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Ground Temperature Profiles in Los Humeros, Puebla, México for Ground Source Heat Pumps Applications

Fernando Rivas-Cruz[1], Alfonso García-Gutiérrez[1], Daniel González-García[2], Cesar Rosales-López[2]

[1] Instituto Nacional de Electricidad y Energías Limpias, Reforma 113, Cuernacava, Morelos, México, 62490

[2] Comisión Federal de Electricidad, Carretera Perote-Humeros km 23, Campamento Maxtaloya, Puebla, 73976

fernando.rivas@ineel.mx

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ABSTRACT

The knowledge of the temperature distribution and the thermal behavior of the ground is important for many projects, for example, to design thermal energy storage systems, to calculate heat losses in buildings, for analysis of biodegradation processes of organic substance, and the design of heat exchangers for Ground Source Heat Pumps (GSHP), among others. This paper presents the shallow ground temperatures profile measurements in Los Humeros, Puebla, México for GSHP applications. For this purpose, a borehole was drilled, and thermocouples were installed to a depth of up to seven meters. The ground temperatures were measured during the period between September 2016 and February 2018. The monitoring and temperature logging was carried out using a CR800 Campbell Scientific datalogger, configured with sampling times at thirty-seconds intervals, and data storage at 15 min intervals. The measured ground temperatures were at 22 °C at a depth of 0.1 m and increased from there onwards until they reached almost 52 °C at 7 m depth. The mean annual ambient air temperature is 12.5 °C. Shallow ground temperatures are predominantly influenced by the ambient air temperature and the marked temperature increase is due to the closeness of the experimental borehole to a geological fault.

1. INTRODUCTION

Information on the subsoil thermal behavior is important, not only for the construction industry but also for the determination of the capacity to thermal systems used for space conditioning in buildings, such as GSHP. It is well known that the underground temperature varies with depth, while on the surface, the soil temperature is affected by short time variations as well as seasonal effects.

Florides et al. (2011) state that in the deeper layers, the soil temperature remains almost constant throughout the seasons of year and is generally higher than that of the ambient air during the cold months of the year and lower during the warm months. Factors like orientation, soil, solar radiation, wind, rain, etc., can influence the subsoil thermal behavior and it is important to know how these factors affect it (Pouloupatis et al., 2011). Works like that of Popiel et al. (2001) mention that for engineering systems such as buildings, pipes, thermal energy storage, geothermal heat exchangers, etc., it is necessary to know the natural distribution of soil temperatures to determine the thermal interaction with the soil.

This work presents the results obtained from the measurement of temperature profiles in an exploratory borehole of 7 meters depth installed in Los Humeros, Puebla, México. The aim of measuring the temperature profiles was to understand the soil thermal behavior in order to design the first installation of ground source heat pumps in Mexico for the climatization of two buildings, a health clinic, and a kindergarten. The period of the information collected is from September 2, 2016 to February 23, 2018, with sampling periods of 30 seconds and data storage intervals at every 15 minutes.

2. LITERATURE REVIEW

The most important aspects and/or the conclusions obtained from some of the research works reviewed in relation to the monitoring of the subsoil temperature profile for GSHP applications are presented next.

Badache et al. (2015) evaluated the subsoil temperature profile to determine the energy balance equation as an input condition for the design of GSHPs. The model predicts the daily soil temperatures in different places such as Varennes (Montreal-Canada), Collins (Colorado), and Temple (Texas) in the USA comparing the experimental data from each site. For each site, to 31 m deep U-tube was installed, and at different depths placed 24 T-type temperature sensors were installed, and a data acquisition system (DAQ) recording every 5 minutes. The subsoil temperature profile is important in many technological fields such as solar energy systems and geotechnical applications.

Jizhong et al. (2015) presented a monitoring study on the migration of the groundwater flow field and the temperature field a GSHPs system connected with groundwater. This application was developed in Shenyang, the city where the GSHP systems are currently most widely used in China, with around 400 systems in use. The study monitored the temperature changes in the soil and the aquifers where GSHPs were installed using groundwater. By analyzing the information of the aquifers and the temperature curves obtained, the temperature behavior of different aquifers with GSHP systems was analyzed and reasonable distances between the pumping and injection wells were determined.

Junfeng and Meixiang (2015) monitored the subsoil temperatures in a vertical heat exchanger borehole. They used digital transmission systems to measure temperatures considered this technology as the most accurate, with high stability in the instrumentation, among other factors. The experiments showed a difference in temperature measured inside and outside the pipe of 0.05 - 0.1 ° C, which reflects the variation in the temperature of the formation. An advantage of using this technology can be the digital monitoring of the dynamic changes in geothermal fields and the distribution of measured temperatures for the development of geothermal energy. The conclusion of the scientific monitoring equipment and advanced technology is the basis for acquiring real high-quality data.

The seasonal evolution of temperatures throughout the year at different depths in Valencia, Spain was presented in ATECYR (2010). In this work, it is observed that as the depth increases, the amplitude of the thermal oscillations decreases, and their maxima and minima become out of phase. A three-dimensional representation is also shown that allows to obtain a global idea of the variation with depth, specifying that the temperature of the soil at certain depths (approximately 10 meters) remains constant and approximates the average annual temperature of the ambient air. The conclusion was that the deeper in the ground, the evolution of the temperature is dampened until it remains constant, depending also on the characteristics of the subsoil such as thermal conductivity and diffusivity, specific heat, etc.

Yasakawa et al. (2008) showed the results of measured temperatures and the performance of an experimental geothermal heat pump system to cool spaces in Thailand operating for 17 months in 2006. The temperature changes in the heat exchanger borehole were measured over an evaluation period, from the surface to 56 meters depth. Additionally, the thermal properties and the short- and long-term operating effects of the system on the surface thermal environment were measured.

Hepbasli et al. (2003) presented the annual variation of soil temperatures at different depths, from the surface to 50 meters of depth. They refer that the temperatures of soil in a particular place depend on the average ambient temperature, the oscillation of the annual temperature, and the soil type. In their work, the soil monitoring system was installed at Ege University, Izmir, Turkey.

3. EXPERIMENTAL STATION

3.1 Site Location: Los Humeros Village, Puebla state, México

To develop new capabilities and assimilate the technology of GSHP systems, the Instituto Nacional de Electricidad y Energías Limpias (INEEL) developed the first demonstrative project with GSHP, located in Los Humeros village, Puebla, México for heating two buildings using this technology.

The Los Humeros village is located near the Chignautla municipality, northeast of Puebla state on its border with the Veracruz state, approximately 30 km northwest of Perote city, Veracruz state (Rivas et al, 2020). The village is located right in the center of the productive area occupied by the Geothermal Field of Los Humeros, operated by the Federal Electricity Commission (CFE) in the geographical coordinates 19°40'43" North latitude and 97°27' 20.35" West longitude, at an average altitude of 2,810 meters above sea level. Figure 1 shows a picture from Google Maps with the proposed sites, one of them is a health center (red square) and the other place is a kindergarten (yellow square), (Rivas et al. 2018).

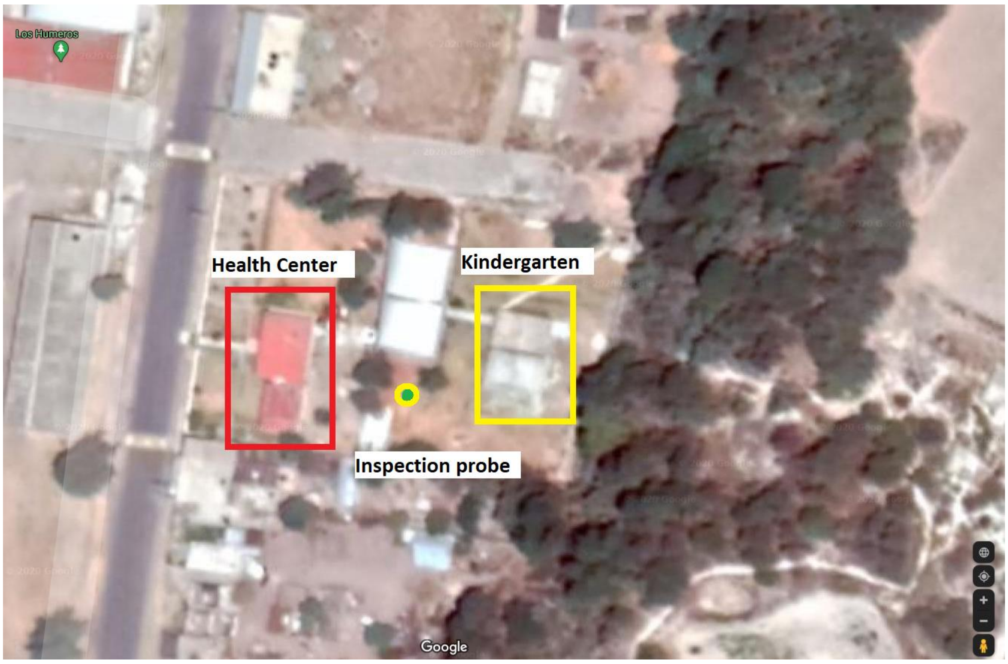

Figure 1: Location of two sites (Modified of Rivas et al. 2018).

3.2 Experimental station concept

Process measurement is essential to generate the best possible results about the use of resources, machines, performance, profitability, environmental protection, and safety. Many sectors need that processes have the implementation of monitoring and control systems to know the behavior process or allow maintaining the operation with great efficiency and flexibility (Rivas, 2006), by these reasons the data acquisition systems (DAQ) based on personal computers have taken great importance in the monitoring and automation of processes.

A DAQ is a system whose function is the control or simply record of one or more variables of a process. All DAQ acquire, store, analyze, present information, and control. Figure 2 showed the main configuration of DAQ.

- Stage 1. Sensor: measure an electrical or physical phenomenon, such as voltage, current, temperature, etc.
- Stage 2. Signal conditioning: convert the analog signal acquired of stage 1 to a digital signal.
- Stage 3. Data acquisition device: concentrates all signals conditioned to store or process the data.
- Stage 4. Application software: uses a graphical interface to visualize the process data online or offline.

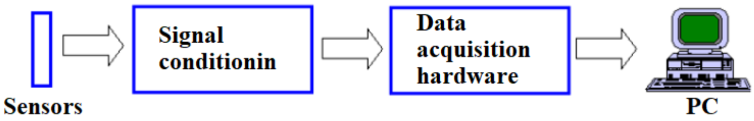

Figure 2: Schematic diagram of data acquisition systems (Rivas et al. 2018).

To implement the GSHP technology the knowledge the subsoil temperature profiles. To achieve this objective, it was required to install an inspection probe instrumented with temperature sensors type thermocouple placed every meter inside a borehole of seven meters depth. The location of the inspection probe is between the two buildings, shown in Figure 1 where the two GSHP systems were installed. Figure 3a describes the concept of the inspection probe instrumented with sensors. Figure 3 describes the concept of the instrumentation probe instrumented with sensors.

The DAQ system includes the temperature sensors, the CR800 equipment from Campbell Scientific, the serial communication, and the local system to measure the temperatures in the borehole, see Figure 4.

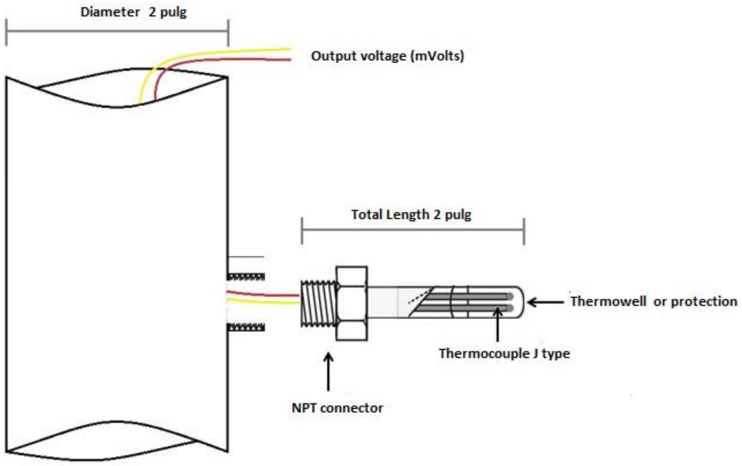

Figure 3: Schematic diagram of the Inspection probe instrumented with thermocouples (Rivas et al. 2018).

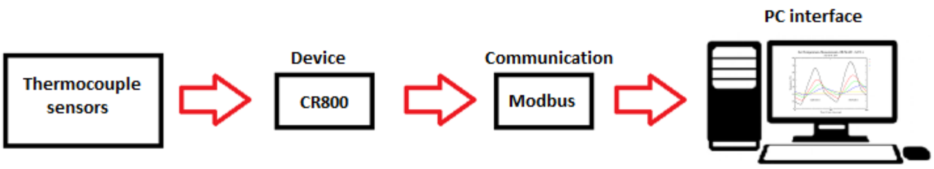

Figure 4: Schematic diagram of DAQ in Los Humeros, Puebla (Rivas et al. 2018).

4. RESULTS

The inspection probe was placed in a borehole of 7 meters depth, described below:

1. The borehole was built to a depth of 7 meters.

2. For the inspection probe, 2 pulg., diameter threaded steel pipes with various lengths are used and a total of 8 sensors integrated along the pipe to determine the soil temperature from depth 0.1 m to 7 m (T0 to T7), see Figure 3.

3. The DAQ is integrated with a CR800 device from Campbell Scientific, wiring with Modbus protocol, and a computer, used only the first time to start the acquisition data.

The Figure 5 presents the general diagram of the steps developed to measure the temperatures profile of Los Humeros, Puebla to know the behavior of soil in the Ground Source Heat Pump applications.

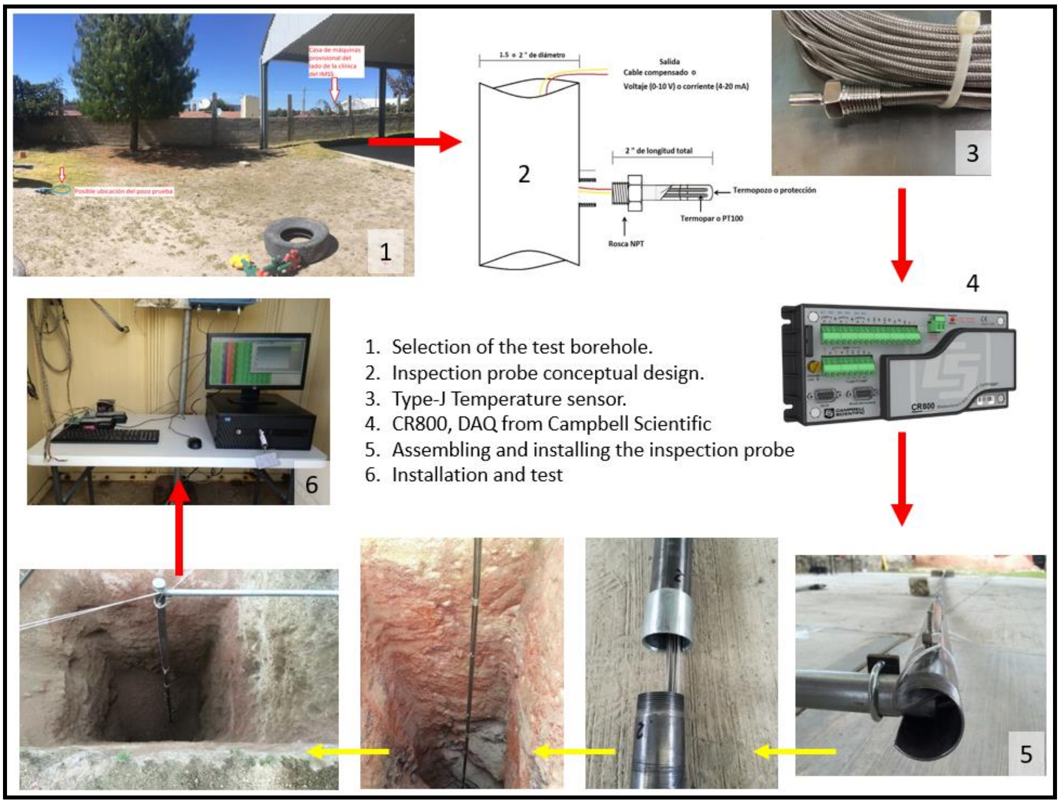

Figure 5: General diagram to measurement the ground temperature profiles (From presentation AGM 2018).

As a result of borehole jobs, data acquisition from the experimental station was started on September 2, 2016 and ending on February 23, 2018. Figure 6 shows the nine temperatures recorded being from T0 to T2 plus T_ambient, the superficial temperatures with a temperature between 11 to 27 ° C. The temperatures from T6 to T7, the deepest of the borehole show a considerable increase in temperature. For T6 starts with 16.6 ° C until 46.1 ° C, and the case of T7, starts at 21.5 ° C until it reaches 52.9 °C, this temperature behavior in this zone (including the Geothermal Field of CFE and Los Humeros village) occurs because are located inside a volcanic structure known as "Caldera de Los Humeros", at the eastern end of the physiographic province of the Mexican Neovolcanic Axis, limits with the Sierra Madre Oriental to the north and northeast, so when installing the inspection probe, the borehole is near to the geological fault, which causes the temperatures to increase as it deepens, see Figure 7.

Figure 6 described the history of the ground temperature:

1. On September 2, 2016, the inspection probe and two CR800 devices were installed, storing data of T_amb, T0 to T1, and T5 to T7.

2. On December 10, 2016, a third CR800 equipment was installed and the monitoring system was updated. With this, was integrate the nine temperature signals.

3. On March 20, 2017, the previous configuration (3 CR800) was replaced by only one CR800 and a multiplexor AN16/32B device, this form the information storage is more practical and the information processing is carried out in less time.

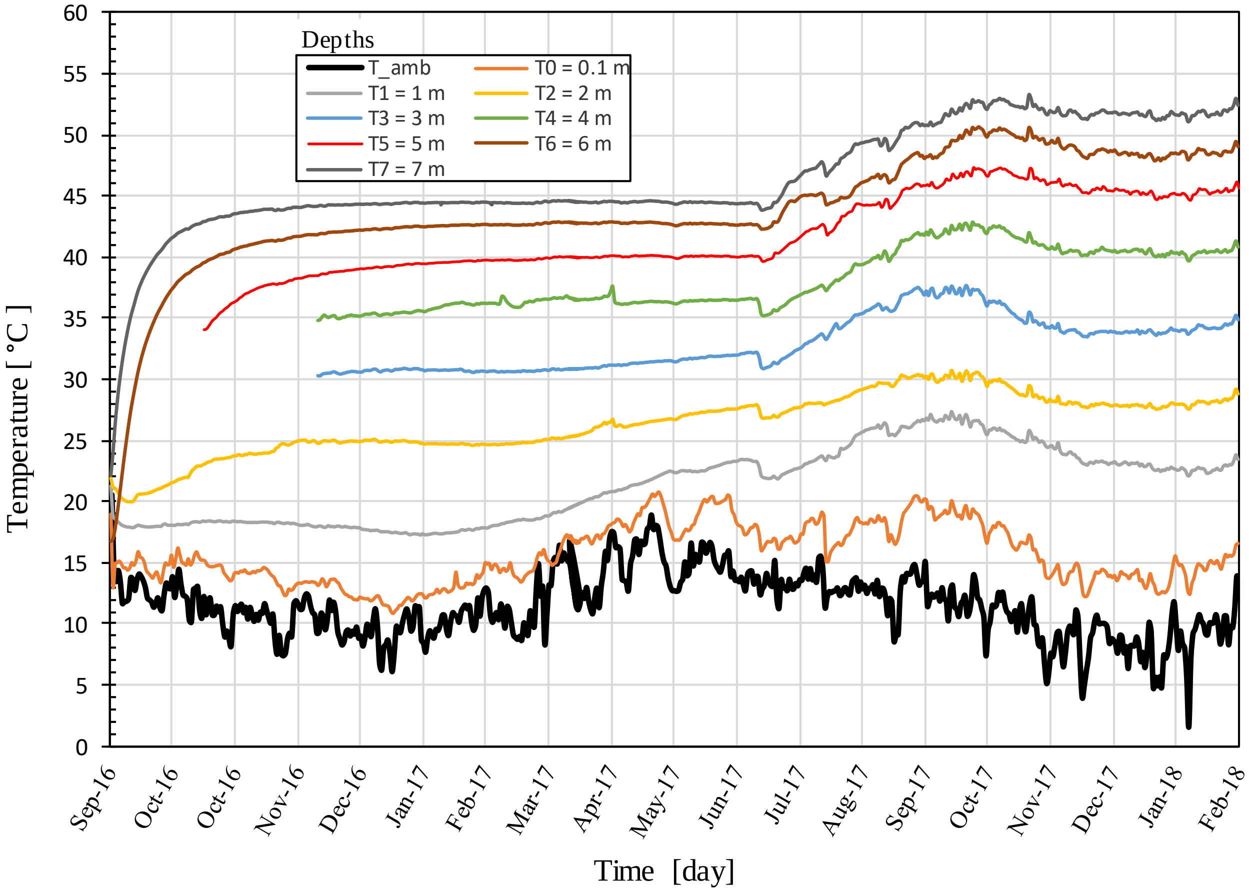

Figure 6: History of the ground temperature at various depths from September 2, 2016 to February 23, 2018 at Los Humeros, Puebla (Modified of Rivas et al. 2018).

Figure 7: Geological fault near of borehole (green).

Figure 8 present detail of the temperature behavior of some of the sensors from July 7, 2017, because was showed a decrease and later a large increase in temperatures (see Figure 6), there was probably a slight change in the subsoil, as mentioned above, it is a high zone of geological faults.

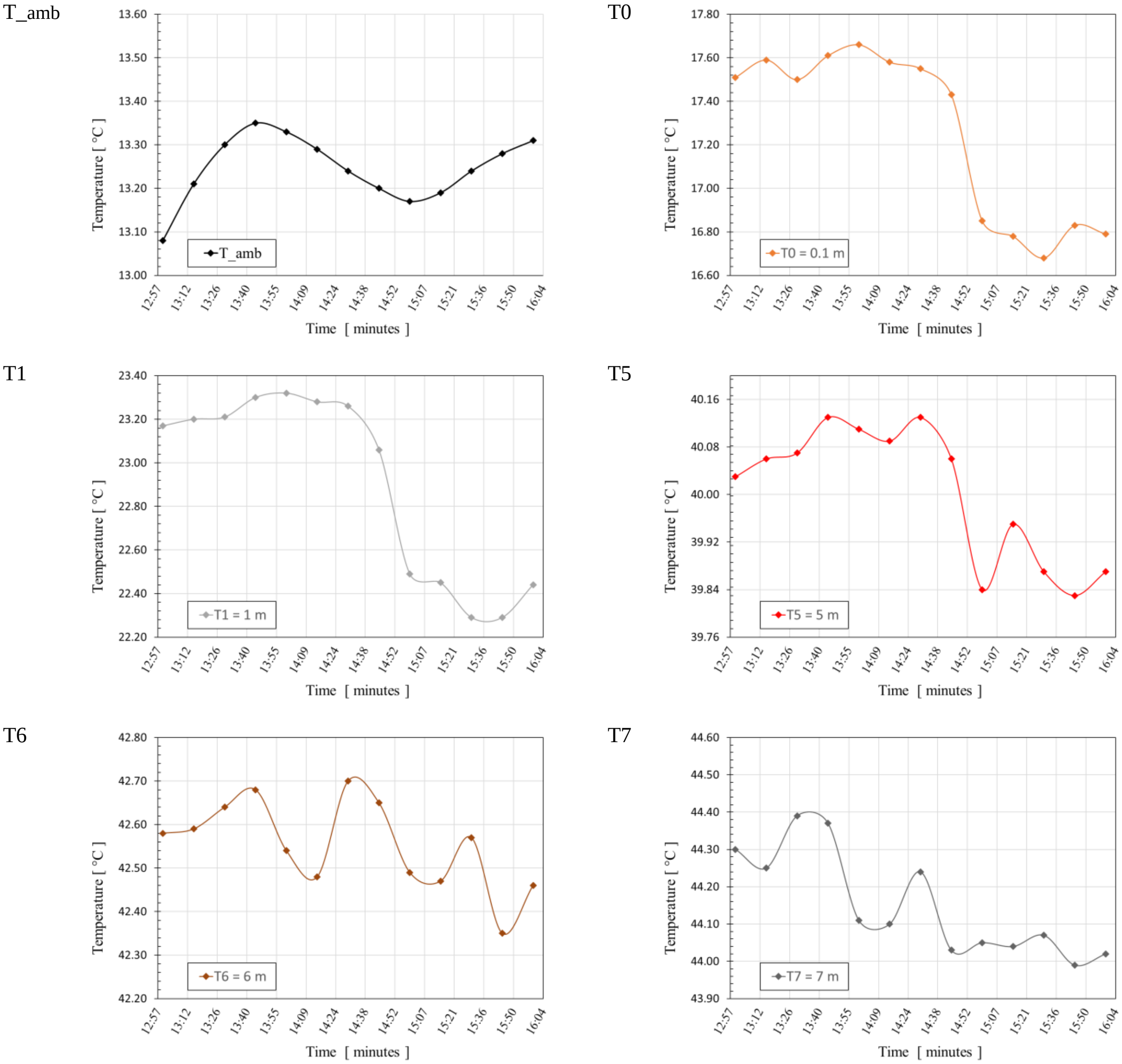

Figure 8: Details of change in the ground temperature on July 7, 2017.

Figure 9 shows the variation of temperatures as function of time for three days, from April 29 to May 01, 2017. The graph shows details of each temperature, highlighting the behavior shape of the ambient temperature with respect to time and climate. This graph is obtained from data monitoring with a sampling frequency of 1 minute and storage frequency 15 minutes. It is appreciated that the temperatures in the mornings 8:00 a.m. reach an average maximum temperature of 8 °C and the afternoons near 17:00 hrs a temperature of 25 ° C on average.

The temperature behavior as a function of depth is shown in Figure 10 which presents the temperature ranges of the eight sensors of inspection probe in the borehole. In (A) it is presented all months, in (B) and (C) details of the behavior are shown because as of July 9, 2017 there was probably a change in the subsoil due to existing geological faults and this caused an increase in temperatures.

5. CONCLUSIONS

Los Humeros area presents thermal anomalies that range from approximately 40 °C to 97 °C because of the interaction of high temperatures from a heat source of volcanic origin and the nearby location of an aquifer. The fluids find a favorable means to rise the surface through geological structures such as faults and fractures when a hydrothermal alteration in the rocks reached by the fluids. Superficially, this hydrothermal alteration is observed as reddish, purple and/or yellow coloration in the rocks and wet clay material in the cases with greater alteration effects.

From September 2, 2016 to February 23, 2018, 31780 data have been stored, with this information, reports and a database (BD) in Excel have been generated on the temperature behavior of the test borehole. Figure 10 shows the temperatures at different depths, the deepest ones are increasing, in a range of 40-54 °C, while the surface temperatures are in a range between 11-30 ° C. This behavior occurs since the well is located near a geological fault. The temperature ranges: T0 (0.1 m) = 11 - 21 °C; T1 (1 m) = 17 -

24 °C; T2 (2 m) = 20 - 30 °C; T3 (3 m) = 30 - 38 °C; T4 (4 m) = 34 - 43 °C; T5 (5 m) = 40 - 48 °C; T6 (6 m) = 43 - 51 °C and T7 (7 m) = 46 - 54 °C. The temperature ranges can be considered as a possible benefit in the performance of the ground source heat pumps to work in heating mode.

By last this is the first experimental study in México that measures the ground temperature profile to know one of the steps in the design of Ground Source Heat Pumps.

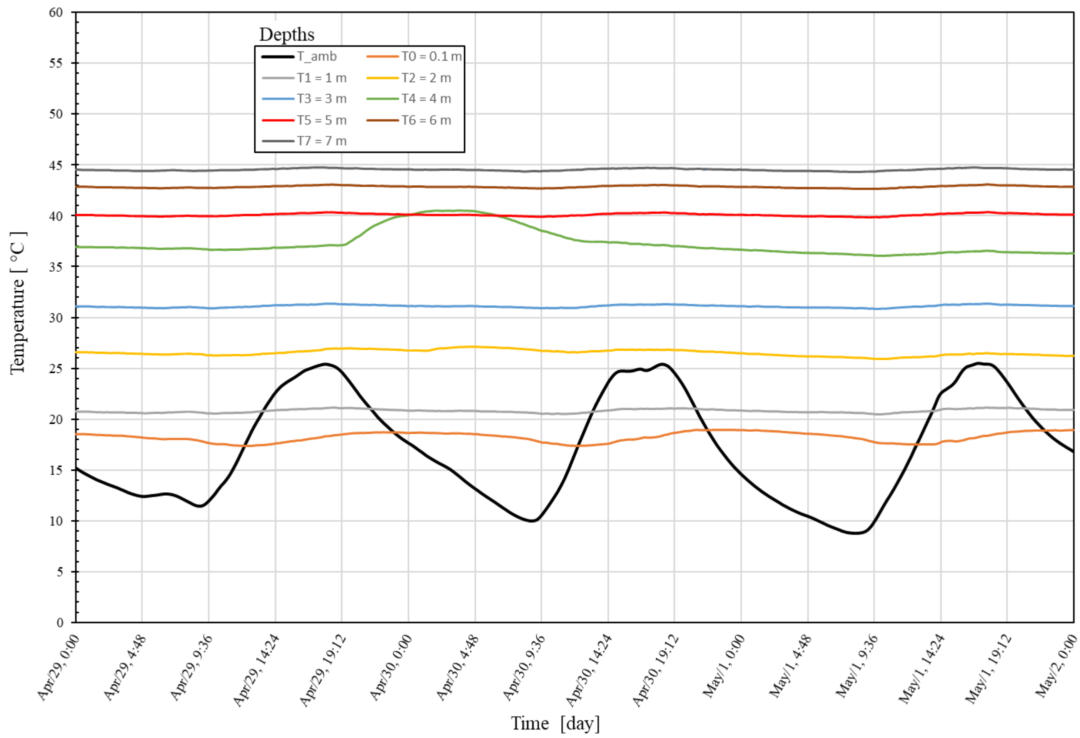

Figure 9: Detail of temperature behavior, 3 days (April 29 to May 1, 2017) 2018 (Rivas et al. 2018).

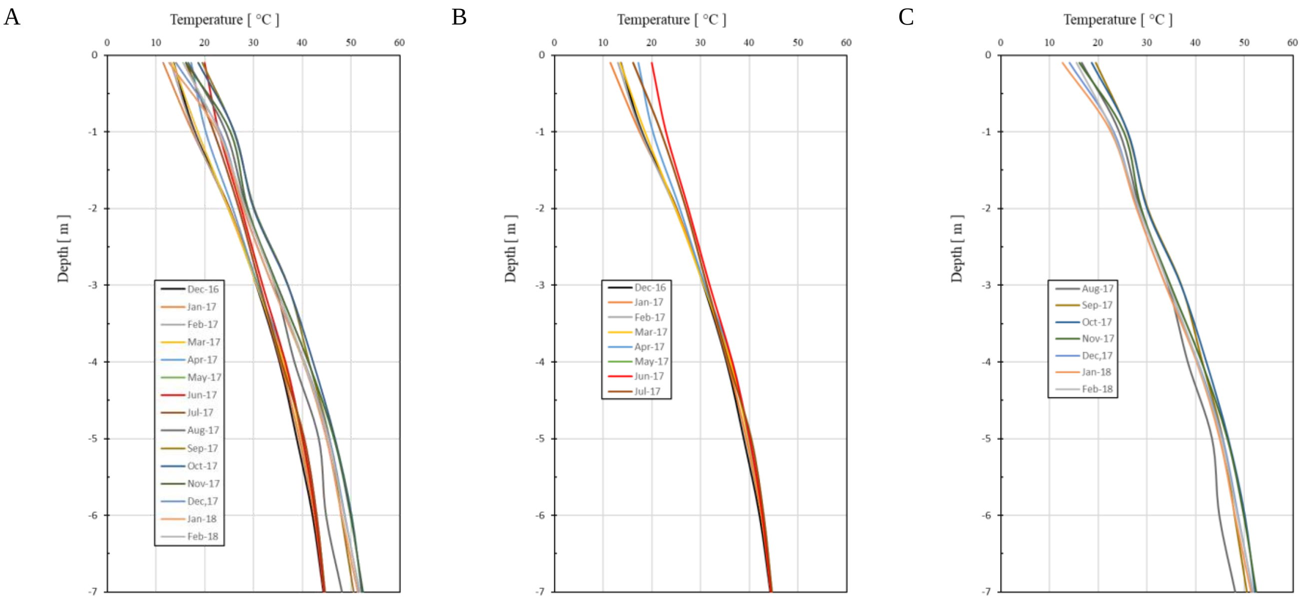

Figure 10: Ground temperature variations for a typical day on (A) December 2016 to February 2018. Details of surface zone activity are shown on (B) from December 2016 to July 2017, (C) from August 17 to February 2018. (Modified from Rivas et al. 2018)

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RECOGNITION

Ph.D. Alfonso García Gutiérrez and Ms.C. Daniel González García are recognized for the initial conception of the P13 CeMIEGeo Project, as well as, for their contributions to the analysis of temperatures profile.

REFERENCES

ATECYR.: Guía técnica de diseño de sistemas de bombas de calor geotérmica. Reporte. Asociación Técnica Española de Climatización y Refrigeración (ATECYR). Reporte, Instituto para la Diversificación y Ahorro de Energía (IDAE), Madrid, España (2010), 52 p.

Badache, M., Eslami-Nejad, P., Ouzzane, M., Aidoun, Z., & Lamarche, L.: A new modeling approach for improved ground temperature profile determination. *Renewable Energy*, *85*, (2016), 436-444.

Florides, G. A., Pouloupatis, P. D., Kalogirou, S., Messaritis, V., Panayides, I., Zomeni, Z., ... & Koutsoumpas, K.: The geothermal characteristics of the ground and the potential of using ground coupled heat pumps in Cyprus. *Energy*, *36*(8), (2011), 5027-5036.

Hepbasli, A., Akdemir, O., & Hancioglu, E.: Experimental study of a closed loop vertical ground source heat pump system. *Energy Conversion and Management*, *44*(4), (2003), 527-548.

Jizhong, D., Y. Ze, Y. Huiming.: Soil temperature monitoring and study of geothermal heat pump systems, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia, 19-25, (2015), April 2015.

Junfeng L. and Meixiang Z.: The ground temperature monitoring method of borehole pipe heat exchangers, *GRC* 2015, Melbourne, Australia, (2015).

Pouloupatis, P. D., Florides, G., & Tassou, S.: Measurements of ground temperatures in Cyprus for ground thermal applications. *Renewable energy*, 36(2), (2011), 804-814.

Popiel, C. O., Wojtkowiak, J., & Biernacka, B.: Measurements of temperature distribution in ground. *Experimental thermal and* fluid science, 25(5), (2001), 301-309.

Rivas-Cruz, F., Torres-Luna V., González-García D., Rosales-López C.: Performance Monitoring of a Ground source Heat Pump with a Horizontal GHE in Los Humeros, Puebla, México, WGC (2020) April 26 – May 2, 2020.

Rivas-Cruz, F., Onofre-Hilario F., Torres-Luna V., González-Reyes I., Fuentes-Torres R.: Measurement of the subsoil temperature profile in Los Humeros, Puebla for Geothermal Heat Pumps application, Mexican Geothermal Association, Morelia Michoacán, (2018), 18-20 abril.

Rivas-Cruz, F.: Design of a process monitoring station: application to a distillation column (Master's thesis, Centro Nacional de Investigación y Desarrollo Tecnológico. (2006), 96.

Yasukawa, K., Takashima, I., Uchida, Y., Tenma, N., & Lorphensri, O.: Ssystem performance of a geothermal heat pump for space cooling at kamphaengphet, thailand. In *Proceedings of the 8th Asian Geothermal Symposium*, (2008), December.