	27,3
100	28,5	28,4	27,2	27,3	27,2	27,3	27,4
110	28,7	28,8	28,7	28,8	28,9	28,8	28,8
120	29,7	29,6	29,5	28,9	28,8	28,7	28,1
130	29,4	29,5	29,6	29,5	29,5	29,4	29,4
140	29,8	29,7	29,6	29,5	29,2	29,1	29,2
150	29,2	29,1	29,0	29,1	29,2	29,1	29,2





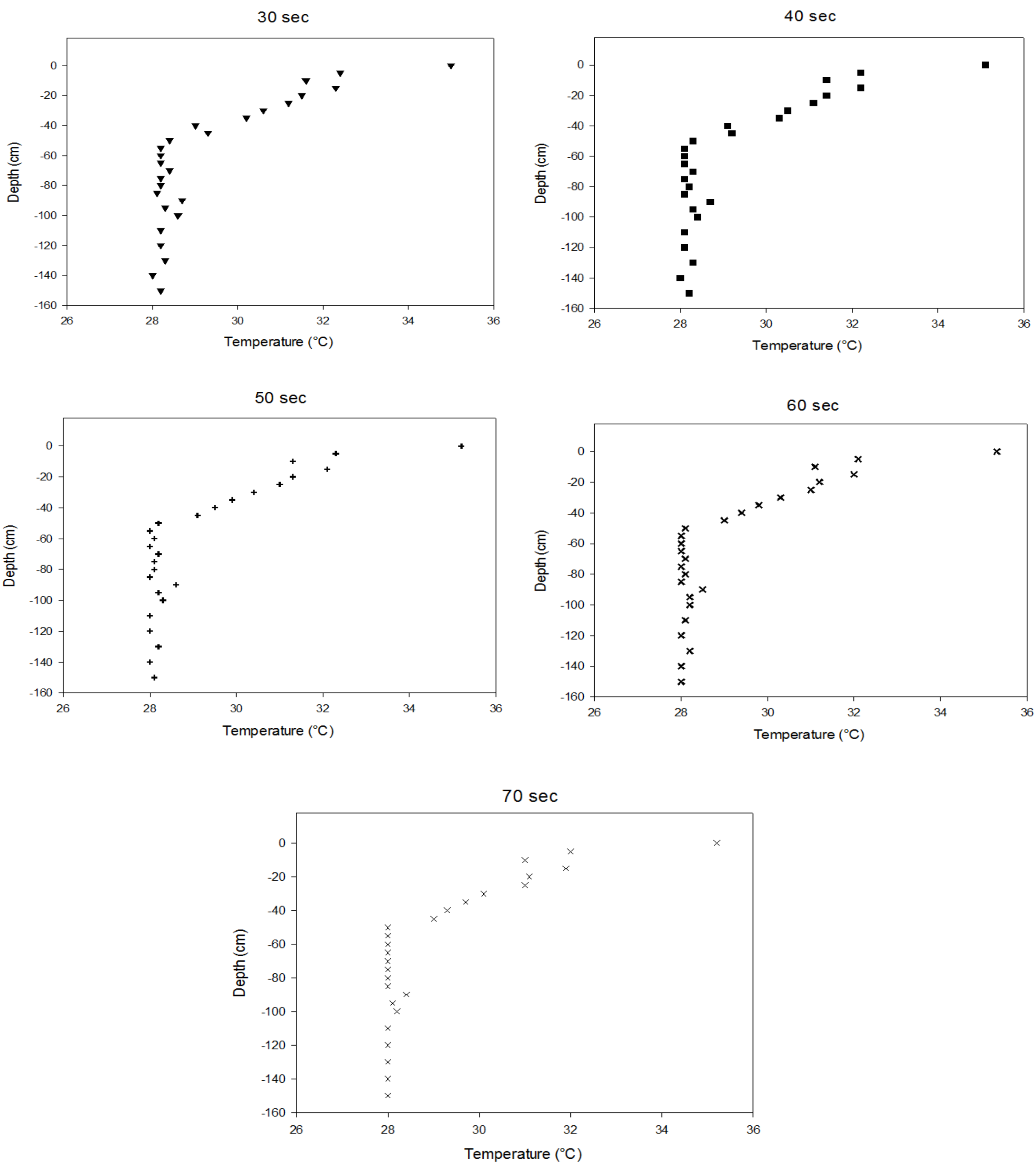
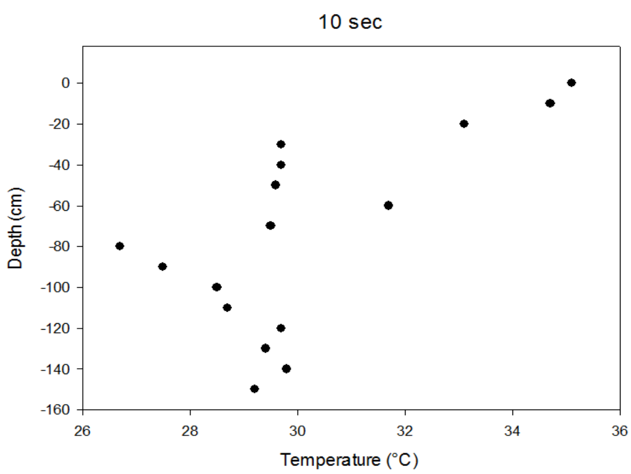
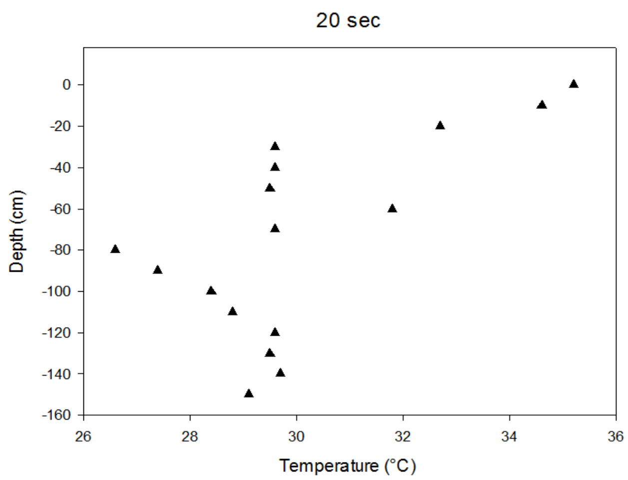


Fig. 6. Temperature measured values for site n° 1 (10 sec to 70 sec)

Table 2
Temperature measurements for site n°2

Description	Site n°2			Time			14:10 (pm)
Location	North-east Bechar			Step			5-10 cm
Coordinates	31.644862, -2.167570			Sensor penetration inside soil			10 cm
Date	11/09/2018			Zone activity			Agriculture
Step	10 s	20 s	30 s	40 s	50 s	60 s	70 s
0	35,4	35,5	35,0	35,1	35,2	35,3	35,2
5	32,5	32,6	32,4	32,2	32,3	32,1	32,0
10	31,8	31,7	31,6	31,4	31,3	31,1	31,0
15	32,5	32,4	32,3	32,2	32,1	32,0	31,9
20	31,8	31,6	31,5	31,4	31,3	31,2	31,1
25	31,2	31,2	31,2	31,1	31,0	31,0	31,0
30	30,8	30,7	30,6	30,5	30,4	30,3	30,1
35	30,0	30,1	30,2	30,3	29,9	29,8	29,7
40	29,2	29,1	29,0	29,1	29,5	29,4	29,3
45	29,4	29,5	29,3	29,2	29,1	29,0	29,0
50	28,6	28,5	28,4	28,3	28,2	28,1	28,0
55	28,4	28,3	28,2	28,1	28,0	28,0	28,0
60	28,3	28,2	28,2	28,1	28,1	28,0	28,0
65	28,4	28,3	28,2	28,1	28,0	28,0	28,0
70	28,5	28,4	28,4	28,3	28,2	28,1	28,0
75	28,2	28,2	28,2	28,1	28,1	28,0	28,0
80	28,4	28,3	28,2	28,2	28,1	28,1	28,0
85	28,2	28,1	28,1	28,1	28,0	28,0	28,0
90	28,5	28,5	28,7	28,7	28,6	28,5	28,4
95	28,2	28,4	28,3	28,3	28,2	28,2	28,1
100	28,0	28,1	28,6	28,4	28,3	28,2	28,2
110	28,3	28,2	28,2	28,1	28,0	28,1	28,0
120	28,2	28,2	28,2	28,1	28,0	28,0	28,0
130	28,3	28,4	28,3	28,3	28,2	28,2	28,0
140	28,2	28,1	28,0	28,0	28,0	28,0	28,0
150	28,0	28,1	28,2	28,2	28,1	28,0	28,0





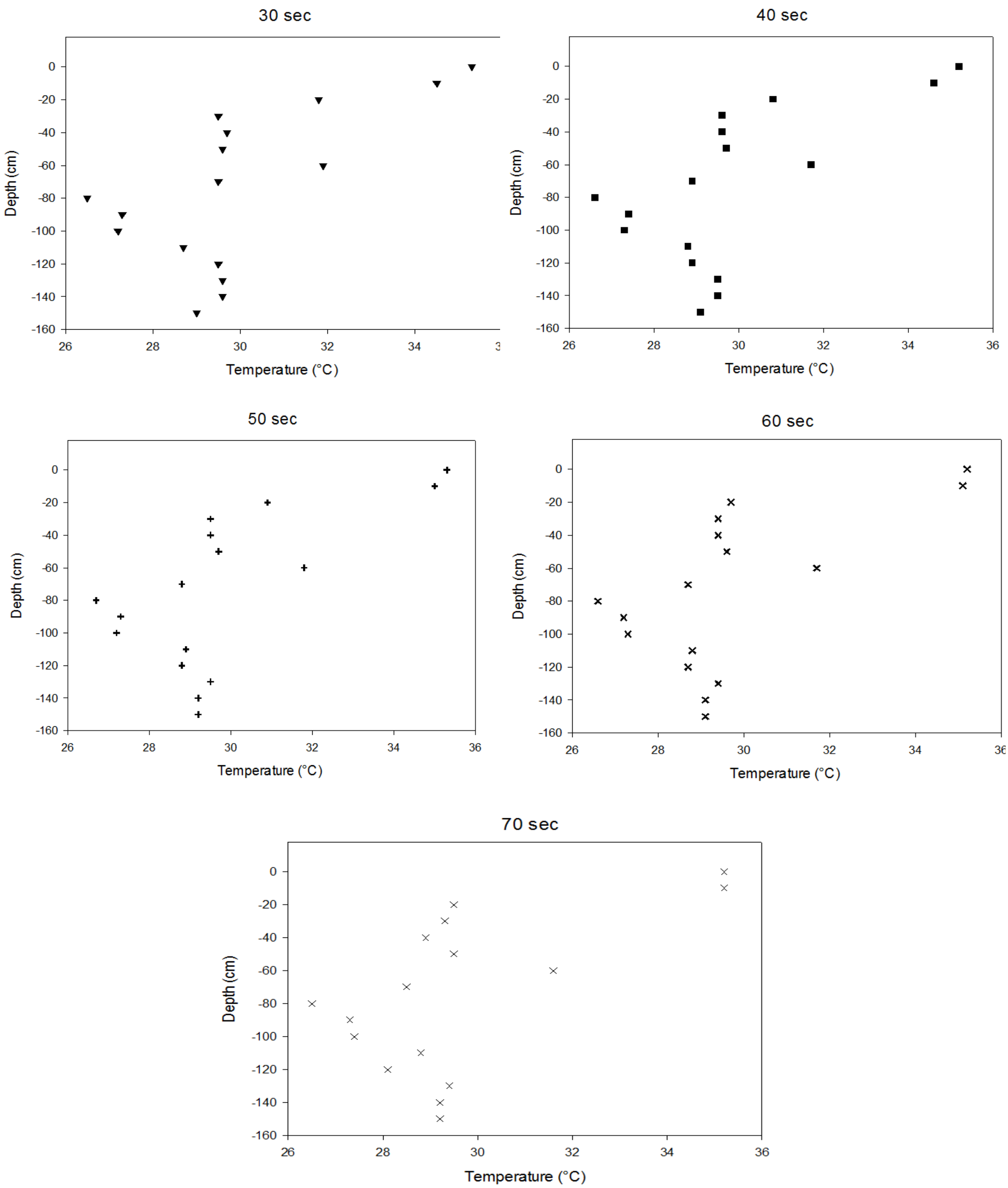


Fig. 7. Temperature measured values for site n° 2 (10 sec to 70 sec)

The results of the in-situ measurements shows that ground surface have approximately the same temperature (35.2 °C) for both sites and began to drop by increasing the depth in both cases of the study.

For the site 1, the temperature of the subsurface at 10 cm depth remains stable (35.2 °C). At 20 cm, it drops by 5.7 °C reaching 29.5 °C. Between 20 to 60 cm, temperature decrease value became stable (close to 0.4 °C). Soil temperature increase by 1.1 °C to reach 31.6 at 60 cm because of the presence of rock bed. At 70 cm, Temperature changes from 28.5 °C to 26.5 °C (80cm) in the level of thin sandy-loam layer with moisture. From 90 to 100 cm, temperature is in the range of 27.4 °C and begins to rise again until it reaches at 150 cm of depth 29.2°C.

Ground vertical temperature of this site described by instabilities and the amplitude of this variation is very significant. It is very important to precise the position of the heat exchanger to avoid soil temperature fluctuations and to limit instabilities in exchange medium (air or water) outlet temperature passing through the underground pipes.

The site n°2 is characterized by a remarkable stability. The surface is at 35.2 °C. At 10 cm deeper, the temperature drop by 4.2 °C and remain stable at 20 cm. In the level of 30 cm, the temperature reduction become stable (approximately 1 °C) until it become 28 °C at 50 cm. Under 50 cm, temperature become undisturbed where fluctuations are very small (between 0.2 and 0.4 °C). From 110 cm, soil temperature remains stable equal to 28 °C.

Site n°2 present bigger stabilities in comparison with the first site (Figure 8). In the scenario of installing a heat exchanger device with air or water, the medium outlet temperature remaining stable all around the year which is advantageous for pre-heating, pre-cooling or ventilation process. For site n°1 better results, it is recommended to place the heat exchanger device between 80 cm and 100 cm depth where temperature is in the range of 26.5 and 27.4 °C.

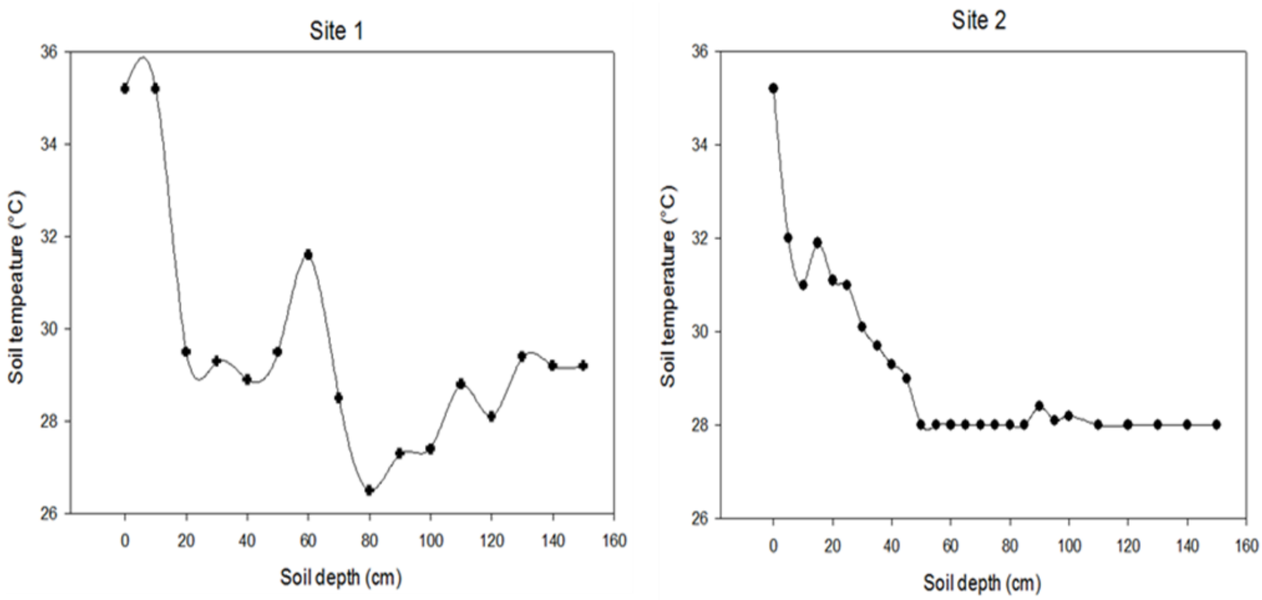


Fig. 8. Comparison of temperature measured values for the two sites.

5. Conclusion

Arid regions are characterized by larger thermal discomfort period (6 months) which has a significant effect on energy consumption (especially electrical). Reducing energy consumption increasing and ensure climate protection is an obligation of an investment in renewable energies based on natural resources available in arid regions among them: wind, solar, ground, etc.

Integrating Earth to Air or Water Heat Exchanger in thermal comfort providing process requires a deep understanding of this natural resources potentials and in particularly desert and arid regions.

Due to the leak of experimental studies about ground vertical temperature profile, the researchers always refer to mathematical models to calculate temperature at different depths which exclude the ground nature, composition, thermal properties, etc. effects on temperature variation and leads to inexact results.

In the present study, we conduct an in-situ measurement of vertical temperature profile of two different sites starting from ground surface until 1.5 m depth.

The results show clearly the effect of soil layer composition, presence of moisture and zone activity on temperature distribution.

The second site which is an agriculture zone presents a stable vertical temperature profile where temperature remains stable under 50 cm to 150 cm of depth in comparison with the first site who present underground temperature instabilities and bigger fluctuations.

Site n°2 present the advantage of using Earth To Air Heat Exchanger, Ground Air Collector, underground water canals or others techniques for pre-cooling or cooling in summer, pre-heating or heating in winter, and natural ventilation for greenhouses, offices and buildings.

The obtained results serve as a base for researchers and designers wiling to investigate the potential of using the underground as a heat sink or heat source for multiples activities.

For further studies, Authors will study with more details deeper vertical temperature profiles (under 1.5 m depth) and different soil types existing in arid regions.

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