USE OF GEOTHERMAL EXCHANGERS FOR THERMOACCUMULATION OF THE ENERGY GENERATED BY CLIMATIZERS ACTIVATED BY PHOTOVOLTAIC SOURCES

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***Abstract* — The use of air conditioning is growing up very much in Brazil and in the world in general. That is no longer a luxury, but a necessity, though they have heavy impacts on the consumption of electricity. The alignment between the peak thermal load and the highest solar incidence of solar energy leads the scientific community to search for machines powered by this type of energy. Energy costs are higher when the solar energy is decreasing so recommending a more powerful storage of energy. Regarding this point of view, soil is one of the oldest, universal and most extensive form of thermal energy storage. This paper shows how thermal energy storage can be used to provide air conditioning at very low costs. A simple technology is dicussed showing that it is possible to store energy underground and recover it in a very efficient way to provide thermal comfort.**

Keywords — Thermal confort, Photovoltaic energy, Geothermal energy, Peak hours.

I. INTRODUCTION

The use of air conditioners is booming in Brazil. Air conditioning in residential and work environments are no longer a luxury, but a necessity nowadays. These impacts on the consumption of electricity and on the increase in electricity bills. The alignment between the peak thermal load and the greater solar incidence leads to the search for air conditioning machines powered by this energy source. There is also the storage of thermal energy that may be a surplus in this process. Efforts are directed so that this stored energy can be used during peak hours just when the cost of electricity is higher and does not coincide with the hours of greatest availability of solar energy or greatest thermal load.

Soil is one of the oldest and most extensive forms of thermal energy storage. The low cost of maintenance, its universality and the possibility of using it close to constructed areas are the great advantages of this means of thermal accumulation.

This paper presents a study focusing on a more efficient way of using the soil as a way of storing thermal energy during times of photovoltaic production and its recovery precisely during the peak hours.

II. USE OF AIR CONDITIONING, HEATING AND PHOTOVOLTAIC ENERGY

A. *Growth in Sales of Air Conditioning Machines*

Annual sales of split-type residential equipment jumped from 2,008 units in 2016 to 4,065 in 2020 [1]. Sales of central equipment, in tons of refrigeration (TR), went from 408.6 TRs in 2016 to 579.6 TRs in 2020 [1]. In the residential sector, the ownership of air conditioning units more than doubled between 2005 and 2017 [2], reaching 0.4 units per household. This number is much lower than the situation in the United States and China, where possession of air conditioners are two and one units per household, respectively. A sharp increase in these numbers is expected for Brazil in the coming years and a consequent impact on electricity consumption, possibly going from 18.7 TWh (2017) to 48.5 TWh in 2035.

Regarding the commercial and public sectors, there is an increase in energy consumption with the participation of environmental conditioning. Issues of work ergonomics and the direct relationship drive such conditioning between thermal comfort and sales volume. This increase in load due to air conditioners raises the general energy needs with a consequent impact on the national energy system. This also brings the need for an increase in the generation of electric energy and a better distribution of loads to meet the demand during peak hours.

B. *Air Conditioning with photovoltaic energy and thermal accumulation*

The strong relationship between the thermal load and the solar incidence for climatization in some buildings leads to further studies for the best use of solar energy. An economic analysis of two air conditioning systems in buildings located in the Brazilian cities of Recife (PE) and São Paulo (SP) was carried out by [3]. This study compares the use of two air conditioning sets: one of the Liquid Cooler type (chiller) and the other of the Variable Refrigerant Flow (VRF) type, both powered by Photovoltaic Panels (PV) and/or the public electricity network. The hypothesis was that the excess of PV energy could be directed to the public grid. The simulations carried out indicated an economic viability of either systems in these two cities. The highest Internal Rate of Return (IRR) was

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29% in the city of Recife, while São Paulo had 23%. The authors understood that there is a relationship between the IRR and the solar incidence of each location, hence the advantage for the first city.

A comparison with three air conditioning models was carried out for a 20-floor building in the city of São Paulo [3]. In this study, it was considered a set of air conditioning by gas compression powered by the public network, a set of air conditioning by absorption and a third one by gas compression and supplied by PV/public network. The conventional set had a consumption of 1.61 MWh. Therefore, the absorption was 7.04 MWh and the solar 0.47 MWh for a typical day in a hot cycle (heating). For the cooling cycle, consumption was 4.27 MWh, 21.50 MWh and 3.08 MWh, respectively. The chiller's low performance of absorption was attributed to the small relationship between the area available on the roof and the total thermal load of the building taken as the basis for this study. The use of PV for powering the chiller provided savings of 28% in cooling energy consumption and 71% for heating.

Policies to encourage the abundant incidence of solar radiation in southern China make the use of PV panels an ideal alternative to the strong demand for HVAC energy [5] in that country. The survey was conducted for the situation of an office building, located in Shuhai, China. A water-cooled chiller with a cooling power of 2,461 kW and a chilled water flow of 552 m³/h made the building’s air conditioning. A sum of PV energy was verified over a year higher than that demanded by the chiller. However, the generation was negative in 4 months of the year (from May to August) and positive in the other months. The authors conclude that the set has greater self-sufficiency and less impact on the network. They also suggest the use of some form of thermal storage to reduce the peak power in the network.

Other units with smaller air conditioning have been tested. In Alicante, Spain, a 35 m² commercial room was air-conditioned with a split-type, wall-mounted (hiwall) air conditioner, with a nominal capacity of 3.52/3.81 kW for cooling/heating [6]. The air conditioner received both PV and public energy, being added when necessary to meet the total demand of the commercial room. Its operation was registered for one year, verifying that the energy from the PV was 53.8% of the total demanded by the air conditioner. It was observed that the greatest demand for a typical summer day at the study site was in the morning. Between 14:00 and 15:00, the power generation of the PV set was higher than that consumed by the air conditioner, remaining in this situation until around 18:00, when the generation of the PV declined.

The occurrence of a surplus in the production of energy from a PV panel for air conditioning in some moments and its scarcity in others has motivated a search for new solutions concerning energy storage. An example of this is the use of thermal energy storage (TES) in the Arizona State University (USA), which is receiving a flow of chilled water from hybrid chillers using PV/public power. The existing TES set was installed to take advantage of the lower energy tariffs at night. In this proposed new configuration, when there is an excess of energy from the PV, the thermal flow is not reduced, but redirected to the TES. The use of accumulated energy to supply the peak demand or the low PV production times allows an increase of approximately 50% of the total energy required for air conditioning to be provided by a PV set. An option for residential heating in the city of Harbin, China, has been developed using solar collectors and the soil with geothermal exchangers using vertical piles as part of TES [8]. Underfloor heating made the air conditioning of 570 m² of a building with a total area of 660 m², since this is mainly for heating. Both did the floor heating. Fig. 1 indicates that the use of heat pump without termal accumulation causes a reduction in soil temperature and a consequent loss of efficiency in the process. The same is also true to a lesser extent when using a heat pump and solar collectors. When thermoacccumulation is used during periods without heating the floor, the soil temperature increases as well as the efficiency of the process.

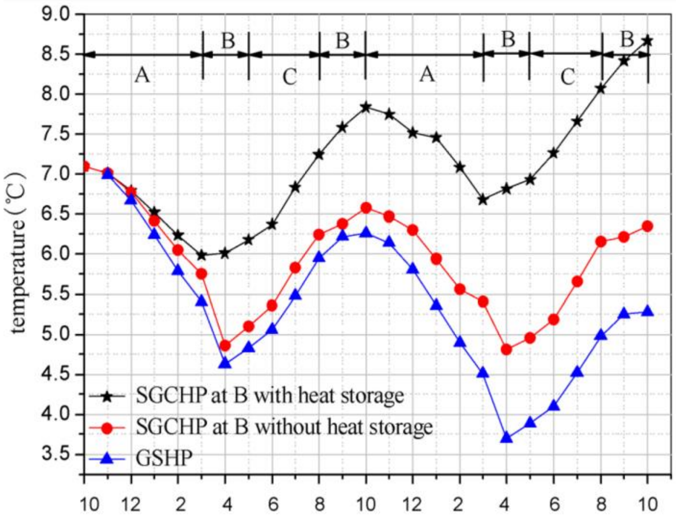

Fig. 1 – Variation of soil temperature. Source: [8]

The thermal energy naturally stored underground was used in a comparative study of climatization in Santa Maria, Brazil [9]. Two environments with identical construction and thermal characteristics, consisting of one air-conditioned of a conventional window-type air conditioner and the other one by a similar fan-coil type through which a flow of water from a horizontal geothermal exchanger passed. The measurement of the amount of heat exchanged between the coil and the room air was 2.03 kW. The average temperature in the test room for the summer of 2014-2015 was 24.87 ^{o}C, having stayed within the thermal comfort limits of NBR 16.401 (between 22.5 ^{o}C and 25.5 ^{o}C). In the reference room with a conventional air conditioner, the average temperature was 24.62 ^{o}C. The geothermal air conditioner consumed 3.37 kWh in the cooling cycle and the conventional one consumed 12.57 kWh in the same period. Despite the good result, it was observed that there was a loss of efficiency at the end of the data collection period, consistent with [8].

III. PEAK HOUR AND THERMO ACCUMULATION TIME IN THE UNDERGROUND

The increase in the share of climate control in energy consumption and the fact that peak hours coincide with the reduction in photovoltaic energy production leads to elaborate new alternatives. These alternatives are related to maintain thermal comfort conditions with less energy consumption. One is the use of soil to store thermal energy, as in [8].

A. Resolutions on Rush Hour and Superficial Geothermal

For this paper, the electricity concessionaire in the Santa Maria region, RGE Sul Distribuidora de Energia SA, was used as a reference for the electricity consumption [10].

As mentioned above, the use of thermal energy from the superficial subsoil reduces the consumption of final energy for air conditioning, which may reduce electricity consumption during peak hours. Its use also has the advantage of reducing water consumption by eliminating cooling towers, the effects of urban heat islands and sound and visual impacts [11]. Surface geothermal is present in the National Energy Plan 2050 in the category of Disruptive Technologies.

B. Analysis of Thermal Pulses in a Geothermal Exchanger

The UFSM/PPGEE/CEESP geothermal experimental house allows the development of various surveys in surface geothermal. To assess the possibility of geothermal TES, a plate type heat exchanger was placed in a reverse cycle window type air conditioner with a nominal power of 2.2 kW. This exchanger replaced the original external coil by a thermal exchange with water flow from a horizontal geothermal exchanger positioned at a depth of 3.5 meters. The water temperature at the inlet and outlet of the plate exchanger was measured, which also corresponds to the outlet and entrance to the geothermal exchanger. In the graphical representation, an average was made for each 20 measurements covering 3 minutes of operation. The flow of circulating water was also measured to obtain the heat flow with equation (1) [12].

$$\dot{Q} = \dot{m} \cdot C_p \cdot (T_s - T_e) \qquad (1)$$

where $\dot{Q}$ is the heat flow *(J/S)*, $\dot{m}$ is the mass flow *(kg/s)*, C_p is the specific heat of the water *(kJ/kg k)*, T_s is the output water temperature of the geothermal exchanger e T_e is the input temperature into the geothermal exchanger.

Considering that the demand for cooling is greater for the geothermal experimental house [9], the process of thermal exchange was that of cooling the soil. Three successful soil-heat exchange operations were carried out with increasing cooling time. The test was not extended to lower temperatures to avoid damage to the air conditioner, especially the plate exchanger, in the event of water freezing. Table 1 shows some of the most significant results of the measurements.

After cooling the soil, the evolution of the return water temperature of the geothermal exchanger was recorded to evaluate the recovery time of the initial soil temperature. Fig. 2 is the graph of cooling for 3.8 hours and 17.2 hours. Fig. 3 is the cooling graph of 17.2 hours and 150.4 hours. It can be seen that the three presented the same initial behavior, with the curves being confused in the graph.

Table 1 - Thermal Pulses

Periods	***3.8 hours***	***17.2 hours***	***150.4 hours***
$\dot{Q}_{av}$	2.35 kW	2.85 kW	2.52 kW
Initial Temperature	19.89 °C	19.92 °C	19.28 °C
Final Cooling Temp.	16.11 °C	13.85 °C	9.70 °C
Heat Recovery Final Temperature	19.78 °C	19.08 °C	18.74 °C
Time of Heat Recovery	49.75 hours	50.7 hours	206.03 hours
Recov. Time for 50% of the Initial Temperature	1.3 hours	3.1 hours	19.3 hours

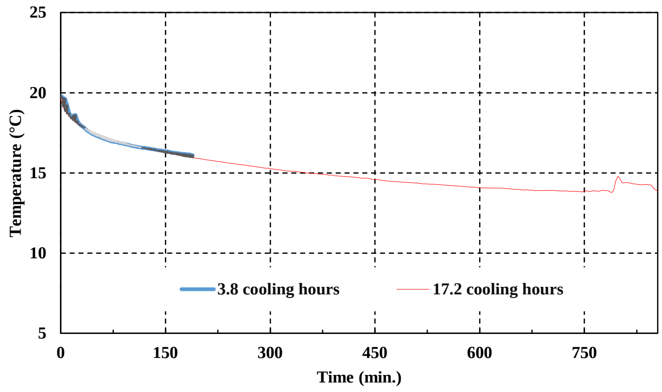

Fig. 2 – Graph of the evolution of soil temperature during cooling. Soil cooling - Thermal pulses 1 and 2.

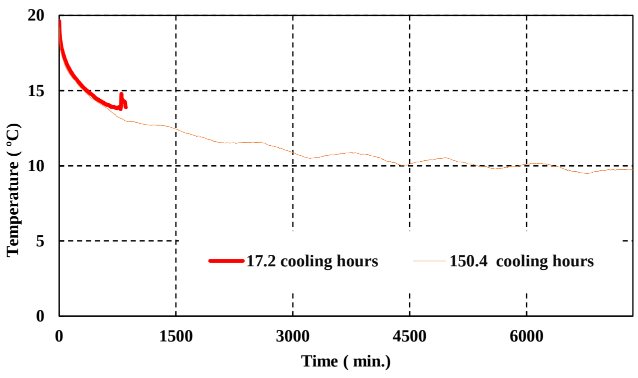

Fig. 3 – Graph of the soil temperature evolution during cooling time. Soil cooling - Thermal pulses 2 and 3.

In order to check the possibility of using the soil for thermal accumulation during peak hours, the whole process was cooled down considering four scenarios. Initially, a cooling was programmed from 8 am to 6 pm. The thermal cycle was reverted at 9 pm when the whole set was then turned off. The same cycle inversion schedule was adopted for tests started at 1:00 pm, 10:00 am and 3:00 pm. Table 2 shows the total heat removed from the soil during its cooling and the total heat supplied to heat it up to the initial process temperature, as well as the effective time for each stage. The heat flow after reaching the initial temperature of thermal accumulation was disregarded.

There is a small variation in the temperature curves of the refrigeration or heating cycle during the measurement period, as shown in Figs. 2 and 3. The same variation can be observed in the natural heat recovery, Fig. 4.

The average heat flow for cooling and heating the soil was 2.66 kW and 3.35 kW, respectively. That is, above the rated capacity of the air conditioner (2.2 kW). It is noticeable that this feature offers a great possibility of using geothermal to acclimatize environments mainly in places further away from the equator and the land poles, which are subject to greater temperature variations.

Table 2 - Thermoaccumulation data

Periods	*08:00 - 18:00*	*10:00 - 18:00*	*13:00 - 18:00*	*15:00 - 18:00*
$Q_{total\ cooling}$ *(kWh)*	25.6	20.7	13.9	8.00
$Q_{total\ heat}$ *(kWh)*	5.0	3.9	4.0	3.1
Percentage heat recovery	19.4 %	18.8%	29.0%	38.8%
Heat accumulation time (hours).	9.9	7.7	5.3	2.9
Warming-up time (hours).	1.5	1.2	1.2	0.9

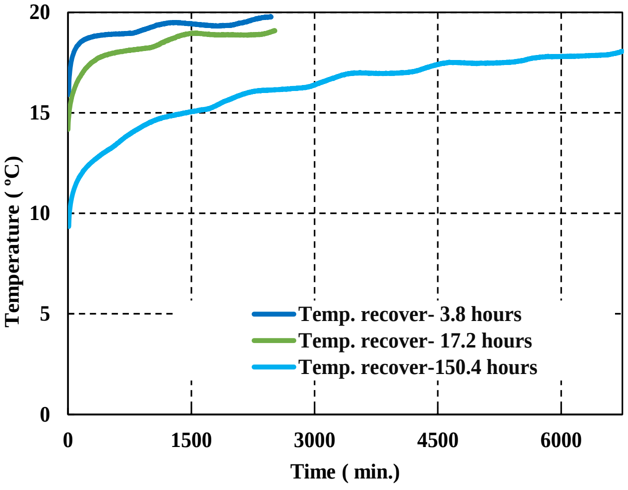

Fig. 4 – Graph of recovery of soil temperature after cooling - Recovery of soil temperature.

C. Testing of thermal properties

The thermal properties of each site can be determined using test equipment similar to that shown in Fig.5 [13]. Its operation consists of maintaining a heat flow by making flow and temperature measurements. The collected data allowed the calculation of the thermal conductivity of the test formation using:

$$k = \frac{q}{4\pi \cdot L_{bore} \cdot slope} \tag{2}$$

$$\Delta t = slope \cdot \ln(\tau) + B \tag{3}$$

where k is the thermal conductivity, q is the heat rate of the test equipment, L_{bore} is the length of the geothermal exchanger, *slope* is the slope of the linear graph of the average temperature versus the natural log of time, τ is the elapsed test time and B is the constant for each graph.

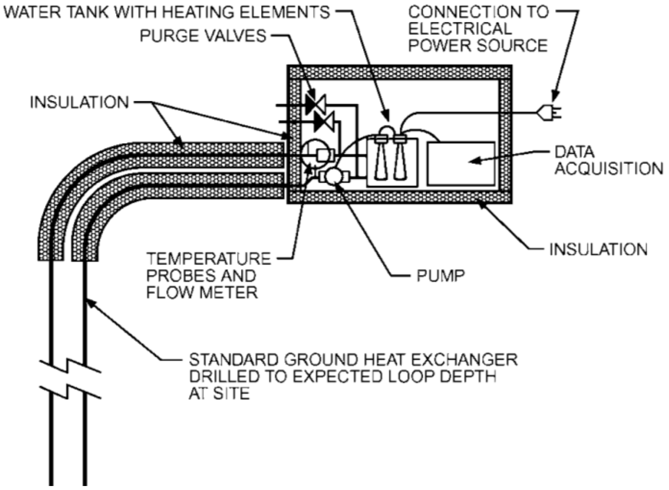

Fig. 5 – Equipment for testing the thermal properties of the soil. Source: [13]

Table 3 - Characteristic curves generated in the thermoaccumulation tests

Periods	*Slope*	*B*	R^2
Heating 1.5 hours	2.5091	11.458	0.9952
Heating 1.2 hours	2.4673	12.055	0.9952
Heating 1.2 hours	2.4464	12.709	0.9949
Heating 0.9 hours	2.3782	14.13	0.9953
***Heating* 9 hours**	-1.031	19.906	0.9955
***Heating* 7 hours**	-1.042	20.245	0.9922
***Heating* 5 hours**	-0.979	19.962	0.9908
***Cooling* 3 hours**	-1.006	21.03	0.9853

The slope value was obtained by the graphic method, observing a significant difference between the heating process and the soil cooling process, as shown in table 3. Fig.6 shows the curve for heating in hours and the curve equation.

The value of k was 7.7 W/m$\cdot$K for a condition of 3 hours of thermal accumulation. Equation (2) was used considering the values q = 3444 W, L_{bore} = 15 m and $slope$ = 2.3782 ^{o}C (Fig. 6).

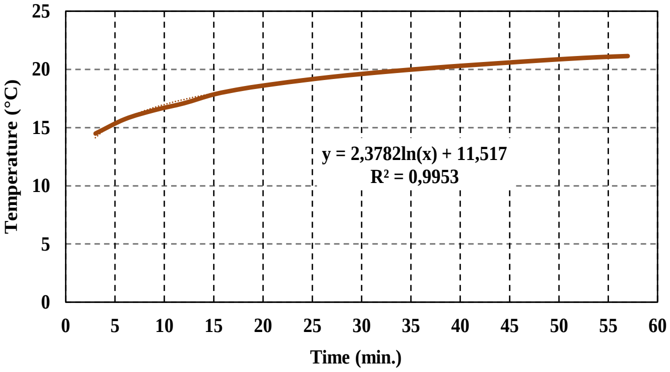

Fig. 6 – Graph of recovery of soil temperature after cooling - Temperature x time. Test with 0.9 hour for soil heating.

D. Discussion

The geothermal exchanger for air conditioning discussed in this paper managed to maintain a stable heat exchange flow, with no saturation observed during the thermoaccumulation tests. In the thermal pulses, that is, in the constant withdrawal of heat and in the subsequent recovery of the temperature by the natural changes of the soil, saturation was also not observed. The amount of heat exchanged did not change despite a reduction in the speed of soil cooling (Fig. 4). In the heat recovery graphs, it can be noticed that there is an external influence with a periodic variation in the speed of heat gain that is consistent with the flow of incident solar radiation throughout the day. Attention should be paid to the fact that the tests were of short duration, with no occurrence of thermal saturation, as mentioned in [8] and [9].

In the tests carried out on the prototype discussed here, the hypothesis of acclimatization of a test room in the experimental geothermal house at CEESP-UFSM was considered, whose thermal load is 0.7 kW, with its maximum at 8:00 am in January [9]. It was found that the energy accumulated in any of the thermal accumulation scenarios was sufficient to meet the demand for thermal comfort during peak hours.

Based on the results discussed here, the use of PV energy combined with room thermal accumulation presents itself as a good alternative for room air conditioning, in agreement with ([3], [4], [5], [6]) and [7]). The thermal load schedule for the test room is similar to that shown in [6]. Fig. 7 shows the total energy consumption of an air conditioner for a typical summer day in Alicante, Spain [6]. The variable P_{TOT} is the sum of energy from the public grid (PGD) and solar P_{PV} and $P_{PV,GD}$ are the energy generated by the set of photovoltaic panels. It is noticeable that there is a reduction in the thermal demand at the time close to the test with a 3-hour thermoaccumulation (3:00 pm to 6:00 pm), which practically coincides with the moment when the downward curve $P_{PV,GD}$ crosses with the total energy demand for air conditioning, P_{TOT}. The thermal energy accumulated in the experiment would be sufficient to meet the demand between 18 and 20 hours, as shown in Fig. 7.

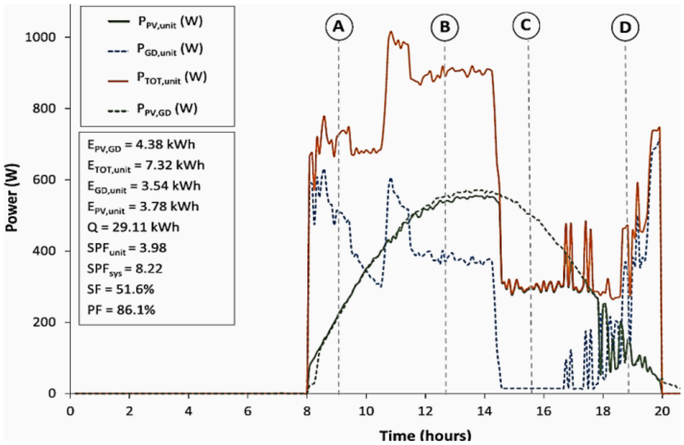

Fig. 7 – Energy share in a hybrid source air conditioner. Source: [6]

IV. CONCLUSIONS

For this paper, measurements of the heat flow were carried out in an existing geothermal exchanger at CEESP at the UFSM Campus (Santa Maria, RS-BR), following thermal pulses of increasing duration and possibilities of cold thermal accumulation. It was verified in the thermal pulses that 50% of the temperature is recovered naturally in a short period of time, consuming 3%, 6% and 9% of the total time of the natural heat recovery. A recovered thermal energy for thermal accumulation scenarios is higher than the thermal load of the test room in Santa Maria, Brazil for the peak hours and the experiment in Alicante, Spain. By considering the thermal energy stored and the results presented in [11] it would possible to consume only 26.8% of the energy consumed by a conventional air conditioning.

The geothermal exchanger used in the tests of the air conditioner was positioned at 3.5 meters of depth responding discreetly to the thermal variations of the surface. During the tests for this paper, the thermal accumulation in the soil showed great losses for longer periods, recovering only less than 20% of the energy deposited. The measurements were not consistent with the situations described in [8] and [9], requiring further tests of longer duration for more conclusive and definitive results. It is recommendable the use of some device to simulate a standart thermal dissipation in these tests.

With the results presented in this paper, it is possible to conclude that there is a great possibility of the use of geothermal energy for climatization of environments mainly in places further away from the equator and the terrestrial poles.

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