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Alexandre F. Santos*, Heraldo J. L. de Souza, Mauricio P. Cantão, and Pedro D. Gaspar

Analysis of geothermal temperatures for heat pumps application in Paraná (Brasil)

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Abstract: Geothermal heat pumps are broadly used in developed countries but scarcely in Brazil, in part because there is a lack of Brazilian soil temperature data. The aims of this work are: to present soil temperature measurements and to compare geothermal heat pump system performances with conventional air conditioning systems. Geothermal temperature measurement results are shown for ten Paraná State cities, representing different soil and climate conditions. The measurements were made yearlong with calibrated equipment and digital data acquisition system in different measuring stations. Geothermal and ambient temperature data were used for simulations of the coefficient of performance (COP), by means of a working fluid pressure-enthalpy diagram based software for vapor-compression cycle. It was verified that geothermal temperature measured between January 13 to October 13, 2013, varied from 16 to 24 °C, while room temperature has varied between 2 and 35 °C. Average COP values for conventional system were 3.7 (cooling mode) and 5.0 kW/kW (heating mode), corresponding to 5.9 and 7.9 kW/kW for geothermal system. Hence it was verified an average efficiency gain of 59% with geothermal system utilization in comparison with conventional system.

Keywords: geothermal heat pumps; cooling; geothermal temperature measurement

***Corresponding Author: Alexandre F. Santos:** University of Beira Interior, Marquês d'Ávila e Bolama Street, 6201-001, Covilhã, Portugal, E-mail: paidakantsy@hotmail.com
Heraldo J. L. de Souza: Professional College – FAPRO, 2213, Eng. Rebouças Street, Curitiba – PR, Brazil
Mauricio P. Cantão: Federal University of Paraná, 100, Coronel Francisco Heráclito dos Santos Avenue, Curitiba – PR, Brazil
Pedro D. Gaspar: University of Beira Interior, Marquês d'Ávila e Bolama Street, 6201-001, Covilhã, Portugal
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1 Introduction

The word "geothermal" according to Egg & Howard [1], comes from the Greek "geo" (earth) and "thermos" (heat) and is applied to the use of heat from the ground. There are basically two energy applications of geothermal heat. The first is the generation of electricity, typically held in huge generation systems in which water is introduced into the soil of geothermal areas of high temperature, generating steam to drive turbines and generate electricity. Such facilities exist only in places with high geothermal activity, some Asian and European countries. In the Philippines, for example, geothermal energy accounts for 8,900 MW and represents 25% of the electricity generated [1]. The second way to use geothermal energy consists of the use of temperature at constant value below the earth's surface in geothermal heat pumps (GHP). Geothermal heat source favors the increase of energy efficiency and can be used in urban building cooling systems, with an energy saving ranging from 70% to 140% in winter, compared to air heat pumps [2].

According to the EERE (Office of Energy Efficiency & Renewable Energy) [3, 4], agency linked to the Department of Energy, a geothermal heat source is an effective mechanism for energy efficiency and can be used in urban building cooling systems, geothermal (ground-source or water-source) heat pumps achieve higher efficiencies by transferring heat between one house and the ground or a nearby water source. Heat pumps are devices with simple operation and good thermal performance, characteristics that indicate a great potential in the air conditioning market. Although they cost more to install, geothermal heat pumps have low operating costs because they take advantage of relatively constant ground or water temperatures. Geothermal (or ground source) heat pumps have some major advantages. They can reduce energy use by 30%-60%, compared to conventional air conditioning and refrigeration systems. As an illustrative example, during study for the demand curve of the Professional Technical School building costs (ETP), established in Curitiba, it was found that 50% of electricity demand used refer to the consumer cooling and heating [5].

In Brazil, the growth of income in recent decades led to the expansion of refrigeration and air conditioning equipment market and the consequent development of the sector companies. According to the Science Globe [6], six of the 10 weather stations with the highest temperatures worldwide were in Rio de Janeiro; three other pointed to temperatures of other states and the only temperature measured at a station outside Brazil was in the city of El Vigia, Venezuela. The ranking was made by the meteorologist for Weather Forecasting and Climate Studies Center Giovanni Dolif, based on information gathered by 4,232 stations worldwide accessed by the National Institute for Space Research (INPE). The stations that registered the highest temperatures were the Jacarepaguá, in the city of Rio de Janeiro, with thermal sensation of 52 °C, and Joinville in Santa Catarina, with thermal sensation of 51 °C. On the other hand, the winter of 2013 was marked by extremely low temperatures in Curitiba with the return of the snow after nearly 40 years.

Therefore, in a country like Brazil, air conditioning is a necessity and refrigeration and air conditioning systems alternatives that generate energy savings are essential.

According to the EERE approximately 60,000 geothermal heat pumps are installed in the United States, indicating a highly promising market. The air conditioning systems market in Brazil is significant, and there was 60% growth in the residential air conditioning sales compared to the first three months of 2012. However, these systems are conventional and a few geothermal systems installed in the country [3, 4].

Brazil does not have the same climatic conditions of the countries where geothermal heat pumps are widely used, which raises doubts about the technical feasibility of the GHP system. Geothermal heat pumps will achieve a significant share of Brazilian air conditioning market only after the evaluation of the soil thermal potential in different locations, in order to ensure that heat pumps show satisfactory performance in many applications. It is worth mention that currently in Brazil there is scarce information on shallow geothermal temperatures and data on the specific geothermal potential for use in heat pumps due to the lack of installed systems. The evaluation of geothermal potential of a significant surface area will help the assessment of the GHP technology feasibility at regional and national level.

Thus, the need to develop this study to determine the technical feasibility of geothermal heat pumps is clearly justified. The results indicate the possibility of creating a consumer market of cooling systems based on geothermal heat pumps.

This experimental work was developed in the State of Paraná (Brazil). The evaluation of the geothermal potential surface was made by measuring soil temperature at 2 m below the surface, typical depth of geothermal loops in closed loop system (Figure 1), which is the most widely used GHP.

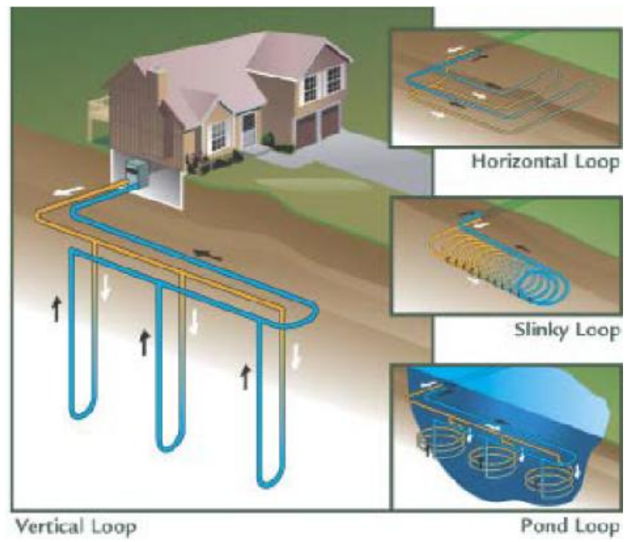

Figure 1: Geothermal heat pump in a closed circuit and thermal bathing ground and lake [3, 4].

The installation of geothermal heat pumps provides reduced power consumption, confirming opportunities for the emergence of the product factories in Brazil. The commercialization of the product in the domestic market may favor the creation of a new market niche in Brazil.

2 Materials and Methods

The selection of cities for the station installation was based on the representation of the different soils of Paraná. Installation locations in different cities were chosen based on ease of measuring the temperature in depth of 2 m, determined primarily by access to the site and carrying capacity of the holes. In these places, the temperature stations have been installed, as shown in Figure 2. The site selection to install the stations prioritized areas covered with awnings to protect sun controllers against the rain, and this fact does not interfere in the obtained results.

The temperature measurement was performed by means of a thermocouple supplied by Full Gauge Controls, inserted and fixed in a PVC tube with a diameter of 9.5 mm. According to the manufacturer, this sensor is in-

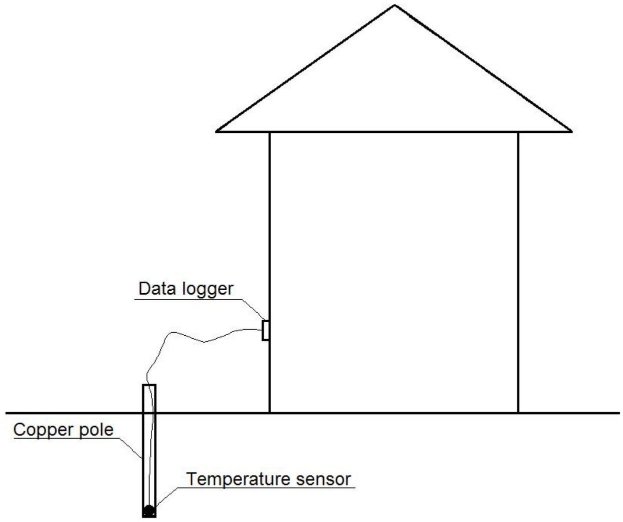

Figure 2: FTemperature analysis station model.

tended for temperature control of cooling systems in conjunction with electronic controllers also manufactured by the company. Figure 3 shows the sensor protected with a PVC film and the sensor-tube assembly installed on the ground.

Figure 3: Sensor (left) and sensor-tube assembly inserted in the soil.

The depth was defined according to Egg & Howard [1], which measured the variation of geothermal temperature in the United States of America (averaged across the country) as function of depth and season. According to the authors, the closest point on the surface and where soil temperatures in summer and winter are almost equal, is located about two meters below the surface level.

Four daily readings were performed making use of a Full Gauge Controls SITRAD system with serial RS-485 interface and a computer. The four readings were performed at the following times of day:

- 2:00 a.m. (dawn, lower external temperature);
- 8:00 a.m. (morning period, influence of radiation east);

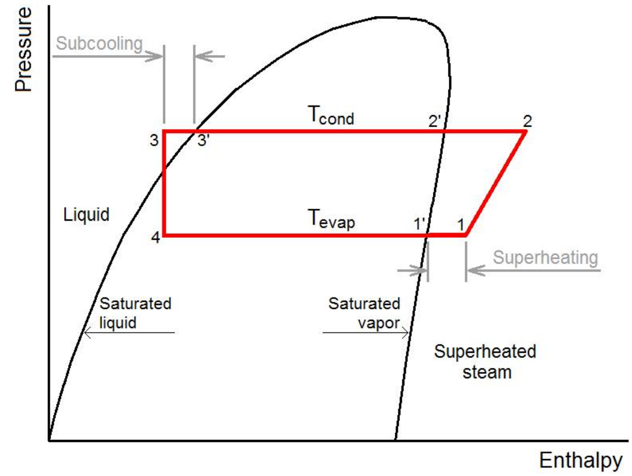

Figure 4: Pressure-enthalpy diagram of a refrigerant.

- 12:00 p.m. (higher external temperature);
- 16:00 p.m. (west irradiation peak).

The device memory is enough to store the 4 daily values for one year.

3 Thermal Performance Assessment

The method to measure the efficiency of a virtual reversible heat pump was the coefficient of performance (COP). The COP of a geothermal heat pump is the ratio of the heating or cooling output to the energy input to run the machine

The results obtained in the measurement stations were used to calculate the COP of a virtual reversible heat pump operating with the ground as the heat source. The COP calculation was performed with the software developed by the company Bitzer GmbH [7]. The calculation is based on the pressure-enthalpy refrigerant diagram (PERD) for the R-410A fluid, adopted in this study. A typical P-h diagram containing the steam compression refrigeration cycle is shown in Figure 4. The COP was calculated from the high pressure (evaporation) and low pressure (condensation) values for superheated refrigerant at the output the evaporator (step 1'-1 in Figure 4) and for subcooled refrigerant at the condenser outlet (step 3'-3). The Bitzer software uses the same calculation principle.

Software input data are: evaporating, T_{evap}, (in winter) and condensation, T_{cond}, (in summer) temperatures, estimated from the values of external, T_{EXT}, and geothermal, T_{GEO}, temperatures. It was also necessary to insert compressor and refrigerant types, and the superheating and subcooling fluid temperatures.

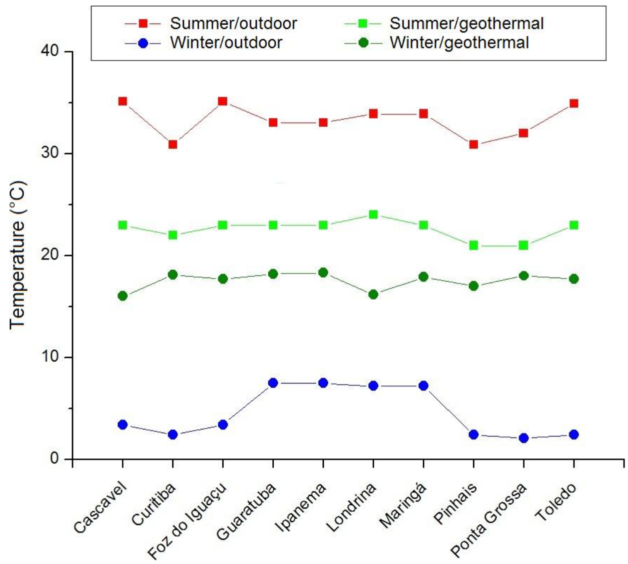

Figure 5: Summary of external and geothermal temperatures, determined in different measuring stations in summer and winter.

The temperature difference (also known as "approach"), ΔT, was determined by means of the system characteristics and of values adopted in real projects of air conditioning systems. For instance: in Foz do Iguaçu city (Iguazu River Mouth) a system was installed with the water cooling tower condensing at 35 °C and water inlet temperature of 29 °C (Santos [8]), resulting in $\Delta T = 6$ °C. On the other hand, the values used for a Curitiba air cooling design consisted in a condensation temperature of 42 °C and an outdoor temperature of 31 °C (Santos [9]), resulting in $\Delta T = 11$ °C. Therefore, ΔT values used in Bitzer software were 11 °C for conventional heat pump and 6 °C for geothermal pump.

3.1 Outdoor temperatures

The temperatures of the outdoor air in measuring stations were obtained from standard basic design parameters settled in Brazilian standard NBR 16401-1/08 [10] or by measurement. Standard design data were used for Curitiba, Foz do Iguaçu and Londrina stations. Tabulated values of these three cities were used for stations located at less than 150 km: Maringa (Londrina), Pinhais (Curitiba) and Cascavel (Foz do Iguaçu). For the remaining stations, the data were obtained from measurements of the winter outdoor temperature, performed in the field using the standard procedure (average of 35 hours warmer or colder months). The design data NBR 16401-1/08 [10] and the measured average values are shown in Table 1.

Table 1: Maximum external temperature of summer and minimum winter.

PLACE/City	T_{summer} (°C)	T_{winter} (°C)
Cascavel	35.1	3.4
Curitiba	30.9	2.4
Foz do Iguaçu	35.1	3.4
Guaratuba	33.0	7.5
Ipanema	33.0	7.5
Londrina	33.9	7.2
Maringá	33.9	7.2
Pinhais	30.9	2.4
Ponta Grossa	32.0	2.1
Toledo	34.9	2.4

3.2 Geothermal temperatures

It was found for all measuring stations that the geothermal temperature changed up to 0.1 °C in one day, 0.3 °C in one week and from 4 to 7 °C during the year, which confirms the thermal stability of soil at 2 m deep. The summer and winter values were obtained from the average of the hottest and coolest 25 hours, respectively, as the procedure stated in NBR 16401-1/08 [10]. Table 2 shows the geothermal temperature values obtained for the summer and the winter in Paraná different stations.

Table 2: Values of geothermal temperatures of summer and winter.

PLACE/City	T_{summer} (°C)	T_{winter} (°C)
Cascavel	22.9	16.0
Curitiba	22.1	18.1
Foz do Iguaçu	23.0	17.7
Guaratuba	22.9	18.2
Ipanema	23.0	18.3
Londrina	24.0	16.2
Maringá	23.0	17.9
Pinhais	20.9	17.0
Ponta Grossa	21.1	18.0
Toledo	23.0	17.7

3.3 Summary of temperature measurements

A summary of all the temperatures obtained in the monitoring stations is shown in Figure 5. The average values are: 33.3 °C (external/summer), 22.7 °C (geothermal/summer), 4.8 °C (external/winter) and 17.5 °C (geothermal/winter). It was found that the difference between the mean outdoor temperature (T_{EXT}) and geothermal temperature (T_{GEO}) is 11 °C in summer and 13 °C in winter. The differences between the average summer and winter temperatures are 28.7 °C for the outdoor temperature and 5.1 °C for geothermal temperatures.

It appears that geothermal temperatures have a lower variation and are less extreme than outdoor temperatures. However, there is no clear trend of temperature dependence with the location, except for the outdoor temperature winter, higher in the cities of Seaside (Guaratuba and Ipanema) and North of Paraná (Londrina and Maringá), as it can be seen in Table 3.

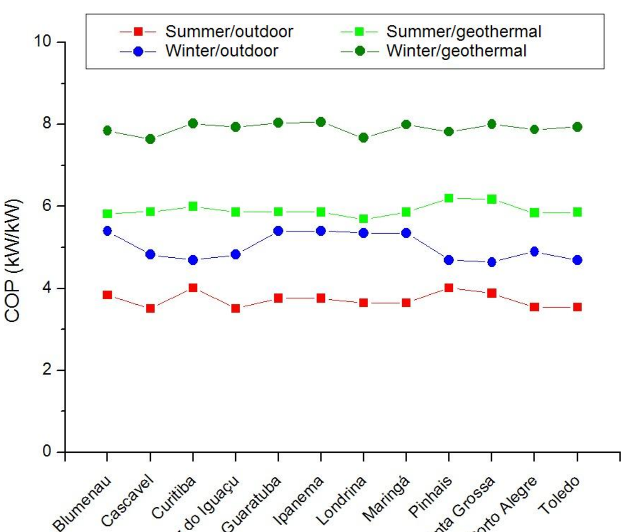

Figure 6: COP values for the measuring stations in alphabetical order.

In summer the difference between the external and geothermal temperature was 11 °C, while in winter this difference was 12 °C. The average efficiency gains was 59% in two temperature extremes, but with greater variation in winter.

The COP values for winter and summer, obtained from external and geothermal temperature data, are shown in Figure 6. The average gain in absolute value of ΔCOP was 2.2 kW/kW for summer and 2.9 kW/kW for the winter, in the ten evaluated Paraná stations.

The efficiency gains values, calculated with the data of Table 3, are shown in Figure 7.

The efficiency gains (ΔCOP) in summer ranged from 50% (Curitiba) to 67% (Foz do Iguaçu), while for winter the efficiency gain ranged from 43% (Londrina) to 72% (Ponta Grossa). Six stations showed efficiency gains over 50% in winter, while in summer the efficiency gains were all above 50%. The average gain values were 59% for both the summer and winter, and in all measuring stations it was found an efficiency gains associated with the use of the geothermal system.

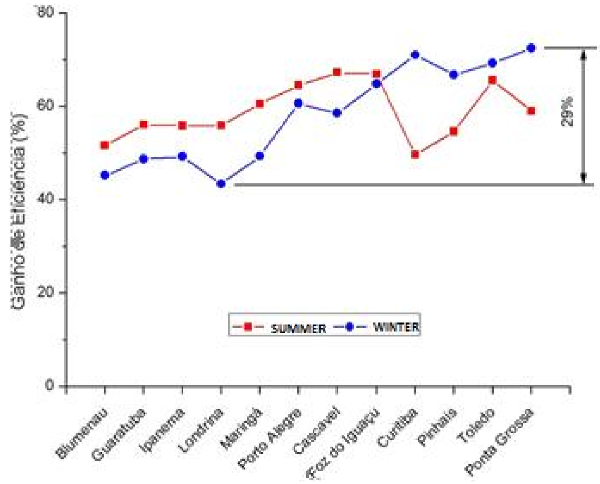

Figure 7: Energy efficiency gain in summer and winter in all stations with the replacement of the conventional system by geothermal system.

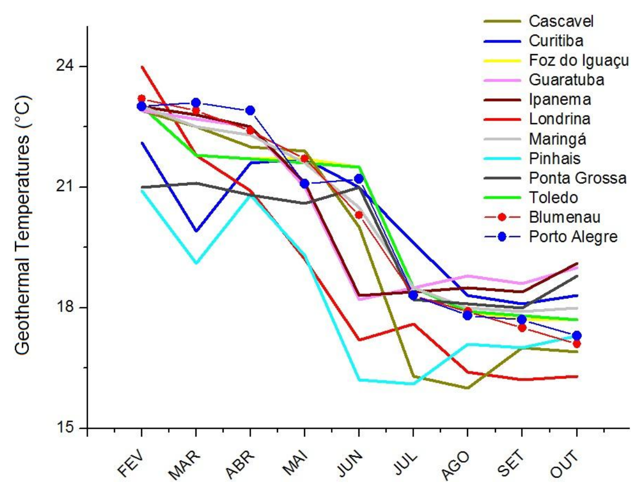

Figure 8: Geothermal temperature between February and October 2013.

The observed efficiency gains is lower than the US-DOE recommended values, between 70% and 140% [2]. This range is expected for the coldest nights of the North American winter, and is consistent with a linear variation of ΔCOP with $\Delta T = T_{GEO}\ \Delta T_{EXT}$ and with the lowest external temperature in the colder states of the USA. However, the situation should be different in summer because temperatures observed in Paraná are higher than in most of the US states. In this case, ΔT (and therefore ΔCOP) should be higher in Brazil.

Table 3: Temperature data, COP and efficiency gain in all Paraná measuring stations.

	T_{summer} (°C)			T_{winter} (°C)			$\Delta T_{averagge}$	COP$_{summer}$ (kW/kW)			COP$_{winter}$ (kW/kW)			ΔCOP$_{average}$
	OUT	**GEO**	ΔT	**OUT**	**GEO**	ΔT	**(°C)**	**OUT**	**GEO**	**ΔCOP (%)**	**OUT**	**GEO**	**ΔCOP (%)**	**(%)**
Cascavel	35.10	22.90	12.20	3.40	16.00	12.60	12.40	3.51	5.87	67.24	4.82	7.64	58.51	62.87
Curitiba	30.90	22.10	8.80	2.40	18.10	15.70	12.25	4.01	6.00	49.63	4.69	8.02	71.00	60.31
Foz do Iguaçu	35.10	23.00	12.10	3.40	17.70	14.30	13.20	3.51	5.86	66.95	4.82	7.94	64.73	65.84
Guaratuba	33.00	22.90	10.10	7.50	18.20	10.70	10.40	3.76	5.87	56.12	5.40	8.03	48.70	52.41
Ipanema	33.00	23.00	10.00	7.50	18.30	10.80	10.40	3.76	5.86	55.85	5.40	8.06	49.26	52.56
Londrina	33.90	24.00	9.90	7.20	16.20	9.00	9.45	3.65	5.69	55.89	5.35	7.67	43.36	49.63
Maringá	33.90	23.00	10.90	7.20	17.90	10.70	10.80	3.65	5.86	60.55	5.35	7.99	49.35	54.95
Pinhais	30.90	20.90	10.00	2.40	17.00	14.60	12.30	4.01	6.20	54.61	4.69	7.82	66.74	60.68
Ponta Grossa	32.00	21.10	10.90	2.10	18.00	15.90	13.40	3.88	6.17	59.02	4.64	8.00	72.41	65.72
Toledo	34.90	23.00	11.90	2.40	17.70	15.30	13.60	3.54	5.86	65.54	4.69	7.94	69.30	67.42
AVERAGE	33.27	22.59	10.68	4.55	17.51	12.96	11.82	3.73	5.92	59.14	4.99	7.91	59.34	59.24
Standard deviation	1.60	0.95	1.12	2.45	0.83	2.51	1.45	0.19	0.16	5.88	0.34	0.15	10.85	6.42

4 Change in Geothermal Temperatures

Figure 8 shows the values of geothermal temperatures in the ten Paraná stations measured between January and October, 2013 [11, 12]. The minimum temperature was 16 °C observed in Cascavel during August, and the maximum was 24 °C observed in Londrina during February.

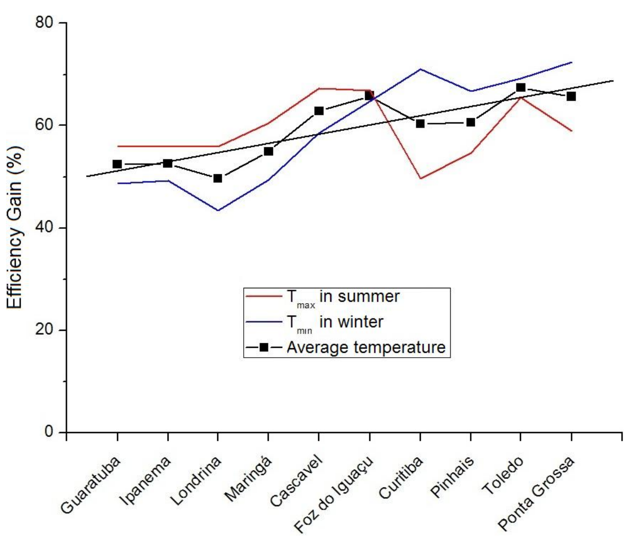

Figure 9: Efficiency gain as function of the winter outdoor temperature (measuring stations in descending order of winter external temperature).

The values shown in Figure 8 form a small data set to the territory of the state, but indicate that it is possible to determine average values of COP, if the measurement is extended to a much larger number of stations and the temperature data geothermal are analyzed along with the average outdoor temperature data. The calculation was not done due to the small number of installed stations and insufficient measurement period for a thorough examination. Considering, however, the significant observed efficiency gains, it is expected that the detailed study should corroborate the technical feasibility of geothermal heat pumps throughout the state territory.

The efficiency gains values for summer, winter and the average of both were analyzed for the different cities as function of the geothermal and outdoor temperatures, with the aim of evaluating a possible trend in the COP variation. No tendency was found, except when the COP gain was ordered according to the outdoor winter temperature, as shown in Figure 9. The lower the winter outdoor temperature, the greater the energy is gained by the use of GHP systems, which explains the difference in the performance observed for the US [2].

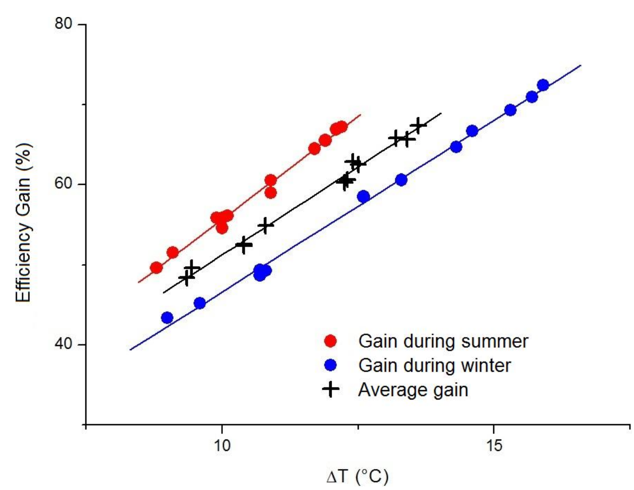

Figure 10: Efficiency gain as function of $\Delta T = T_{EXT} - T_{GEO}$.

Although it was observed a trend of higher gain with lower external temperatures of winter, it cannot be established that there is a direct relationship between ΔCOP and T_{EXT} or T_{GEO}. However, it was found that the average efficiency gain varies linearly with the difference between the external temperature and geothermal ($\Delta T = T_{EXT} - T_{GEO}$). This behavior is seen in Figure 10.

Average values of ΔCOP are important for evaluation of the system during the year. The average temperature difference ΔT varied between 9 and 14 °C, corresponding to a range of average efficiency gains between 48% and 67%. Therefore, a small variation ΔT results in great variation in efficiency gains.

5 Conclusions

Geothermal temperatures of Paraná State are very similar to geothermal temperatures of other temperate climate places like the state of Florida in the United States.

Geothermal temperatures in Paraná State, measured at 2 meters from the surface, showed feasibility for GHP technology with efficiency gains ranging between 20% and 45%. These values are coherent with the values of energy savings reported by USDOE (25% to 50%).

In winter the gain ranging between 43% and 72% and in summer between 50% and 67%.

The purpose of the study was achieved. The evaluation confirmed the viability of the use of an environmentally friendly technology, based on natural resources (land). The insertion of GHP technology can reduce the energy matrix expansion needs in the state of Paraná in Brazil.

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