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# Application of Subterranean Geothermal Energy to Lower Residential Energy Consumption

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## Abstract

In order to help reduce the amount of energy used in a home or small company, this article explains the construction of a geothermal air conditioning system. The conditioning system that is being outlined here makes use of surface geothermal heat, which is a clean, quiet, renewable, and all-purpose source of thermal energy. The entire system relies on a tiny water pump to circulate a liquid refrigerant within the buried pipe, allowing the soil to regulate temperature differences in both summer and winter. The heat is subsequently transferred to the ground mass; in other words, heat or cold can be transferred between them without the need for a heat pump if the temperature within the building is greater or lower than the subsurface. To optimize the performance of the water pump and ventilation system, the prototype system now uses an electronic control in tandem with a geothermal heat exchanger.

## 1 Introduction

The surface geothermal energy is a renewable source still little known in the southern hemisphere. In particular, the energy of interest in this work is a promising field for surface geothermal energy, which is based on a heat layer under the the earth surface to typical depths up to 6 meters. At this depth, the annual average surface temperature of the surrounding environment is between 16°C and 21°C in the United States of America [1].

According [2], the soil temperature in a depth of about 20 meters, the temperature is insensitive to any surface temperature variations. The annual average surface temperature of the surrounding environment in this paper is taken as 19.5 °C at a depth of 2 to 3 meters, the maximum ground temperature occurring about 6 months later than the average maximum temperature of the surface. The surface geothermal systems do not use much space and its energy is independent of the season and climate, since most of its components are arranged beneath the soil.

The geothermal surface is based on the circulation of a cooler inside an underground hose hose with the aid of a small pump, so that the ground can absorb cool temperatures in the summer and provide heat in the winter relatively to ambient temperature. The heat is then exchanged and removed from the environment by a radiator with circulating water and a fan. If the room temperature is lower than the underground temperature, the earth heat can be used to warm it up [3]. The results of this project suggest the geothermal surface energy for thermal conditioning of small rooms but it could easily be extended to residential buildings still under construction or the already existing ones through modeling, developing and implementing projects using only geothermal energy and heat exchangers without any heat pump.

## 2 Project Methodology

### *A. Project Conditions*

When designing an air heating or cooling system of a building it is meant to fetch its conditions of temperature, humidity and ventilation to the thermal comfort zone, which for most people sleeping or doing light activities varies between 23 to 27°C [4]. The existing challenge in the project is to weatherize the environment based on the external site conditions, which varies greatly with time.

For the project described in this paper, a heat exchanger involves different mechanisms of heat transfer. First, heat is transferred from the ground to the wall of a heat exchanger by conduction through the wall and also by conduction through the inner wall by fluid convection. This process involves two resistors related to the conduction materials. So the total thermal resistance network can be given as [5, 6]:

$$R_{total} = R_{ground} + R_{wall} + R_{fluid} \quad (1)$$

The heat transfer between these surfaces is continuous as:

$$Q = \frac{T_1 - T_2}{R_{total}} \quad (2)$$

$$R = \frac{1}{S \cdot k} \quad (3)$$

where:

S is a geometrical form factor;

k is the thermal medium conductivity.

The shape factors were determined for a number of geometric configurations usually encountered in practice and in the case of this project are applicable only when there is a heat transfer by between two conducting surfaces. The major interest here is the shape factor of a driving an isothermal cylinder of length L buried in a semi-infinite medium with L >> D and z > 5 D, where z is the tube distance from the ground surface and L is the length of the tube.

$$S = \frac{2L}{\ln(4z / D)} \quad (4)$$

The conduction resistance between the soil and the heat exchanger wall is:

$$R_{ground} = \frac{\ln(4z / D)}{2 kL} \quad (5)$$

The resistance of the conducting layer is cylindrical:

$$R_{wall} = \frac{\ln(D_o / D_i)}{2 kL} \quad (6)$$

where "i" and “o” represents respectively the internal and external surfaces of the heat exchanger.

The thermal resistance of the internal convection fluid is calculated by:

$$R_{fluid} = \frac{1}{h \cdot A} \quad (7)$$

$$A = DL \quad (8)$$

where:

A is the surface area of the heat exchanger (m²);

h is the coefficient of heat transfer convection calculated as follows:

$$h = kN_u / D \quad (9)$$

$$N_u = hD / k = 0.023 R_e^{0.8} P_r^n \quad (10)$$

$$R_e = VD / v \quad (11)$$

$$v = \frac{\mu}{p} \quad (12)$$

where:

Nu is the Nusselt number for a fully developed turbulent flow in smooth hoses with n = 0.4 to 0.3 for heating and cooling fluids flowing through the tube (equation Dittus Boelter):

$R_e$ is the Reynolds number;

$P_r$ is the Prandtl number;

v is the kinematic viscosity (m²/s);

µ is the dynamic viscosity (kg/m · s);

p is the fluid density (kg/m³).

*B. Project Execution*

In Santa Maria - RS - Brazil, the South facade is less sunny most of the year and the winter tends to be damp and cold. The east facade receives the morning sun and the west facade receives the afternoon sun, with longer duration and considerably warmer. The North facade receives sun all day through. Since the buried heat exchanger is the main responsible for the geothermal energy efficiency, it should be designed to provide the energy needed to acclimatize the environment. If the buried heat exchanger is underestimated, the thermal energy source will be depleted and the heat exchange with the ground system becomes inefficient, causing increased soil temperature in the vicinity of the hose hoses.

To obtain maximum capacity of heat exchange, the flow time of water through the buried hoses will depend on the flow rate and geological characteristics of the soil. If the water flow is too fast, there won't be enough time for an appropriate heat exchange and if the water flow time is too slow, there won't be enough heat transfer to condition the room. An optimized electronic pump speed control to force the water flow and a fan for the airflow are managed by a microcontroller and sensors that monitor the temperatures in the soil, in the outside environment and in the inlet and outlet of the heat exchanger and the environment to be conditioned. The number of tubes and the volume of water stored in it must necessarily be in accordance with the thermal load necessary for the environment to be properly conditioned. The ground heat should be equal to the required heat load of the environment to be conditioned.

The water pump control adjusts the step-down voltage converter used to drive the pump cycle, thus varying the water flow. The duty cycle is controlled by reading temperature sensors fitted at the inlet and outlet of the hose. After reading these temperatures it is searched the best possible thermal exchange between coolant and ambient temperature, using an algorithm known as "hill climbing control" (peak search).

The search for the maximum point checks if the external temperature is equal to the ground temperature, since there is no heat exchange. In this case, the system is shut down after an hour and a check is made under this condition. Moreover, it is estimated whether a saturated heat condition occurred in the soil, then a comparison is made between the soil temperature and the water inlet temperature in the hose where saturation occurred. The system is switched on again after sufficient time for the soil recover its initial temperature to compensate for system restarting.

The control applied to the fan follows the same duty cycle varying principle, but now based on the average temperatures supplied by the sensors installed in the room. To control the fan speed it was also used to search for the maximum heat point, In this case is taken the average temperatures among the sensors and compared to the reference temperature (18 °C, winter case). If the average indoor temperature reaches the reference temperature, the system is turned off. After ten minutes it is made a new evaluation. If the reference temperature is not reached, the temperatures is read and compared to the previously reading. Thus, in the winter case, the fan speed increases as the temperature falling down, and slows down as the temperature increases up.

*1) Data Logger for the thermal data acquisition*

To collect the thermal data was used a circuit mesh with 5 temperature sensors DS18B20 (MAXIM Programmable Resolution 1-Wire Digital Thermometer). The DS18B20 sends these measured data to a PIC 18F4520 microcontroller through a serial communication bus. This device is a 12-bit precision sensor, reading the temperature in steps of 0.0625 °C.

Data from the digital temperature sensors are stored in a memory SD Card. To organize the recorded data it was included a circuit clock PCF8583 from NXP Semiconductors. This clock performs every serial communication with the microcontroller through an I2C bus, informing the day, month and year, as well as the hours, minutes and seconds. This device can also capture the voltage drops through 6 10-bit accuracy analog inputs.

A "Data Logger" was used for acquisition of the thermal data. This dedicated electronic device was developed with the purpose of acquiring the fluid temperatures to be transferred from the soil to the conditioned room. All temperatures were monitored at the hose inlet and outlet with coolant water. They were also monitored the temperatures outside and inside (heated) the conditioned room and of the reference room.

The temperature acquisitions was made by the data logger and stored in daily files. Each file is named by the respective day, month and year.

*2) HCC Control of the water pump and fan*

To obtain the optimal water pump and fan speeds in the internal environment of the testing room, it is necessary to determine continuously optimum daily temperature difference between the inner and outer temperature of the testing room. Based on this temperature difference it is controlled the water pump and thus the flow speeds of the refrigerant. Therefore, it was obtained the highest possible temperature difference between the external environment and the internal room temperature of the heated test room. The HCC (Hill Climbing Control) is represented in figure 1 [7] where successive increments or decrements of the controlled variable are used to force the difference between the internal and external temperatures to their maximum extent.

As long the maximum point is reached, the step size is divided to smooth down the curve convergence, as shown in figure 1, for the water pump. Figure 2 shows the block diagram of HCC to control the water pump speed.

Additionally, the algorithm can also takes into account the possibility of soil saturation by monitoring the temperature difference between the room environment and soil.

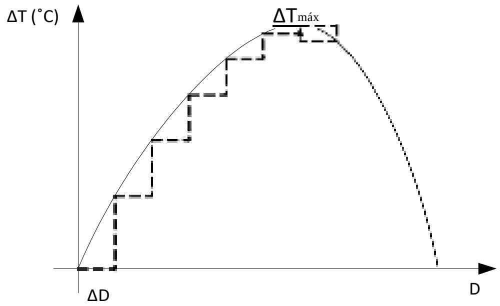


Figure 1: Theoretical representation of the algorithm HCC.

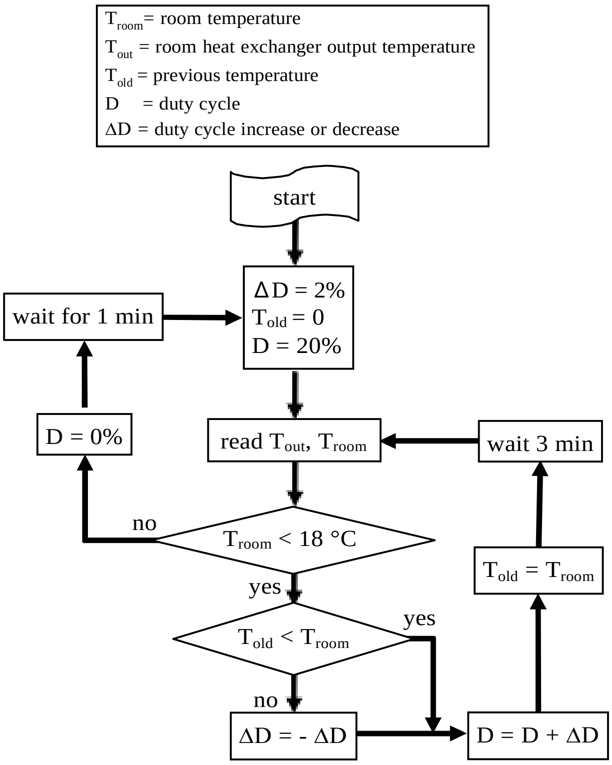


Figure 2: HCC flowchart control of the water pump.

| Temperature | Location sensors |
|---|---|
| Water outlet | Temperature sensor located in the piping of water after passing through the heat sink / radiator. |
| Reference room | Temperature sensor located in the reference room, which has the same physical characteristics of the testing room. |
| External | Temperature sensor located outside the house, measuring the outside temperature of the day. |
| Water inlet | Temperature sensor on the water hose coming out of the ground before passing through the heat sink / radiator. |
| Testing room | Temperature sensor located in the testing room, which has the system installed. |

Table 1: Legend of the sensors.

## 3 Experimental Results

The room tests of the temperature control prototype of geothermal air conditioning was turned on and started on the afternoon of July 10th, 2013. On this day the external temperature was approximately 8 °C. The water inlet temperature was about 19 °C and stabilized at 18.25 °C. The outlet temperature of the coolant water started at 12.25 °C and stabilized at approximately 16.44 ºC. Initially the system was turned on without the HCC control, being only connected to a DC power source, with a consumption of 80 W/h. External temperature noise occurred due to direct exposition to sunlight, wind and shadows from clouds

Figures 3 and 4, record the temperatures of the testing room (Room 1) where the system is installed and the reference room (Room 2). Interestingly, when connecting the geothermal system, the speed at which the temperature stabilized at about 16 °C, the room temperature reached the reference temperature (11.7 °C) with a temperature reduction of 4.3 °C regarding the room.

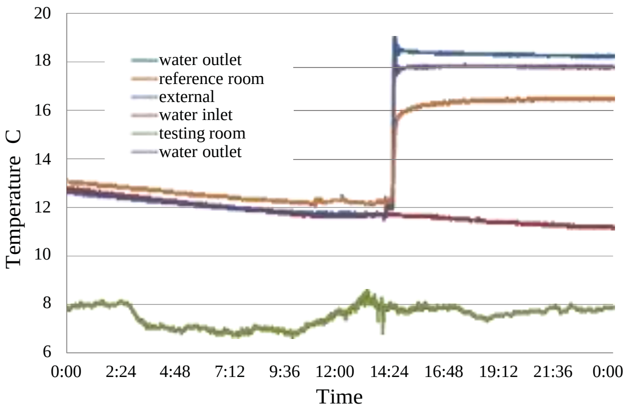


Figure 3: System turned on at 2:20 pm (winter Jul 10th 2013).

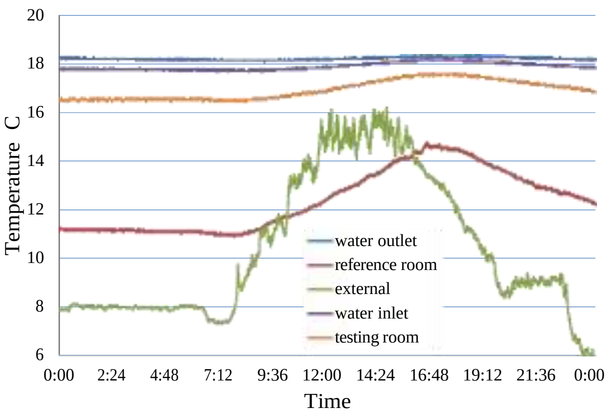


Figure 4: Graphic temperature sensors at all during the day (winter Jul 11th 2013).

Figure 5 and 6 register the sensor temperatures on the Jul 22th. Notice that at 08:10 am the testing room temperature was at 15 °C and the reference room was at 7,875 °C, keeping an average of 7,125 °C.

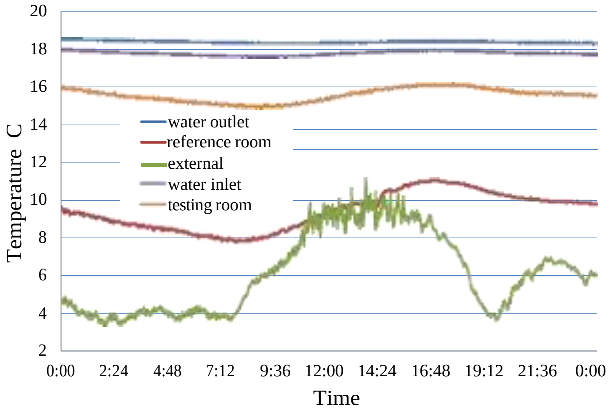


Figure 5: Temperature sensors at all during the day (winter Jul 22th 2013).

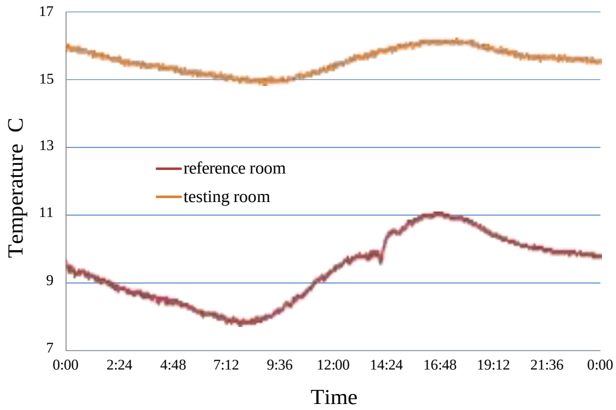


Figure 6: Graphic of temperature on the heated room and the reference room during the day (winter Jul 22th 2013).

Below, the HCC control was turned on and figures 7 and 8 register the reference room and testing room temperatures under the HCC control and the total electrical energy consumption graph The resulting average consumption was about 55,6 W/h for the day (June 9th). The inlet temperature of the water was approximately 20.4 °C. The outlet temperature of the coolant water was approximately 19.4 °C when the HCC control was set to 18 ºC. There was a temperature difference of 5.6 °C at the lowest temperature in the reference room.

Figure 9 presents the temperatures in all sensors. Notice that the system was off, because the testing room temperature was higher than 18°C, so the control was not activated. When the temperature has fallen down to 18°C, the water pump and fan were turned on again. Figures 10 and 11 show the graph of the reference and the testing room temperatures, with the total electrical energy consumption graph, which resulted in an average consumption of 20,55 W/h for the day, June 14.

Notice that the testing room temperature was almost constant even in colder environmental conditions. In this worst case, the testing room temperature fell down to 17.5 °C. When the reference room has fallen down to 12 °C, there was a difference of 5.5 °C between the rooms.

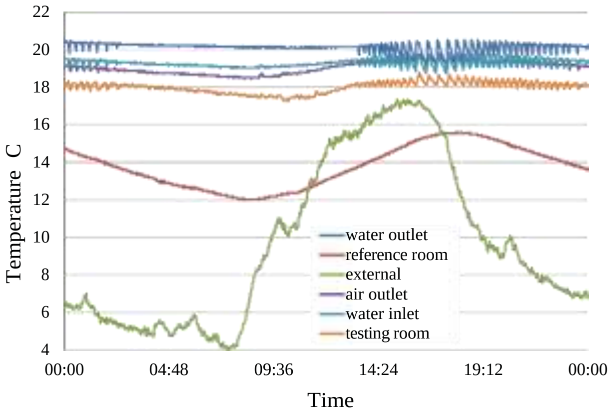


Figure 7: Temperature in the heated room and reference room using the HCC control (Autumn Jun 9th, 2014).

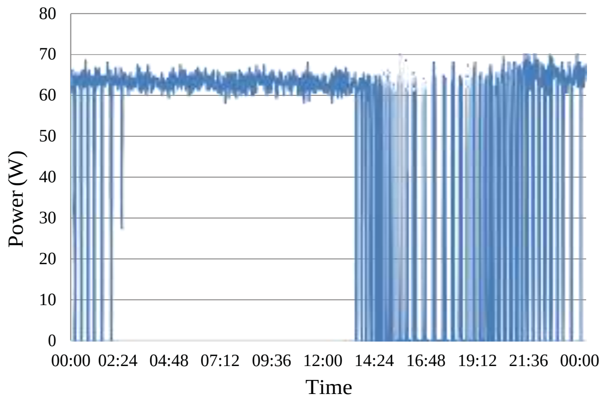


Figure 8: Electrical consumption (Jun 9th, 2014)

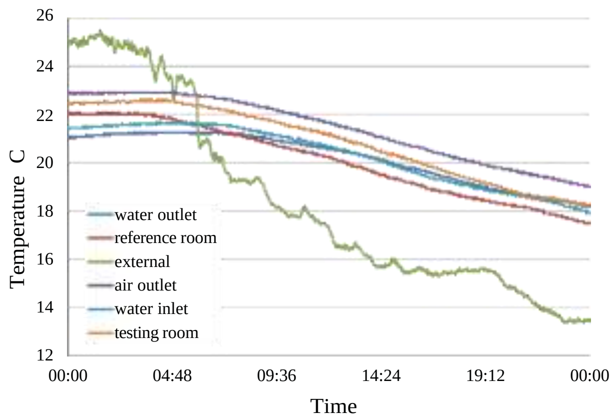


Figure 9: Temperature on the heated room and the reference room (Autumn Jun 13th, 2014)

Variations in the power observed in figures 9 and 11 are due to the hill climbing control determining the maximum water pump operation point. Whenever the water pump is turned off by the HCC, the inlet and the outlet water temperatures fall down close to the testing room temperature. It was also observed that the power spent by the whole system is no more then 70 W representing an appreciable reduction in electrical consumption.

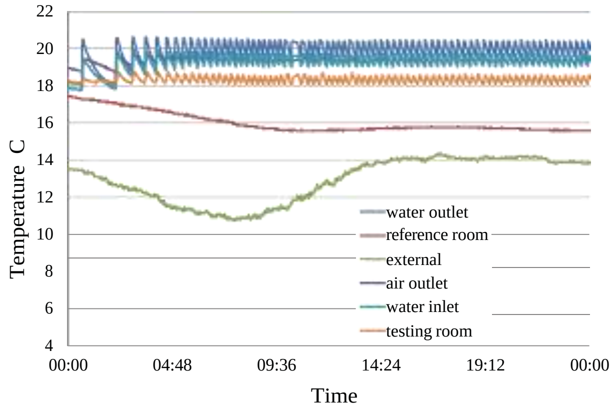


Figure 10: Temperature on the heated room and the reference room with HCC control (Autumn Jun 14th 2014).

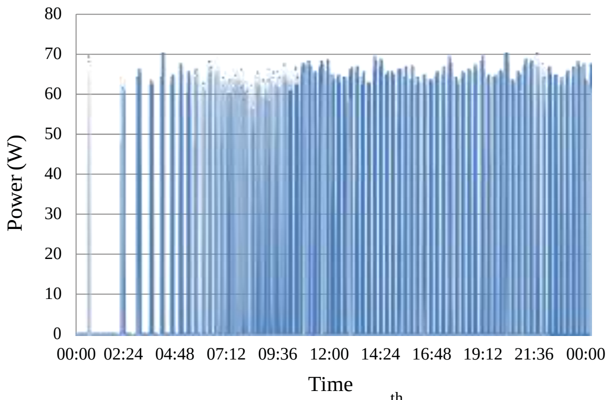


Figure 11: Electrical consumption (Jun 14th 2014)

## 4 Conclusion

This paper describes a way of harnessing surface geothermal energy, including ideas for the correct dimensioning of the underground and room heat exchangers. The set up established in all tests is based on the surface geothermal used to reduce expenditure with electrical power by using a very low installation and maintenance costs. In addition, it is proposed a better utilization of the traditional conditioning systems throughout heat exchangers between the room ambient and underground.

The necessary buried hoses and constructive works were of a reasonable size using only conventional landscape machines to bury them. Moreover, the conditioning geothermal energy does not require any fuel tank, requiring only an internal clean coolant fluid through the hose (water in the case of this project), pointing down to further ease of operation and low maintenance costs.

With the calculations discussed in this paper it is possible an appreciable heat gain with appreciable reduction in power electricity necessary to exchange heat between the external environment and the internal environment to be air-conditioned. Thus, knowing the amount of heat that must be removed from the conditioned room to put it into thermal comfort conditions is sufficient to design the heat exchangers. To improve the precision these calculations it is necessary to know in advance each object and the equipment to be used inside of the room.

The results so far obtained in this project are enough to prove the effectiveness of the prototyped set up mainly for small houses and business. By using only a low power consumption devices (water pump and a small fan), this system is capable of keeping the room temperature at 18°C even in sensibly colder times. To improve even more the system proposed in this paper it is necessary:

1) Improve the balance between the room thermal load in kW and the amount of heat extracted from the buried hoses and the heat exchanger in the room ambient;

2) Improve the thermal insulation of the external walls or cavity walls, insulating roof, windows and doors;

3) Even better tune fan speeds and water pump;

4) Heated room coverage with vegetation;

5) Use of water wells and cisterns existing in the neighborhood to increase the amount of heat exchangers in the underground;

6) Use of commercial heat exchangers that have higher yields than those used so far in order to ease future geothermal projects;

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