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RESEARCH ARTICLE

MEASUREMENT OF GROUND TEMPERATURE FOR COOLING HOUSES IN THE LOCALITY OF HÊVIÉ IN ABOMEY-CALAVI (BENIN)

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ABSTRACT

The present work consists of determining the geothermal resource of the locality of Hêvié, in the municipality of Abomey-Calavi, in the Republic of Benin, for the conditioning of individual houses. The study area is characterized by a hot and humid climate. To do this, the evolution of the temperature in the underground between 0m and 10m depth was determined. Three sites were then chosen for temperature measurements. At each site, ten holes of depth 1m, 2m, 3m, 4m, 5m, 6m, 7m, 8m, 9m, and 10m were drilled. Temperature sensors were installed in the different holes to measure the temperature every hour for 8 months (February to September). The results of these various measurements show on the one hand that the temperature at each depth remains practically constant all the time. On the other hand, the temperature varies according to the depth. From 0m to 5m depth, the temperature decreases from 32 °C to 28.2 °C with a gradient of -0.78 °C/m. From 5m to 10m, the temperature begins to increase but does not appear monotonous. From these results, it is then possible to use the geothermal resource at 5m depth to condition the air of the premises in the locality for the thermal comfort of the users while taking into account the effect of air speed on the perceived temperature.

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INTRODUCTION

Access to energy is a major challenge for human development. Given the influence of the energy sector on the environment, the various energy sector development policies in our different countries now take environmental protection into account. Other factors, such as the rising price of petroleum products, the need for industrialized countries to reduce their greenhouse gas emissions, and strong demographic growth in developing countries, are prompting decision-makers to pay increasing attention to renewable energies. These forms of energy, whose sources are inexhaustible on a human scale, are referred to as green energies. The climate emergency that the world is increasingly facing today is putting pressure not only to characterize the various renewable energy sources available in each region, but also to accelerate the energy transition, of which green energies are the real pillar. Geothermal energy is one of these types of green energy whose applications are booming. Geothermal energy is applied to most forms of energy used by mankind, such as electrical, mechanical and thermal energy. The use of geothermal energy to meet energy needs is no longer a secret. Geothermal energy is a well-known and widely-used renewable energy source. As far back as 1904, electricity was generated by the first geothermal power plant in Larderello, Italy[1]. This production continues in this city thanks to other modern geothermal power plants. In 2012, Mexico was already producing a total of 983 MW of geothermal electricity, with plants installed in several cities[2,3,4]. Other countries such as France[5,6], the USA, Iceland, Germany, Austria and Kenya[7-12] have geothermal power plants to generate electricity. Today, more than thirty countries use geothermal energy to generate electricity[13]. In addition to its use for power generation, the direct use of underground heat for energy purposes is widespread in many countries, including China, Europe and North America[13]. It is used to produce hot water and also for thermal comfort in buildings (cooling and space heating). These applications are made possible by low and medium-temperature geothermal energy. Conventional air-conditioning systems make a major contribution to the increase in energy consumption, since most of our premises, whether residential or administrative, are equipped with these systems not only to protect the health of users, but also to ensure business performance. Conditioning premises with geothermal systems will reduce not only energy bills, but also the environmental impact caused by the use of conventional energy sources. Many researchers have demonstrated the relevance of integrating geothermal sources into the energy management of premises. In 2009 Vikas Bansal et al studied the performance of an earth-duct-air heat exchanger for winter heating. Their study revealed that earth-duct-air heat exchanger systems can be used to reduce the heating load of buildings in winter[14]. In 2010 N. Moummi et al also presented an experimental theoretical study of geothermal cooling in the Biskrasite[15] and established an analytical model of the air temperature in the room through an experimental setup. In 2014 Bisoniya et al studied the performance of an air/soil heat exchanger under hot, dry climatic conditions in Bhopal, India[16]. After simulation, the results obtained show that for air flows of 2m/s, 3.5m/s, 5m/s the air temperature drops rapidly in the first meters of the tube than the last. The experimental and numerical study of an earth-air heat exchanger carried out by Mohamed Khabbaz et al focuses on air cooling, connected to a residential building located in Marrakech (Morocco) with a warm semi-arid climate[17]. The heat exchanger consists of parallel PVC pipes buried at a depth of 2.2 to 3.2 m. Air temperature and humidity measurements at the exchanger inlet and its outlet to the building showed that the earth-air heat exchanger is a good semi-passive system for air cooling, as the supply air temperature recorded in the building is almost constant at 25°C with an air humidity of around 40%. In 2017 Nabil A.S. Elminshawy et al conducted an experimental study on the efficiency of the earth-air pipe heat exchanger for different levels of soil compaction for thermal applications in hot and arid conditions[18]. The results show that the thermal performance of the EAPHE system is highly dependent on soil compaction and must therefore be taken into account right from the design stage. In the same year, B. Kaboré et al[19] carried out an analytical and experimental study of an air-to-soil heat exchanger in Ouagadougou. This study was carried out under meteorological conditions in the city of Ouagadougou in 2014. The results justify the influence of certain parameters such as soil depth, tube length and air flow rate on the annual operation of the exchanger. In 2018 Misra et al had investigated passive air heating and cooling technologies by exploiting air-ground exchangers[20]. They obtained energy efficiencies of around 52.25% and 53.18% respectively for dry and wet soil. Misra et al concluded that thermal performance can be improved by increasing the water content of the soil in which the exchanger is installed. In 2022, Farkad A. Lattieff et al[21] carried out a Thermal Analysis of horizontal earth-air heat exchangers in a subtropical climate, sandy soil in Baghdad, Iraq. Parameters such as ambient temperature, soil temperature, coefficient of performance and heat exchanger efficiency were measured during the months of January and June 2021. The different values of these various parameters prove that this system could be used effectively to reduce the cooling and heating needs of buildings in the region's hot and cold weather. In 2019, Ufuk Durmaz et al[22] had investigated the effect of wet soil on the thermal performance of an air-fluid heat exchanger for heating. They had concluded after the results that wet soil has better performance than dry soil for space heating as the temperature difference between the exchanger inlet and outlet with wet soil increases by 46.28% compared to that of dry soil. To contribute to the use of geothermal energy for space cooling in Benin, the aim of this work is to measure soil temperature down to a depth of 10 m in the locality of Hêvié, commune of Abomey-Calavi, Republic of Benin. Abomey-Calavi is the second most populous commune in Benin. With an annual population increase estimated at 6.7%, it is a dormitory town due to the exodus of Cotonois, who prefer the tranquility of the area. Hêvié is one of the nine arrondissements of the Abomey-Calavi commune, which is increasingly welcoming civil servants and workers from neighboring towns.

MATERIALS AND METHODS

To determine the geothermal potential for air-conditioning of premises in the study area, direct measurement of the subsoil temperature was carried out at depths of 0 m (ground temperature: free surface of the earth), 1 m, 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m and 10 m in three different districts (HOUINMIN, ADOVIE, SOGAN) of the Hêvié arrondissement. The positions of the sites are shown in Figure 1 below.

Figure 1. Indication of measurement sites

At each site, ten holes of different depths (1 m, 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m and 10 m) were drilled. These holes were drilled using manual drilling equipment consisting of a motor-driven pump and a drilling rig (Figures 2 and 3).

Figure 2. Manual drilling equipment: motor pump

Figure 3. Manual drilling equipment: Right: drilling device

Once the hole has been drilled to the given depth, the sensor and sensor probes are installed. The hole is then sealed with the sand recovered during digging. The sensors used are temperature and humidity sensors with digital LCD mini-display, SKU Series: C11A162 (figures 4 and 5).

Figure 4. Appearance of excavated holes: unclosed hole

Figure 5. Appearance of excavated holes: closed hole with sensor installed

Temperature measurements were carried out from February 2023 to September 2023. Values were taken every 60 minutes (1 hour) from 07:00 to 21:00 by a two-person team at each site. The two persons do the rounds every day, taking turns every 7 hours. One person monitors from 07:00 to 14:00, the second from 14:00 to 21:00. The values recorded are processed in Excel. Excel was also used to plot the various curves presented.

RESULTS AND ANALYSIS

The data collected at each site are used to determine the average temperature at each hour for each depth. These mean values are used to plot the various curves presented in this section. Figures 6 and 7 show temperature trends at site 1 (HOUINMIN) as a function of time for different depths.

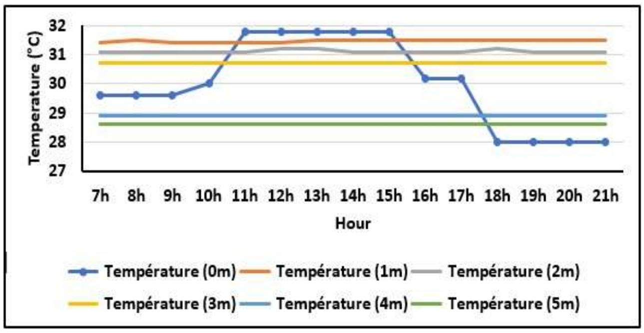

Figure 6: Temperature trends at the HOUINMIN site for depths from 0 m to 5 m

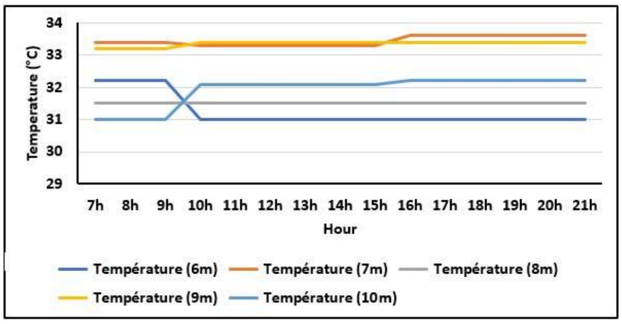

Figure 7: Temperature trends at the HOUINMIN site for depths from 6 m to 10 m.

Figures 6 and 7 show that temperatures at depths of 1 m to 5 m do not vary with time. As for the temperature at 0 m (on the ground), it varies significantly with time and period. From 7 a.m. to 10 a.m. and from 6 p.m. to 9 p.m., the temperature values are low (29.6°C and 28°C respectively), but between 10 a.m. and 6 p.m., the ground temperature rises to 31.8°C. At depths of 3 m, 4 m, 5 m and 8 m, temperatures remain constant. At depths of 6 m, 7 m, 9 m and 10 m, temperatures vary slightly over time. Variations are of the order of ± 1 for depths of 6 m and 10 m, and ± 0.5 for depths of 7 m and 9 m. Temperature also varies with depth at the HOUINMIN site (figure 8). From 1 m to 5 m, temperature decreases with depth, reaching a low of 28.6°C at 5 m depth. From 6 m to 10 m, however, temperature rises and falls with depth. From 1 m to 5 m, the average geothermal gradient is 0.76 °C/m.

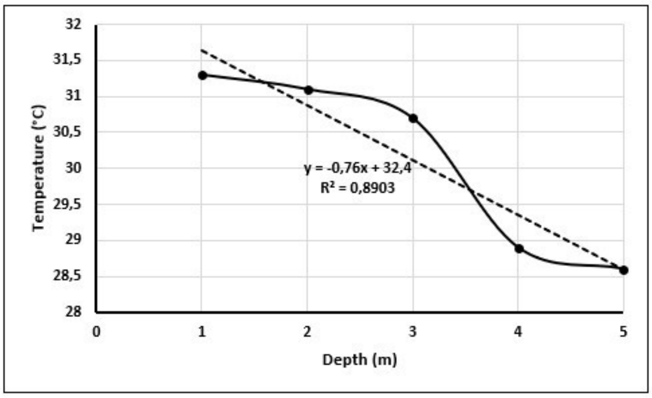

Figure 8: Temperature variation with depth (HOUINMIN site)

At site 2 (SOGAN), the findings are virtually identical to those at site 1. Figures 9 and 10 show temperature trends as a function of time for each given depth.

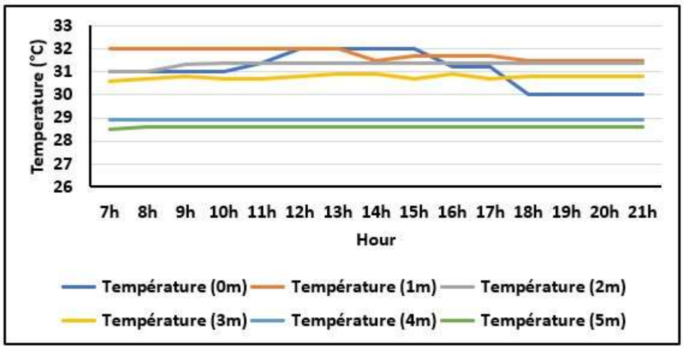

Figure 9: Temperature trends at the SOGAN site for depths from 0 m to 5 m.

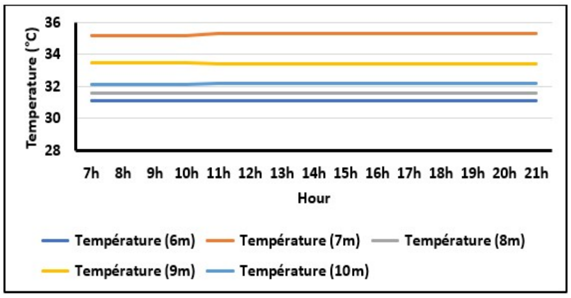

Figure 10: Temperature trends at the SOGAN site for depths from 6 m to 10 m

The curves in figures 9 and 10 show that temperatures at depths from 1 m to 10 m do not vary significantly with time. For depths of 1 m to 3 m, the variation is± 0.3°C, while for depths of 6 m, 7 m and 9 m, it is of the order of ± 0.1°C. Depths of 4 m, 5 m, 8 m and 10 m show constant temperatures. The temperature at 0 m (on the ground) varies significantly with time and period. From 7 a.m. to 10 a.m. and from 6 p.m. to 9 p.m., temperatures are 30°C and 31°C respectively, but between 10 a.m. and 6 p.m., the ground temperature rises to 32°C. As at HOUINMIN, temperature also varies with depth at the SOGAN site (figure 11). From 1 m to 5 m, the temperature decreases with depth, reaching a low of 28.6°C at 5 m depth. The average geothermal gradient between 1 m and 5 m at the SOGAN site is 0.89 °C/m. But from 6 m to 10 m, the temperature rises and falls with depth.

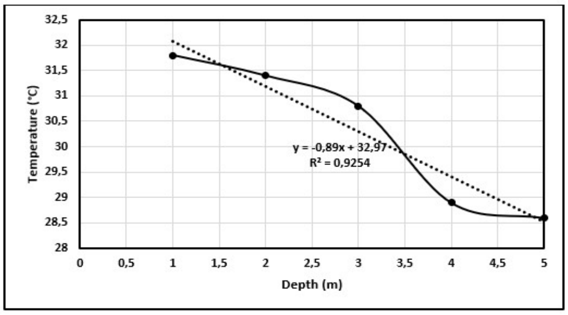

Figure 11. Temperature variation with depth (SOGAN site)

Site 3 (ADOVIE) shows a slightly different behavior to the other two sites. At every level in the soil, the temperature hardly varies as a function of time (see figures 12 and 13), except at 6 m and 7 m depth. The latter two show slight variations of plus or minus 0.3°C over time. Between 1 m and 5 m depths, temperature variation is no longer uniform. Temperatures at depths of 1 m and 2 m are virtually identical. In contrast to the HOUIMMIN and SOGAN sites, the temperature at 3 m is higher than at 1 m and 2 m. The lowest temperature is recorded at 5 m, as at the other two sites. From 6 m to 10 m, temperature changes with depth are not uniform either. It follows a sawtooth pattern, similar to that at HOUIMMIN and SOGAN.

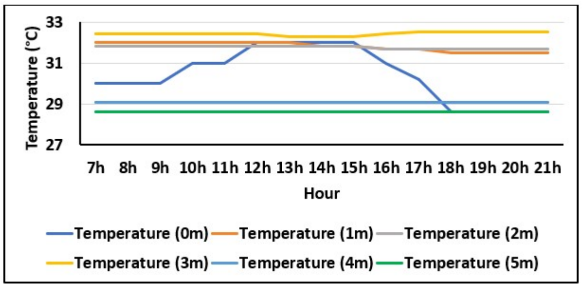

Figure 12: Temperature trends at the ADOVIE site for depths from 0 m to 5 m

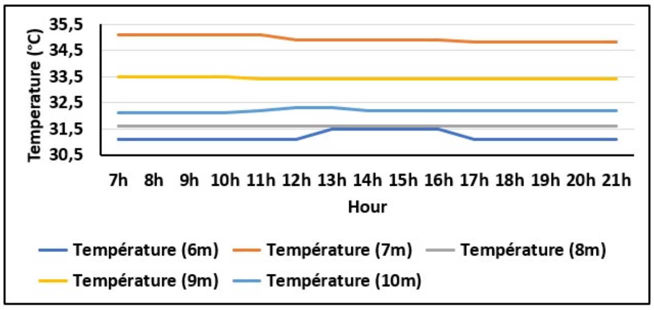

Figure 13: Temperature trends at the ADOVIE site for depths from 6 m to 10 m

Summary

These various curves show that soil temperature in the Hêvié area varies with depth, but remains constant over time at each subsoil level. As a function of depth (Figure 14), the overall temperature decreases from 32°C to 28.6°C between 1m and 5m. Between 5m and 10m, it does not follow a uniform pattern, but varies in a sawtooth pattern. The lowest temperature is 28.6°C at a depth of 5m.

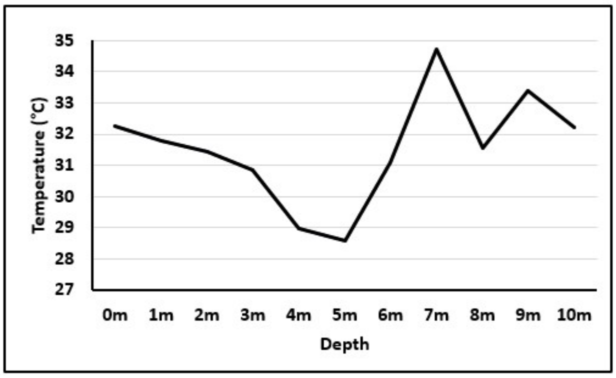

Figure 14: Variation of average temperature according to depth

The average temperature gradient with depth is -0.78°C/m between 1m and 5m (figure 15). A depth of 5 m in the subsoil is the most favorable for the probable installation of geothermal collectors in the study area.

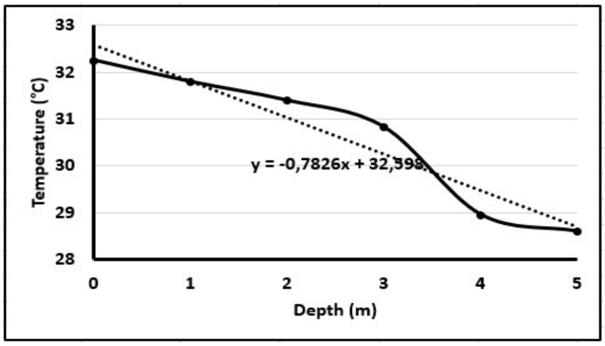

Figure 15: Variation of average temperature according to depth (0m to 5m)

Hêvié is a humid tropical environment where the internal temperature of unconditioned premises is high, even exceeding the external temperature when buildings are overheated. The use of geothermal collectors would be an asset for cooling premises in this environment. As the comfort zone in this environment (a humid tropical environment) is limited by temperatures ranging from 20°C to 27°C [Carrier], the temperature at 5 m depth (28.6°C) is slightly higher than that required for thermal comfort. But this temperature is very favorable for keeping the room in the zone where thermal comfort requires ventilation. By taking into account the effect of perceived temperature as a function of air speed, indoor living conditions can be further improved. But we mustn't forget that air speed can have a negative impact on air-to-ground heat exchangers. For this reason, air velocity in air-to-soil geothermal heat exchangers needs to be the subject of a special study.

CONCLUSION

This study made it possible to determine the ground temperature down to a depth of 10 m in the Hêvié district, with a view to geothermal exploitation for cooling premises. Given the temperature values at different levels in the ground, a geothermal collector could be installed at a depth of 5 m, where the temperature remains constant at 28.6°C. To achieve this, however, we need to rely on the effect of the air velocity cooled in the air-to-soil heat exchangers to be installed. A system of this kind, which fits in well with the objectives of the ODD, could be a solution to overheating in buildings in and around the area.

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