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DESIGN OF A COOLING SYSTEM FROM UNDERGROUND THERMAL ENERGY STORAGE (UTES, UNDERGROUND) THERMAL ENERGY STORAGE) BASED ON EXPERIMENTAL RESULTS

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Geothermal energy is a renewable and clean source that has been used for electricity generation in some countries since the 50s, the main characteristic to be used in this application is that the subsoil must have a high temperature geothermal resource (+150 °C). However, it can also be used in applications such as air conditioning in places where the temperature is around 30°C; In Europe alone, there are more than one million thermal installations operating by harnessing geothermal energy. The objective of the work was to design a cooling system from the storage of underground energy, for that, it is essential to know the variation of subsoil temperatures during a certain period of time. For this purpose, sensors were used that were installed at different depths and by means of an Arduino, information of a whole year was stored; so that these data are as representative as possible of the energy storage conditions and the changes depending on the seasons that pass. Additionally, the characteristics of the soil (conductivity, humidity and composition) were taken into account, where the equipment is intended to be installed in subsequent works. For the determination of the necessary cooling load, the design requirements of the ASHRAE standard were used and for the design of the underground heat exchanger, references of designs recommended through experimental tests in other research works are included, together with internal fluid methodology and one-dimensional heat transfer. It includes elements that can help improve the dissipation of energy into the subsurface and maintain transfer properties as stable as possible. This design is designed for the air conditioning of a classroom of normal dimensions that are used in the University and therefore avoid the energy consumption of conventional air conditioning equipment.

Keywords: geothermal energy, renewable source, underground energy storage, air conditioning

1 INTRODUCTION

Geothermal energy for electricity generation has been produced commercially since 1913 and for four decades at a scale of hundreds of MW for both electricity generation and direct use. [1]. Geothermal energy is an ideal candidate to dominate the energy industry in the future [2]. Geothermal heat pumps have the characteristics of being economical and energy saving, as well as offering environmental protection benefits [3]. These use the earth as a heat source for heating or as a heat sink for cooling, depending on the season. [4]. For all its advantages, information on the actual impact on groundwater temperatures is still scarce. [5, 6].

Drilling heat exchangers (BHEs) are widely used when there is a need to install sufficient heat exchange capacity under a confined surface, where the Earth is rocky near the surface. [7]. Initially, geothermal exchange systems were developed for heating in cold climates, consequently, their development in northern European countries, the United States and Canada, but they are also used for cooling, increasing their profitability and interest in South American countries. [8]. In cooling mode, heat is extracted from an enclosed enclosure and dissipated into the subsoil. [9].

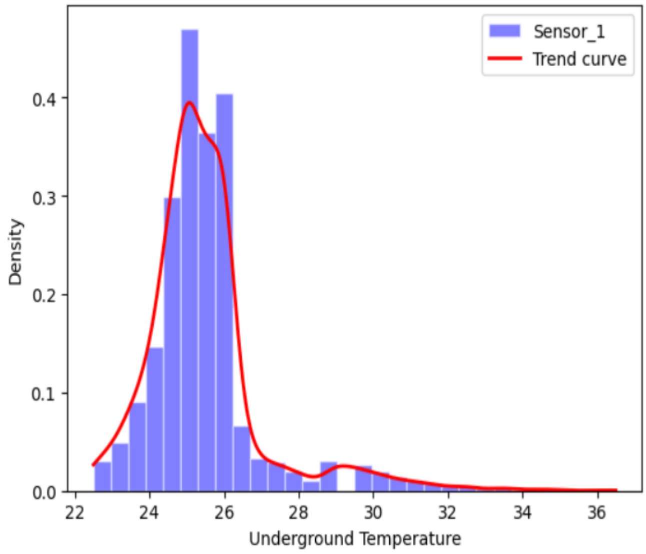
Our work shows the result of the performance of the design of a cooling system using the subsoil as an energy dissipator in regions of the coast of Ecuador, where the average ambient temperature is 31 ° C and the highest humidity period lasts 8 months. To determine the appropriate characteristics of the equipment, the actual values of the soil temperature at a depth of 3 and 5 meters. The period was from September 2020 to March 2022, because it was necessary to cover all the variations in temperature and humidity during the seasons of a year. With this information are considered, by installing thermistors and an arduino; and then proceed with the sizing of the cooling system and the respective simulation.

2 MATERIALS AND METHODS

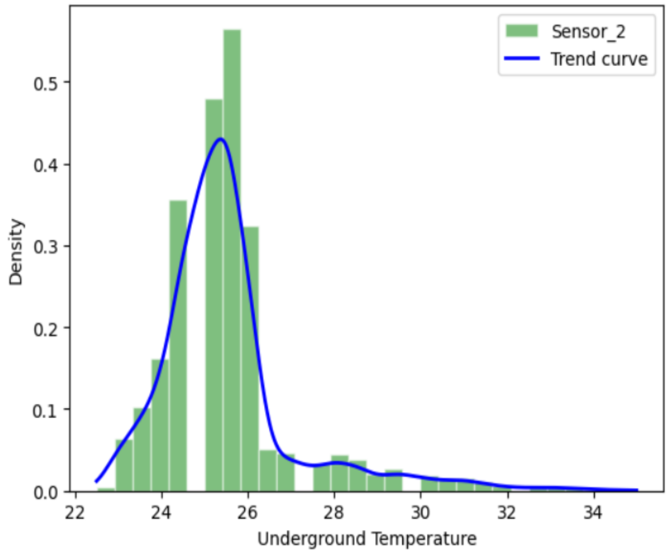
The experimental methodology consists of measuring subsoil temperatures at a certain depth (0.5, 1, 1.5, 2 and 2.5 meters). With these results, we proceeded to design and size the components of the refrigeration system for a refrigeration capacity corresponding to the area of a classroom of the University. Subsurface temperatures were recorded with the use of 4 PT-100 thermistors that have a measuring range between 10 °C to 200 °C and an accuracy of: ±1°C. Additionally, it is taken into account the use of an aqueous solution of ethyl alcohol to reduce the freezing point of the secondary fluid [10]. Once the measurements of the sensors were collected, they were tabulated (Table 1) and graphed where it was possible to verify that, according to [11], the temperature variation decreases with depth. The distribution of the values can be seen in the Figure 1.

Table 1. Underground temperature variation

Parameter	Sensor _1	Sensor _2	Sensor _3	Sensor _4	Sensor _5
count	3813	3813	3813	3813	3813
mean	25,46	25,50	25,19	24,89	24,88
std	1,62	1,61	1,42	1,30	1,22
min	22,50	22,50	21,00	20,00	20,00
25%	24,50	24,50	24,50	24,50	24,50
50%	25,00	25,50	25,00	25,00	25,00
75%	26,00	26,00	26,00	25,50	26,00
max	36,50	35,00	34,00	28,50	27,50



(1)



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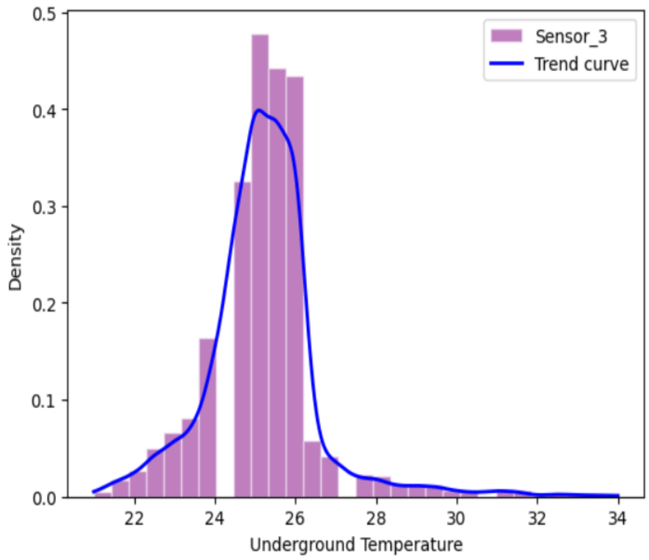

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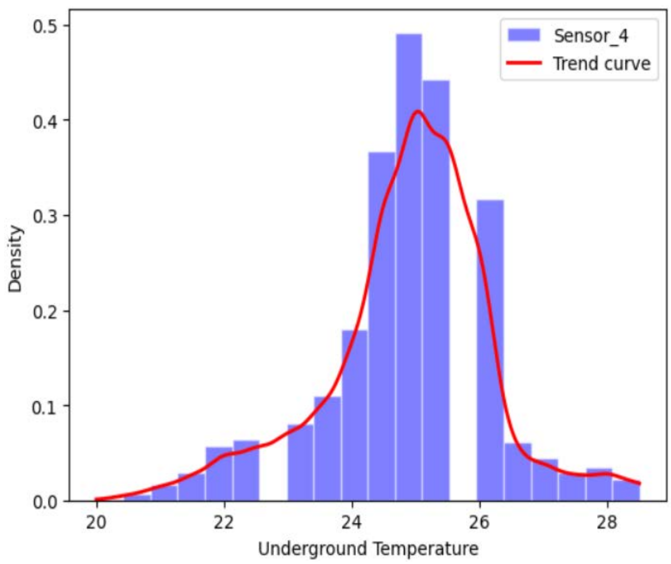

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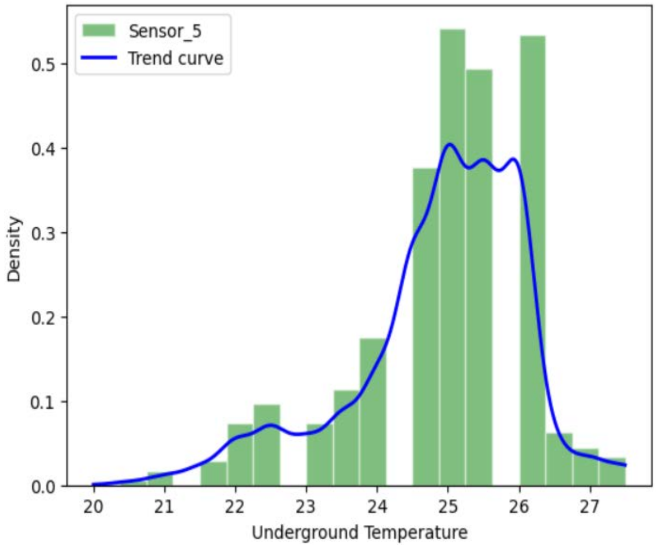

(5)

Fig. 1. Temperature variation at different depths: (1) 0.5m; (2) 1m; (3) 1.5m; (4) 2m; (5) 2.5m

3 RESULTS AND DISCUSSION

3.1 Calculation of thermal load

Based on the method of calculating load by differential temperature approved by the ASHRAE, for buildings with an area of 48 square meters and with an occupation of around 35 people, the thermal power of the air conditioning required is: 7 KW. With the previously determined thermal load, the operating parameters of the corresponding cooling cycle are established. The components that make up this cycle are represented in Figure 2.

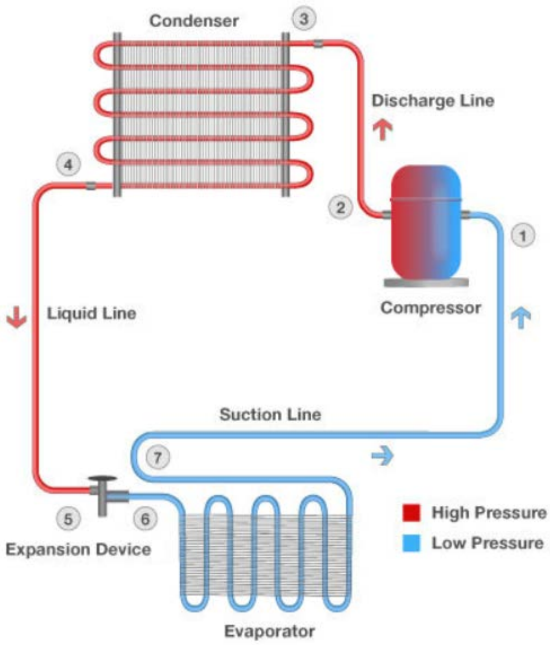

Fig. 2. Air conditioning cycle

The same way as in a conventional system, R410A refrigerant is selected, which is a good alternative for air conditioning in buildings and offices due to its capacity and its little impact on the environment. [12]. Table 2 shows the operating parameters of all elements of the refrigeration cycle for the calculated thermal load.

Table 2. Operating parameters of the air conditioning cycle

Operating parameters	
Refrigerant	R410A
Mass flow (Kg/s)	0,042
Cooling capacity (W)	7000
Power (kW)	1,95
COP	3,582

Operating parameters	
Subcooling temp. (°C)	6
Overheating temp. (°C)	7
Condensation temp. (°C)	45
Evaporation temp. (°C)	3

In our work the condenser is replaced by a heat exchanger of concentric tubes to counterflow, so that the heat extracted by the refrigerant fluid is exchanged with the water and this, in turn, dissipates that same heat in the subsoil, according to [13, 14].

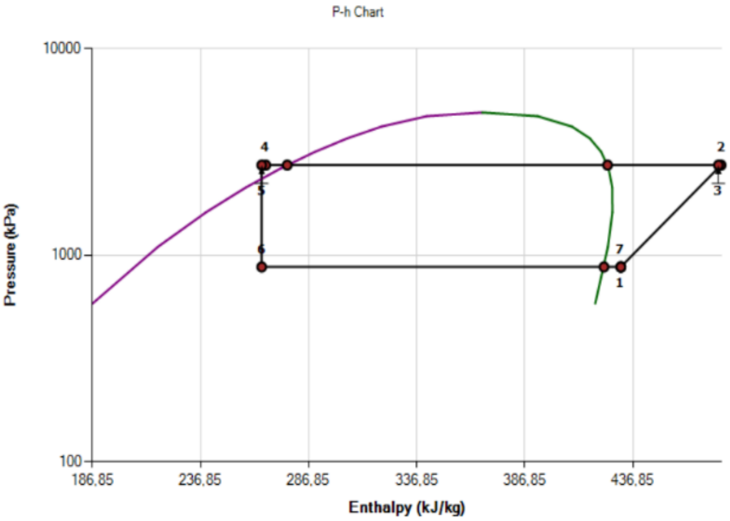

Fig. 3. Mollier diagram

The practical effectiveness of this equipment is proportional to the value that can be calculated experimentally. In this way it is expected to achieve better performance and efficiency because it takes advantage of temperature stability at a certain depth. Figure 3 shows the Ph or Mollier diagram for the case raised.

For the calculation of the condensing power, it is done by means of the product of the mass flow of the refrigerant by $\dot{m}_R$ the variation of the enthalpies between the inlet h_2 and outlet of the condenser h_5.

$$\dot{Q}_{cond} = \dot{m}_R \left(h_2 - h_5\right) \quad (1)$$

Therefore, the energy that the capacitor needs to dissipate is: 8600 W. To determine the inlet and outlet temperatures of the heat exchanger on the condenser side, the variation of subsurface temperatures is taken into account, consequently, the inlet temperature can be considered a value of 27 °C. The energy transfer of the water side can be calculated as follows:

$$\dot{Q}_{cond} = \dot{m}_{agua} \cdot Cp \cdot \Delta T \quad (2)$$

Where:
$\dot{m}_{agua}$ = *mass flow of water (Kg/s),*
Cp =*Specific heat of water (J/Kg.K),*
ΔT = *Variation of inlet and outlet temperature (°C).*

The mass flow corresponds to a 24 W pump, so the outlet temperature in equation (2) is: 31°C.

To calculate the area of the concentric tube temperature exchanger, the logarithmic mean temperature difference method can be used, as follows:

$$\dot{Q} = U \cdot A \cdot \left(\frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}\right) \quad (3)$$

Where:

U =Global heat transfer coefficient (W/m^2K),

A =heat exchanger area (m^2),

ΔT_1 =temperature difference between hot fluid inlet and cold fluid outlet (°C),

ΔT_2 = temperature difference between cold fluid inlet and hot fluid outlet (°C).

The area needed for that heat exchanger is: 0.11 m^2

3.2 Design of the underground heat exchanger

I agree [15–17], the most efficient design is the helical cylindrical shape, therefore, now the length of the pipe necessary to ensure the amount of energy to be dissipated to the subsoil must be defined. For this purpose, the heat transfer equation for tube flow is used:

$$\dot{Q} = h \cdot A_s \cdot \left(\frac{T_i - T_e}{ln[(T_s - T_e)/(T_s - T_i)]}\right) \quad (4)$$

Where:

h =Average convection heat transfer coefficient (W/m^2°C),

A_s =Surface area (m^2),

T_s =Surface temperature (°C),

T_i =Pipe inlet temperature (°C),

T_e =Pipe outlet temperature (°C).

$$Nu_{cil} = 0.3 + \frac{0.62 * Re^{\frac{1}{2}} * Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{28200}\right)^{5/8}\right]^{4/5} \quad (5)$$

Where:

D =pipe diameter (m),

k =pipe conductivity coefficient (W/mK),

Re =Reynolds number,

Pr =Prandtl number.

The resulting Nusselt number of (5) is equal to: 101.28 and therefore the overall heat transfer coefficient by convection is: h = 2491.54 (W/m^2°C). The pipe length of the underground exchanger is obtained by replacing the area in (4).

$$L = \frac{\dot{Q}}{h \cdot \pi \cdot D \cdot \left(\frac{T_i - T_e}{ln[(T_s - T_e)/(T_s - T_i)]}\right)} \quad (6)$$

According to [18, 19], the best efficient underground heat exchanger is the helical distribution pipe, in order to increase the area and time for heat transfer from the inside of the tube to the subsoil. For the pipe polyethylene was selected (diameter = 25 mm and thickness = 2.3 mm). With this information, the heat exchanger was designed. For pipes with internal flow, the resulting Nusselt number of (2) is equal to: 101.28 and, therefore, the overall coefficient of heat transfer by convection is: h = 2491.54 (W/m^2°C). With this information, the length of the pipe was 12m.

Figure 4 shows a representation of the heat exchanger, including the arrangement of the ground, bucket and grout.

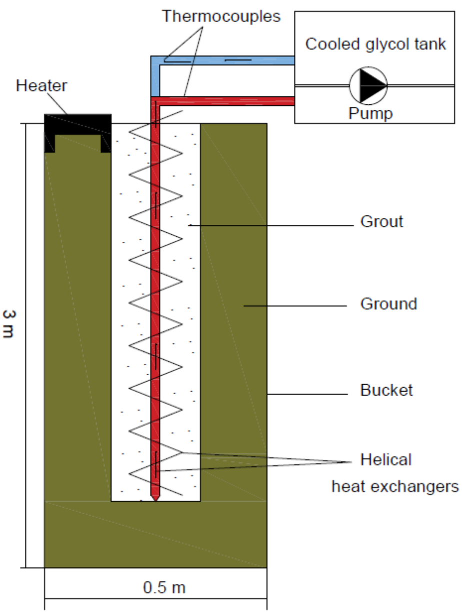

Fig. 4. Heat exchange

4 CONCLUSIONS

With the measurements of temperatures at certain depths, it was possible to verify as in other investigations, that with the increase of the distance under the surface the temperature of the soil tends to maintain a stable value regardless of the climatic conditions, and that this characteristic applies to practically all types of soil. Similarly, temperature variation also decreases with depth, which benefits for efficient heat transfer and, therefore, better performance of the cooling system (COP). However, conditions may occur where a thermal short circuit occurs. [20] and heat transfer is intermittent, however this phenomenon would not affect the design because its operation would be intermittent.

The design of the heat exchanger that replaces the conventional condenser represents an advantage for heat transfer conditions, but it is necessary to note that, in this case, a pump must be used that allows the flow of water throughout the underground pipe. However, given the required operating conditions, it should have a fairly low power and consumption (1/2 HP). Therefore, its consumption would still be lower than conventional equipment.

Since the proposed design is for air conditioning in cooling mode, the total length of the pipe is 12 m; which means that with the installation of the exchanger at the depth that the experimental procedure was carried out would be sufficient to ensure the required conditions, however, in case of needing greater energy requirements to dissipate, variables such as: the increase in the mass flow of the refrigerant can be modified. Similarly, to improve operating efficiency (COP) or reduce the variability of the outside surface temperature, a layer of insulation can be installed around it with certain conductivity conditions as recommended [18].

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