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An Analysis of the Geothermal Energy of Surface Water in Fátima do Sul, Mato Grosso do Sul, Brazil with an Emphasis on the Climatization of Buildings Environments

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Abstract

Investment in unrenewable energy sources has grown at a rapid pace during the beginning of the 21st century, and they may be exhausted by the middle of this century if this rhythm of consumption is maintained. Sustainable solutions have become a priority and the use of Geothermal Energy from Surface Water has attracted interest as a source of clean and renewable energy which can be used to climatize constructed environments. This article analyzes the surface water of a reservoir located in Fátima do Sul, Mato Grosso do Sul determining its temperature at depths of 0.3 to 1.5 meters (1 to 5 feet) using our own method which employs an *Arduino Mega 2560 R3, a free electronic hardware prototype with a single board. The results demonstrate an inverse relationship between the variation in the water's temperature* *and an increase in depth, or in other words, there are smaller variations in temperature at greater depths. This fact gives these waters the capacity to store heat, and thus it can be employed in heating and cooling constructed environments.*

Keywords: Geothermal energy with low enthalpy; Geothermal heat pumps; Water as a source of heat exchange.

1. Introduction

Recently the issue of sustainability has received great attention around the world in all areas of knowledge. Energy efficiency is among the main alternatives that are being prioritized given the variety of energy sources employed in climatizing constructed environments (Hughes, 2008; Raposo & Pinheiro, 2015), which for the most part still uses non-renewable energy for this purpose.

In Brazil, 53.9% of the energy matrix consists of non-renewable sources of energy. This total is even more of a concern when we look at the world stage, where this number surges to 86.1% (Empresa de Pesquisa Energética [EPE], 2020). This exacerbated use of non-renewable sources of energy has led to concern about its possible scarcity, as well as the effect of the greenhouse gases that they release into the atmosphere which aggravate climate change (Kanbur et al., 2001; Pereira, Horn & Dos Santos, 2010; Ferreira, Vieira, Da Silva & Da Cruz, 2017; Omido, Barboza & Moreira Júnior, 2017).

It is known that practically half of the world's oil reserves have already been used up, and if we continue at the same pace of consumption the rest will be used up in 50 years. Natural gas, for example, will last for 60 years, while coal which still has unexplored reserves, may last 250 years (Goldemberg & Lucon, 2007). In addition, between 2030 and 2050, the mean world temperature may rise by 1.5ºC (2.7°F) if we continue at the same rate of consumption (Intergovernmental Panel on Climate Change [IPCC], 2018).

Under this scenario, surface geothermal energy, a clean and renewable source of energy, has been attracting greater attention. This way of obtaining energy is being employed by various countries with different climates, but it has not been used widely in Brazil, mainly due to an absence of information and studies which demonstrate the viability of its use in this country (Fonseca, Casalini, Tucci & Battisti, 2014).

2. Surface Geothermal Energy

Geothermal energy, in its literal sense, is energy that is stored underground in the form of heat that comes from underground movements of the Earth's water, its nucleus and mantle, and mainly solar radiation which can be converted into electricity or thermal energy (Barbier, 2002; Ferreira, 2013). According to Trillo and Angulo (2008), geothermal energy has attracted a lot of attention, given that it can be used for a variety of purposes and is also considered one of the largest existing sources of renewable energy.

Geothermal energy can be divided into four categories in terms of its enthalpy, each of which has its respective use:

Text Table 1 - Classification and Utilization of Geothermal Energy

Geothermal Energy		
Enthalpy	*Temperature (°C)*	*Utilization*
High Enthalpy	≥ 150	Generating electricity through water vapor
Medium Enthalpy	90 ≤ T < 150	Generating electricity
Low Enthalpy	30 ≤ T < 90	Used for thermal purposes in direct and indirect ways
Very Low Enthalpy	T < 30	Used for geothermal heat pumps

Source: Adapted from Trillo and Angulo (2008).

According to Text Table 1, high and medium enthalpy geothermal energy are used to produce electricity, since they have greater geothermal potential precisely due to the fact that they are obtained at great depths under the ground, and thus require geothermal plants for their extraction. Unlike these forms, very low enthalpy energy is used to heat and cool constructed environments for recreational and leisure purposes, given that it has less geothermal potential because it is extracted from depths close to the surface, and thus requires a ground source heat pump (GSHP) for its extraction.

The extraction of very low enthalpy geothermal energy through ground source heat pumps (GSHP) is one of the most efficient ways of climatizing constructed environments. It consists of a heat exchanger, a pipe system, and a heat pump which is responsible for transferring the thermal energy from the circuit to the pipes (Self, Reddy & Rosen, 2013).

Heat pumps, known as thermal machines, transfer heat from a cool source to a warm source through vapor compression cycles. Their importance comes from their wide range of applications, which includes in this context, the transfer of heat between buildings and the outside environment, or in other words, the heating and cooling of the constructed environment (Naicker, 2015).

The vapor compression cycle consists of a change in its physical state to a liquid which is found inside the heat pump in the evaporator and condenser compartments, as can be seen in Figure 1. Normally a refrigerant liquid is selected in accordance with the type of GSHP being used (Self et al., 2013).

Figure 1 - Vapor Compression Cycle.

Source: Adapted from the Efficient House (2021).

Figure 1 highlights the heating of a constructed environment in which the heat pump used to climatize the environment functions in the following manner (Self et al., 2013):

I. The refrigerant liquid in the first circuit removes the heat from the external environment (a heat source which could be water, the ground, or the air), transporting it to the evaporator where the first energy exchange takes place, which transforms the refrigerant liquid in the heat pump into low pressure vapor (evaporation);

II. The vapor passes through a compression process within the compressor, which increases its pressure producing high temperature and high pressure vapor;

III. This vapor, in turn, is transported to the condenser, where it is cooled and condensed (condensation), producing a high temperature and high pressure liquid;

IV. The refrigerant liquid in the secondary circuit, installed in the constructed environment, captures the heat of the high temperature and high pressure vapor, sending it to the constructed environment that we wish to heat (diffusion of heat);

V. Finally, the refrigerant liquid in the heat pump circuit is submitted to an expansion process in the expansion valve, reducing the pressure which results in a low temperature and low pressure liquid, making it possible to restart the entire vapor compression cycle.

The efficiency of a heat pump is represented by the coefficient of performance (COP), which takes into consideration the quotient between the quantity of heat produced by the heat pump and the quantity of electricity needed for this process. This performance mainly depends on the configuration and size of the adopted system, the ground's characteristics, and climatic conditions, which can present values between 3 and 6 (Lopes, 2014).

In this sense, the capture of surface geothermal energy can be accomplished through an open or closed GSHP system (European Geothermal Energy Council [EGEC], 2015). Open GSHP systems work directly with underground water (the water table) or surface water (a lake, lagoon, river or creek), in accordance with Figure 2.

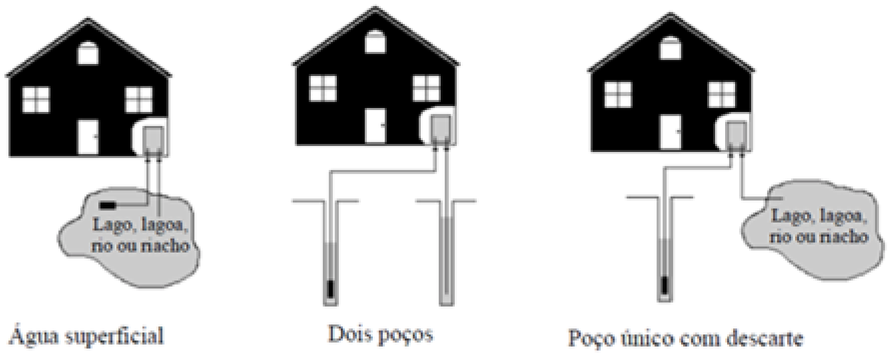


Figure 2 - Open Circuit System.
Source: Adapted from Swenka (2008).

In these open circuit systems, the water is extracted by the primary circuit, and then passes through the heat pump, and can be disposed of in the source itself, as we can see in Figure 2 for "*surface water*" in which the water is extracted from a lake (lagoon, river or creek) and returned to the same environment. In addition, water can also be disposed of in another location distinct from where the water is extracted as we can see in Figure 2 for "*two wells*" and "*single well with a disposal*", where the water is extracted from a well and sent to another well or to a lake (lagoon, river or creek) respectively. This is a system with a low implementation cost, but requires greater attention in terms of the water quality and system maintenance (Swenka, 2008).

In closed GSHP systems, the transfer of heat occurs by passing the refrigerant liquid through a pipe system installed underground or underwater. This heat transfer which goes from the ground (or the water) to the edifice, or from the edifice to the ground (or water), depends on the season (Swenka, 2008; Ramalho et al., 2014). According to Brandl (2006), in closed systems, pipes can be installed vertically or horizontally, as can be seen in Figures 3 and 4.

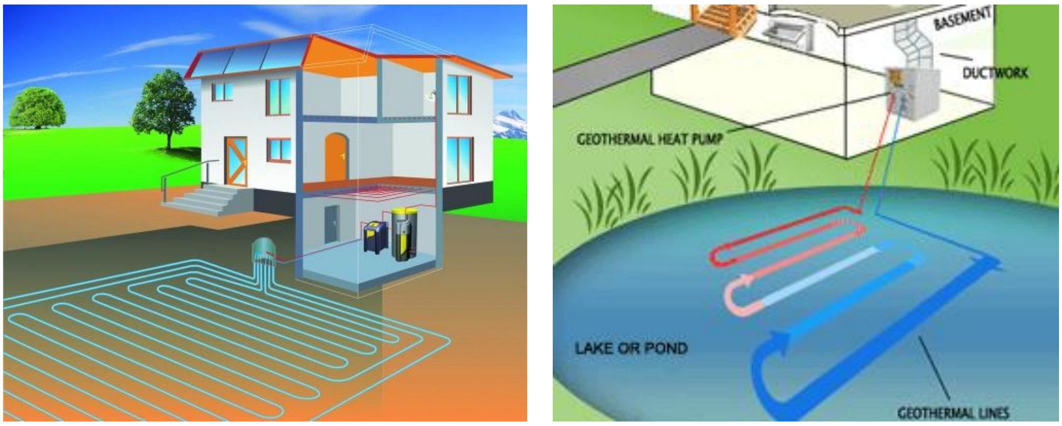


Figure 3 - Horizontal Closed Circuit Systems in the Ground and in the Water.
Source: Biomass Geothermal Energy (2017) and Ingram's (2021).

A horizontal closed system (Figure 3) normally is installed in places which have a large amount of space available (Rio, 2011) with a depth between 1.2 and 2.0 meters (4 to 6.5 feet) (Sanner, 2006). The advantage of this system is its low cost installation (Marzbanrad, Sharifzadegan & Kahraman, 2007).

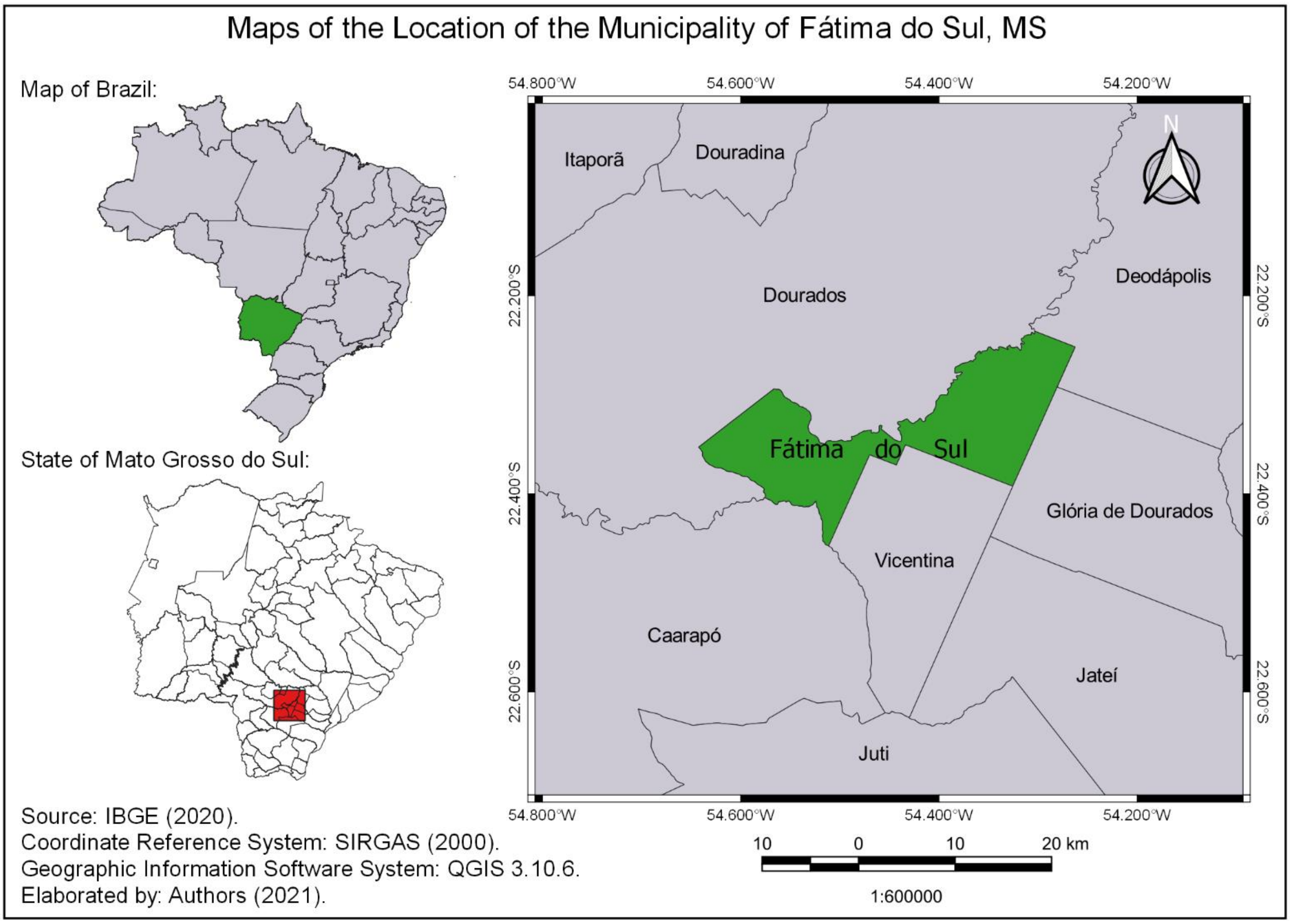
Figure 4 - Vertical Closed Circuit Systems in the Ground and in the Water.
Source: Rodríguez (2015) and Geo Journal (2009).

A vertical closed circuit system (Figure 4) is required when there is not that much space available. Thus, the advantage of this system is the space needed for the installation, which is much smaller compared to the horizontal system. On the other hand, the installation of a ground system is expensive, because there's the need to make holes (Rio, 2011), while a surface water installation is less expensive.

This article seeks to trace the profile of water in a reservoir located on a private property in Fátima do Sul, Mato Grosso do Sul to provide a base for the installation of auxiliary climatization systems which employ surface water as a source/dissipator of heat. The intent is to contribute to the widespread utilization of surface geothermal energy using the installation of heat pumps, since in Brazil these systems are predominantly used for tourism and recreation.

3. Methodology

This study was developed in the city of Fátima do Sul, Mato Grosso do Sul, Brazil, located in the Greater Dourados region, specifically at the coordinates of 22º 22' 26" S and 54º 30' 50" W (Figure 5). Fátima do Sul is 248 km (154 miles) from the state capital Campo Grande and its altitude is 352 meters (1,155 feet). It has a tropical climate characterized by a rainy summer and a dry winter, with average annual precipitation ranging from 1500 to 1700 millimeters (59 to 67 inches), and an average annual temperature which varies from 22ºC to 24°C (71.6°F to 75.2°F) (Instituto Nacional de Meteorologia [INMET], 2020).



Maps of the Location of the Municipality of Fátima do Sul, MS

Source: IBGE (2020).
Coordinate Reference System: SIRGAS (2000).
Geographic Information Software System: QGIS 3.10.6.
Elaborated by: Authors (2021).

Figure 5 - Location of Fátima do Sul, Mato Grosso do Sul.
Source: The authors (2021).

The predominant soil is Red Oxisol (84.98%), and there is also a portion of Haplic Gley (15.02%) (Brazilian Institute of Geography and Statistics - Environmental Information Database [IBGE-BDIA], 2020), as can be seen in Figure 6.

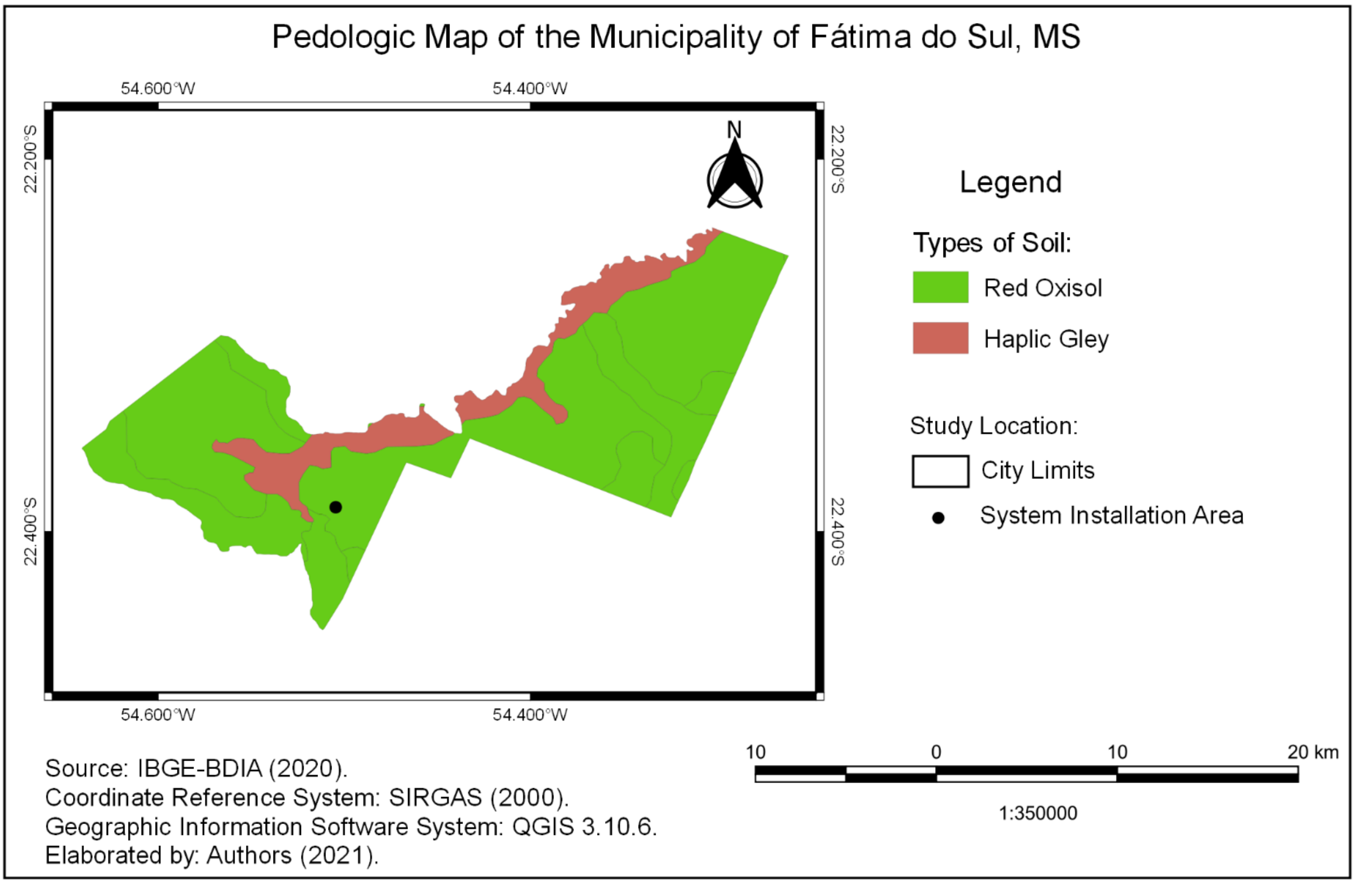


Figure 6 - Map of the Types of Soil in Fátima do Sul, Mato Grosso do Sul.
Source: The authors (2021).

The setting up and installation of the device responsible for collecting and storing ambient temperature readings at different depths in the reservoir was performed on June 30, 2018. The reservoir where the study took place is on a private property located at Avenida 9 de Julho n° 3181, where the type of soil is classified as Red Oxisol (Figure 6).

Water temperature data (from the reservoir) had to be acquired through digital sensors and later was correlated with the ambient temperature to analyze the thermal behavior of the water, and we opted to use the quantitative method described by Pereira, Shitsuka, Parreira & Shistsuka (2018).

To monitor the water temperature, we installed two DS18B20 temperature sensors at different depths. The first, which was closer to the center of the reservoir, was taken at a depth of 1.5 meters (5 feet), and the second, close to the edge of the reservoir, was taken at a depth of 0.3 meters (1 foot). A third temperature sensor was installed next to a shed to take the ambient temperature reading. In Figure 7 you can observe the temperature collection points on the property.

Figure 7 - The Property and the Location of the Temperature Sensors.
Source: Google Earth Image (2018).

The data acquisition and storage device consists of a waterproof DS18B20 temperature sensor, a Mega 2560 R3 Arduino board with a USB cable, a 9V power supply, an 830-point prototyping board with jumper cables, a Cat E6 ethernet cable, and 3 modules: DHT22, RTC DS3231 and the Micro SD Card (with a capacity of 8 gigabytes). The first of these items is responsible for collecting the ambient temperature and humidity readings in a shed, and the second supplies the exact date and time of the temperature readings, while the third stores all of the data in text files. This equipment was connected to electricity in the shed which was protected from the elements as depicted in Figure 8.

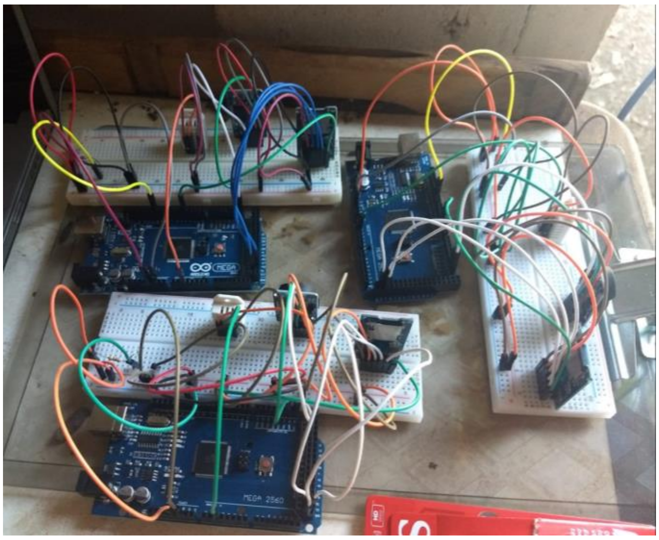


Figure 8 - Data Acquisition and Storage Device.
Source: The authors (2021).

According to Martinazzo and Orlando (2016), DS18B20 digital sensors coupled with the Arduino are more reliable and efficient than analog sensors (Termistor and LM35). The DS18B20 temperature sensors were obtained from the factory with just 1 meter of cable and thus they required a Cat E6 ethernet extension cable of the necessary length.

The necessary extension cables were approximately 100 meters long from the data acquisition and storage device (located in the shed) to the DS18B20 temperature sensor (located in the reservoir). This length of the extension cable increased the resistance of the Cat E6 cable, which in turn would compromise the transport of the data collected from the temperature sensors to the Arduino prototyping board, which thus made it impossible to feed information from three sensors to a single board. Thus, we decided to use three Arduino boards, or in other words, a board for each sensor, as illustrated in Figure 8.

In order to keep the temperature sensors more stable physically and guarantee the collection of the temperature data at the initially defined depths (0.0m, 0.30m and 1.50m), we had to make sensor tips. These tips were made up of ¾" PVC pipes 25 cm (10 inches) in length and ¾" PVC caps fixed with adhesive tape and isolated with silicone, as shown in Figure 9.

Figure 9 - DS18B20 Temperature Sensor Tips.
Source: The authors (2021).

Next the DS18B20 temperature sensor was installed near the device shed to collect ambient temperature data (Figure 10-a). Then two temperature sensors were positioned inside the reservoir, one at a depth of 0.30 m (1 foot) (Figure 10-b) and the other at a depth of 1.50 m (5 feet) (Figure 10-c) with the help of weights to keep them submerged.

(a) (b) (c)

Figure 10 - DS18B20 Temperature Sensors Placed on the Property.
Source: The authors (2021).

After it was installed, the system collected temperature data continually every 20 minutes and stored it in the Micro SD cards. To maintain greater control over measurement errors and possible sensor problems, the data was collected weekly. The data was then analyzed using the OriginPro 8 software package.

4. Results and discussion

The collection and storage device for the ambient temperature and the temperature readings at various depths in the reservoir (0.0 m, 0.30m (1 foot) and 1.50m (5 feet)) continued to operate for a period of four months from June 30, 2018 through October 30, 2018. The behavior of the reservoir temperature compared to the ambient temperature can be observed in Figure 11.

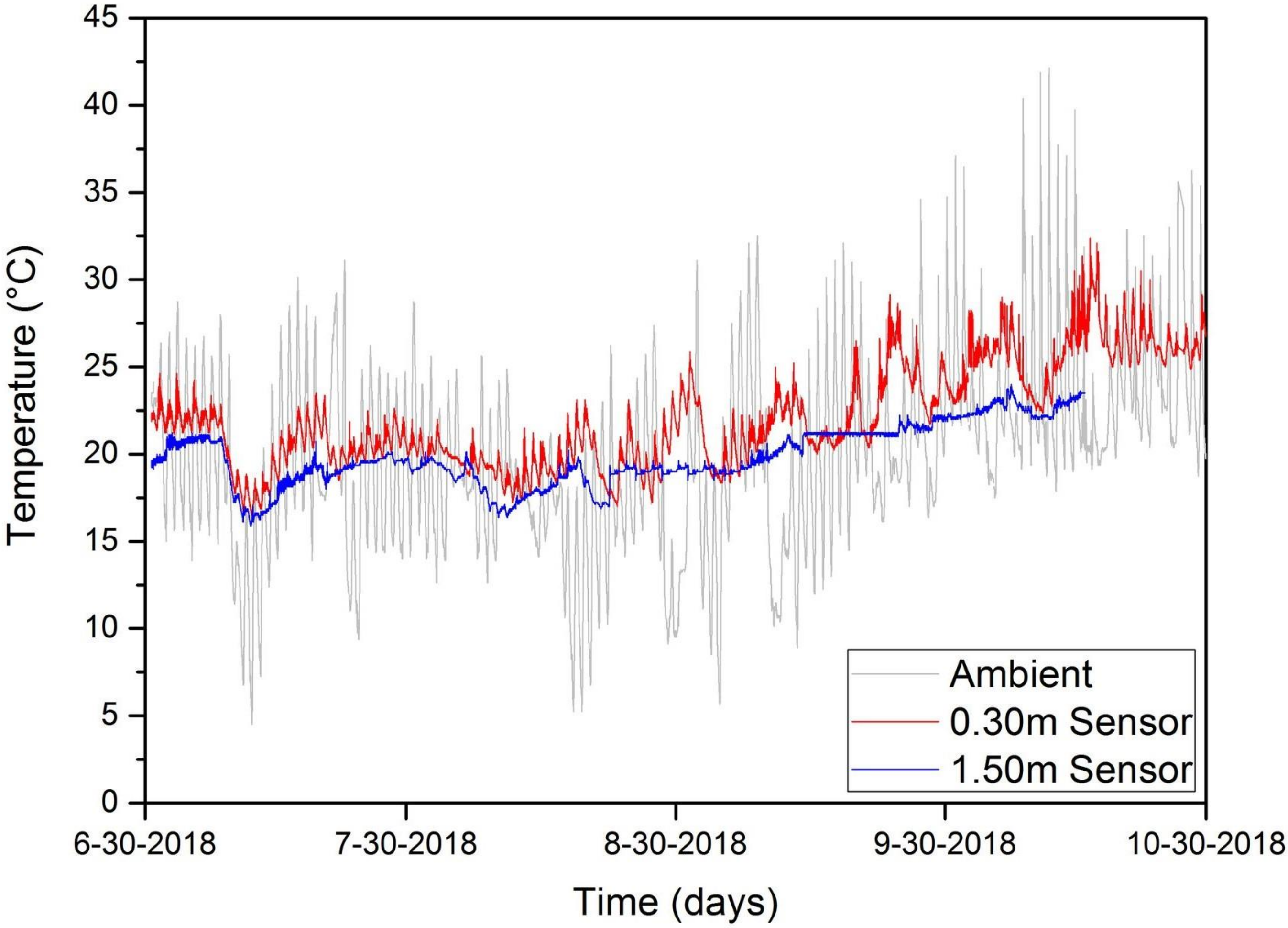


Figure 11 - Ambient and Water Temperatures of the Reservoir in Fátima do Sul, Mato Grosso do Sul. Source: The authors (2021).

The collection period lasted almost the entire winter (83 days) and included the beginning of spring (37 days), as can be observed in Figure 9, in which the ambient temperature reached minimum values close to 5 degrees Celsius (41°F) and later rose constantly reaching a temperature close to 20 degrees Celsius (68°F).

The behavior of the ambient temperature is reflected in the behavior of the water temperature, and it is possible to perceive from the graphic analysis (Figure 9) that the water temperature at 0.30m (1 foot) is more sensitive to the ambient temperature compared to the water temperature at 1.5m (5 feet), given that the thermal amplitude is greater at a depth of 0.30 meters. In this way, as we go deeper in the reservoir the water assumes a more and more constant temperature, confirming a low variation in the water temperature due to its high specific heat.

In Table 1, we can observe the thermal amplitude for the three depths analyzed over four months in this study.

Table 1 - Thermal Amplitude during the Measurements

	$T_{MAXIMUM}$ *(ºC)*	$T_{MINIMUM}$ *(ºC)*	*Thermal Amplitude (ºC)*
0.0m Sensor	42.13	4.50	37.63
0.3m Sensor	32.38	16.38	16.00
1.5m Sensor	24.00	15.88	8.12

Source: The authors (2021).

In Table 1, note that the thermal amplitude of the ambient reading was 37.63ºC, while at depths of 0.30m and 1.50m this amplitude was 16.00ºC and 8.12ºC, respectively. Thus, the diminution of thermal amplitude with increased depth in surface water is confirmed, revealing its capacity for thermal storage.

In Table 2 we may observe two extreme moments in relation to the ambient temperature during the analyzed period. The first was a cold day (7/12) and the second was a warm day (10/11), and we examine both in terms of the water temperature at 0.30m and 1.50m.

Table 2 - Ambient Temperature Extremes during the Measurements.

Date	*Time*	*Temperature (°C)*		
		0.0m Sensor	*0.30m Sensor*	*1.50m Sensor*
7/12/18	6:17 am	4.50	16.63	16.25
10/11/18	10:53 pm	42.13	24.13	22.13

Source: The authors (2021).

At both times, according to Table 2, we may perceive that independent of the conditions of extreme cold or warmth, the temperature at 0.30 meters and 1.50 meters in depth remained less severe, again revealing the thermal storage capacity of water. Thus, for July 12, 2018 which presented cooler temperatures, the water could be used as a source of warmth to heat constructed environments. On October

11, 2018, on the other hand, the water could be used as a cold source that could be exchanged with heat to cool these environments.

Another important aspect is the verification of the temperatures during a single day at different times. Table 3 shows the variation in the data for September 1, 2018.

Table 3 - Temperature Extremes during a Single Day under Observation

Date	*Time*	*Temperature (°C)*		
		0.0m Sensor	*0.30m Sensor*	*1.50m Sensor*
9/1/18	11:04 am	31.13	22.88	19.00
9/1/18	11:44 pm	13.00	22.13	19.00

Source: The authors (2021).

At both times, according to Table 3, we may perceive that during one day the temperature at the depths of 0.30m and 1.50m remained practically constant. Even though the ambient temperature varied by 18.13°C in a single day, the variations in temperature at the depths of 0.30m and 1.50m were 0.75°C and 0°C, respectively, revealing a lower thermal amplitude in the reservoir as depth increases. Figure 12 depicts the daily thermal behavior of the water.

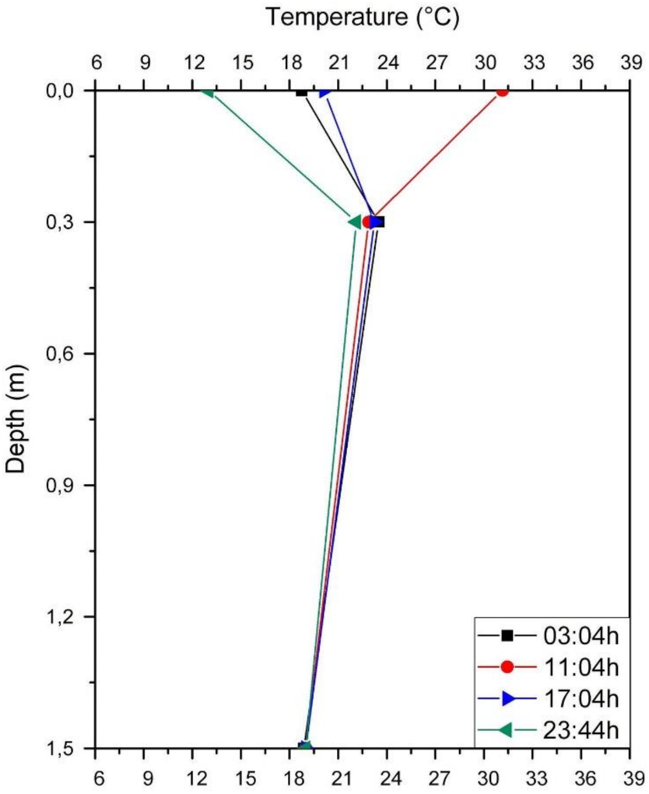


Figure 12 - Daily Thermal Behavior of the Reservoir Water.

Source: The authors (2021).

In this sense, analyzing graphically the daily change in temperature of the water at depths of 0.30m and 1.50m at 3:04 am, 11:04 am, 5:04 pm and 11:44 pm (Figure 12), it is possible to note greater thermal stability with increasing depth independent of the fact that the ambient temperature (0.0m) experiences an elevated thermal oscillation.

These results corroborate studies conducted by Márquez, Bohórquez & Melgar (2016), Omido, Barboza, Sanches & Sanches, (2018), Omido, Barboza, Sanches & Sanches, (2019), Sanches, Sanches, and Omido, Barboza, & Jordan, (2020), which display the possibility of using surface geothermal energy to support the climatization of constructed environments.

5. Conclusion

This evaluation of the potential utilization of Geothermal Energy from surface water in a reservoir located in Fátima do Sul, Mato Grosso do Sul makes it possible to conclude that water temperature tends to be more and more constant (has a lower thermal amplitude) as depth increases in the reservoir, or in other words, they are inversely proportional.

The difference between the ambient temperature and the underwater temperature reveals the possibility of using the energy stored in the water as a form of heat to run a heat pump to climatize constructed environments, or in other words, during winter the water can be a source of heat, and in summer it can dissipate heat.

Future studies should employ greater proximity between the data acquisition and storage mechanism and the location where the sensors are installed so that just one Arduino prototyping board will be necessary.

6. Acknowledgement

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