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Application of Ground Source Heat Pump to a Supermarket in Portugal

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Abstract: The objective of the present paper is to describe a technical and economical visibility study of the application of ground source heat pumps (GSHP) in a supermarket in Portugal. The study was developed under the European project “Integration of Geothermal Energy Into Industrial Application - IGEIA”, project number EIE 06/001, supported by the Intelligent Energy for Europe, IEE, of EACI, European Commission. In general for supermarkets installed in single buildings, the building envelope has higher rates of envelope areas per indoor air volume. In Portugal this fact produces high need of heating during the winter season and high cooling needs during the summer season. Inside the building there are strong internal heat loads produced by high densities of lights and equipments. However these internal loads are not distributed uniformly. There are some areas with high production of heat but there are others with production of cooling. Therefore the acclimatization of this kind of buildings is not so easy and the balance of heating and cooling needs is depending of different parameters which should be well evaluated. The energy consummation of the cold display cases and deep freezers in market area and storage is also very high. The different energy needs could be studied in an integrated way and could be partially satisfied by geothermal energy using ground source heat pumps. At the same time the boreholes could be used as an energy reservoir increasing the efficiency of whole system. Four different climatic zones in Portugal were selected, (north coast, interior north, south coast and interior south) using the same system. The results of the study show that the all energy needs can by partially satisfied by geothermal energy but they need to be integrated to increase the global efficiency. The paper shows that the geothermal energy can be an attractive application for the supermarkets in Portugal if the energy solution is studied in an integrated way and if it is also considered as a cost the emissions of CO_2 avoid by the new system.

Key words: Geothermal energy, ground source heat pump, high efficiency.

1. Introduction

The climatic conditions are a major concern when dealing with geothermal applications, being one of the key factors in determining the thermal energy demand. In general, south Europe has both, cooling and heating demands. In the coast the climate is more pleasant due to the proximity to the sea, contrary to the mainland regions that have summers and winters more demanding. Portugal weather is influenced by topography, latitude and proximity to the sea, which can provide soft winters, especially in the south of the country. At north the winter are colder and it snows at the highest point of Portugal. The summers are hot and dry at north, and moderate at south. The average temperature rounds 13℃ in the north regions and 18℃ in south regions. Regarding to solar radiation, the annual average values diverge along the year, with July being the month with greater solar radiation and December the month with less radiation. The south regions have greater solar radiation than north regions. The follow figures are illustrative of the average temperature and solar radiation in Portugal.

According to the new thermal regulation for buildings, Portuguese climate is divided by regions which have special characteristics. Both summer and

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winter seasons have three zones (V1, V2, V3 and I1, I2, I3). However in summer these zones are also divided in north zones and south zones, so in total we have 6 climatic zones for summer and 3 for winter. The South regions are correspondent to the area south of Tejo River and some areas North-West just above the river as Lisbon region. Table 1 and Fig. 1 show the characterization of each climate regions, concerning heating degree-days and daily thermal amplitudes.

Regarding the geology of Portugal, there is a great diversity due to the different physic-chemical composition of Portuguese mineral water. In general the geothermal potential is directly related to the tectonic features, which beneficiate the circulation of the fluids. Portuguese territory has three different main structures, hesperic massif, meso-cenozoic occidental and meridional front and Tejo and Sado tertiary aquifer. Hesperic massif is formed by ancient soils with metamorphic, sedimentary and magmatic rocks from Pre-cambrico. In the north part of Portugal, abound granite and other plutonic rocks, in the centre and south, schist, limestone, sandstone and quartzite. Fig. 2 shows the geological map with thermal occurrences in Portugal.

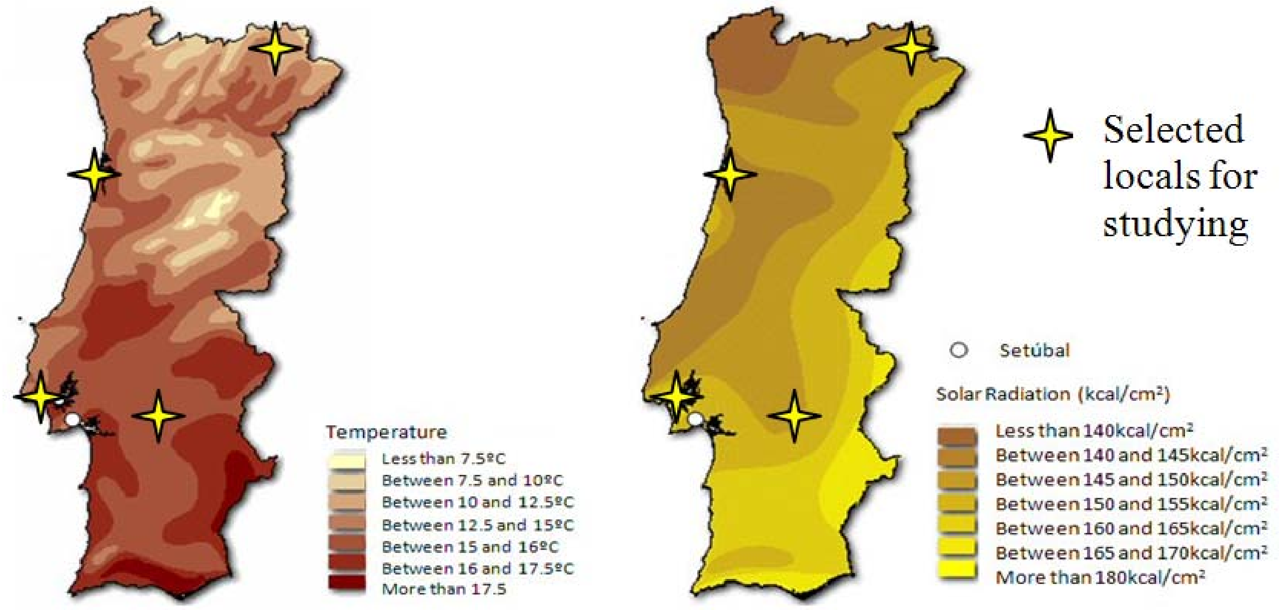

Fig. 1 Average temp and solar radiation in Portugal (Source: Instituto do Ambiente).

Table 1 Climate regions characterization.

Zone	Heating Degree-days (20℃ basis)	Daily Thermal Amplitudes	Notes	Selected locals
I1V1	940 to 1500	Smaller in summer, due to sea proximity	Softest seasons	-
I1V2	1010 to 1490	Smaller in summer, due to sea proximity	Soft climate Special attention in summer	Lisbon
I1V3	1100 to 1470	High, due to mainland influence	Climate drier, due to mainland influence	Evora
I2V1	1530 to 2090	Coast side has smaller daily thermal amplitudes than the mainland side	Winter is more demanding than summer	Porto
I2V2	1510 to 2090	Average thermal amplitudes in summer	Winter is more demanding than summer	-
I2V3	1510 to 2100	High thermal amplitudes	Climate drier Summer is more demanding	-
I3V1	2120 to 3000	Low thermal amplitudes in summer	Winter is more demanding than summer	-
I3V2	2180 to 2860	High thermal amplitudes due to mainland influence	Winter is more demanding than summer	Bragança
I3V3	2150 to 2670	Very high thermal amplitudes in summer, due to mainland influence	Hardest seasons	-

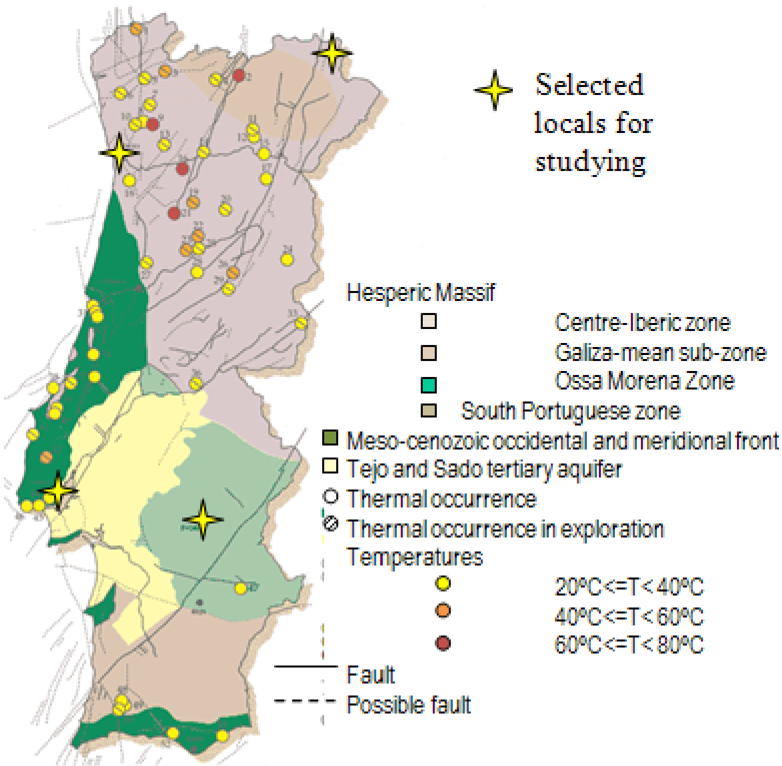

Fig. 2 Geological map with thermal occurrences (Source: INETI, Portugal).

The real supermarket studied is located in Porto region (north coast). However for studying the influence of the climatic conditions it was simulated the same building, but in other three different climatic zones in Portugal. They were selected (interior north, south coast and interior south, see Table 3 and Figs. 3 and 4) to implement a supermarket and to study the option of using geothermal energy to acclimatize the building. The building is composed by a parking, as hopping area, and electrical devices shop, the supermarket selling area, the supermarket administrative area and a technical area. For this study purpose, only the supermarket selling area will be considered, since it is independent from the other areas. The supermarket selling area has 8308 m^2 and an average height of 9.5 m. The ideal temperature is around 20℃ in winter and 25℃ in summer. The roof is made of metallic plates with a 10 cm thermal isolation and it has glass skylights. Currently the acclimatization system is composed by natural gas boilers for heating and chillers for cooling with an ice bank used as a complement of the chillers.

Fig. 3 shows the evolution of the average temperature for the four selected locals (Porto, Bragança, Lisbon and Evora).

2. Methodologies

The heating and cooling loads were calculated through the simulation program HAP 4.31 Carrier's Hourly Analysis Program (HAP), from Carrier. HAP 4.31 is a computer tool used for designing HVAC systems for commercial buildings. HAP can be used for two kinds of studies. HAP can be used for estimating loads and designing systems but also for simulating building energy use and calculating energy costs. HAP uses the ASHRAE-endorsed [1] transfer function method for load calculations and detailed 8,760 hour-by-hour simulation techniques for the energy analysis. The version HAP4.31 is certified by standard ASHRAE 140-2004. This program is released as two separate, but similar products. For present study the need capacity for cooling and heating were estimated by the HAP [2] and they were compared with the installed capacity. After that it was simulated the

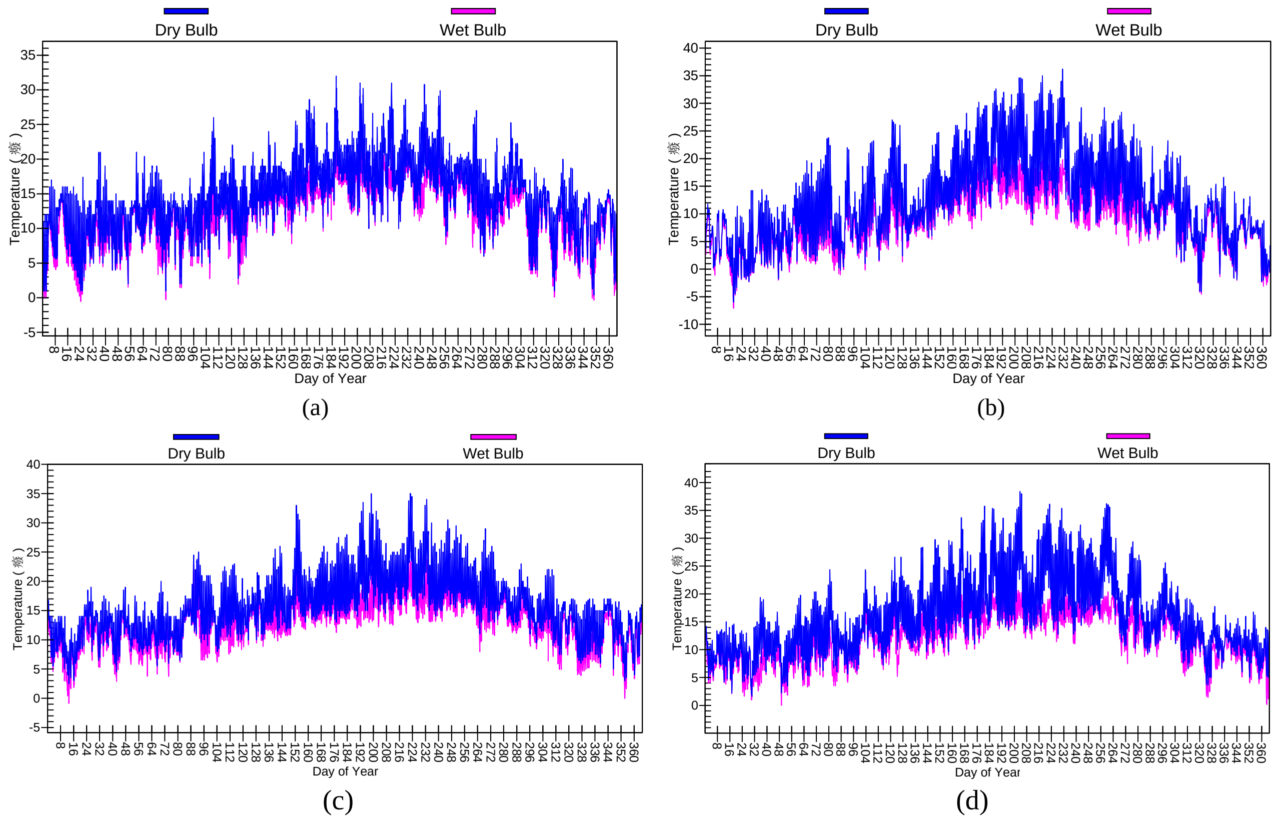

Fig. 3 Average temperature evolution for a typical year (simulation from HAP software): (a) Porto (I1V1North); (b) Bragança (I3V2North); (c) Lisbon (I1V2South); (d) Evora (I1V3South).

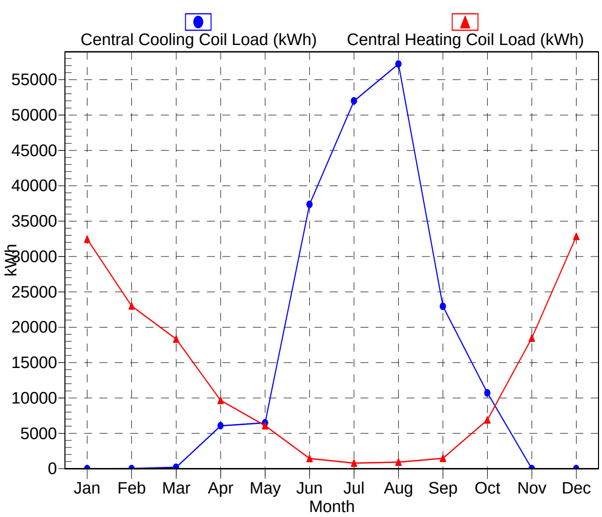

Fig. 4 Monthly simulation loads results for supermarket system (simulation from HAP software) in Porto region.

building to predicted the energy consummation for the installed system. The results were compared with the results from the ground source heat pumps system. The number of boreholes was estimated considering the heating capacity and considering an average value of 60 W/m of extracted heat from the boreholes (75 W/m of heating deliverable into the building). The cooling capacity is partially satisfied by the ground source heat pumps and by the ice banks and auxiliary air chillers. For a correct estimation of the number of boreholes it should be used a dedicated software as the software EED [3]. During the drilling of the boreholes the total of boreholes length should be confirmed due the uncertainness as the presence of water flow in the underground and the non-uniformity of the soil composition, to obtain a correct number. There are some equipment that could done the Thermal Resistance Test of the soil as the TRT-equipment of UBeG GbR [4, 5].

3. Results and Discussion

Considering the supermarket heating needs in different region, since the cooling needs can be compensated, if necessary by the ice bank and auxiliary

Table 2 Number of boreholes and total deep results.

Boreholes calculation	Porto	Bragança	Lisbon	Evora
Heating capacity (kW)	256	344	234	252
Deliverable power (kW/m)	0.075	0.075	0.075	0.075
Boreholes total deep (approximately) (m)	3,413	4,587	3,120	3,360
Boreholes deep (approximately) (m)	150	150	150	150
Number of boreholes	23	31	21	23

Table 3 Cost of perforation and ground source heat pumps.

Costs	Porto	Bragança	Lisbon	Evora
Perforation cost (€/m)	35.0	35.0	35.0	35.0
Boreholes heat exchanger total costs (€)	120,750	162,750	110,250	120,750

air chiller, and an deliverable heating power into the building around 75 W/m of the borehole, the total deep of the boreholes was calculated, as well as the number of boreholes, considering a deep of 150 m per borehole. The results are showed in Table 2.

It was considering that the main difference in the installation costs for the different systems (boilers plus air chillers versus ground source heat pumps) is the boreholes costs. Taking into account these results a preliminary cost study was performed, considering the perforation cost of 35€/m, the total costs are presented in Table 3.

Comparing the current acclimatization system and the building needs, the annual costs and a simple payback were calculated, through HAP software. Thenext figure shows the monthly simulation results of cooling and heating needs, for supermarket in Porto region.

As the system has heat recuperation from the extracting air, the central cooling load has a higher peak comparing with the central heating, considering the all year. To have an idea of the different energy consumer's costs, the annual component costs are represented in the Fig. 5 and Table 4. The detailed study will be present only for the supermarket located in Porto.

As we can see, the non HVAC components have the highest costs in this building. Considering the HVAC components, object of this study, the heating components have higher costs comparing to the cooling costs. Monthly component costs can also be analyzed in Fig. 6 and Table 5. The table has only the results for the HVAC components, object of this study.

From the graphic is possible to see the most demanding months for heating and for cooling. As expected, from October to May, the heating demands are higher and from June to September are the cooling demands, as it can be concluded from the costs of HVAC components. Considering the total costs, the months of January, July, August and December have highest costs, since they are the most demanding months, concerning cooling needs, July and August, and heating needs, December and January.

From the results it is possible to see that the electric costs are a very important element. For these reason, a simple payback was made, considering the electric consumption of the different options. From Table 6, the

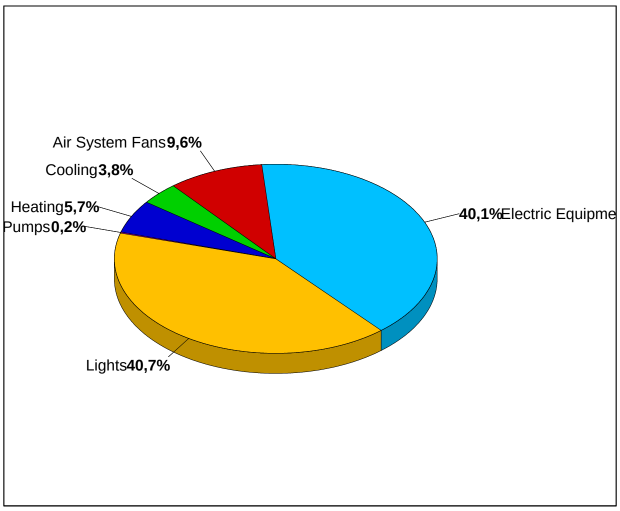

Fig. 5 Annual component costs.

Table 4 Annual component costs.

Component	Annual Cost (€)	(€/m²)	Percent of Total (%)
Air System Fans	15.926	1.917	9.6
Cooling	6.362	0.766	3.8
Heating	9.415	1.133	5.7
Pumps	271	0.033	0.2
HVAC Sub-Total	31.974	3.849	19.2
Lights	67.646	8.142	40.7
Electric Equipment	66.763	8.036	40.1
Non-HVAC Sub-Total	134.409	16.178	80.8
Grand Total	166.382	20.027	100.0

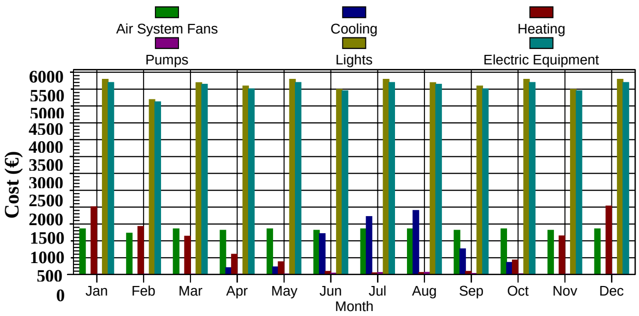

Fig. 6 Monthly component costs.

Table 5 Annual energy costs.

Component	Annual cost (€/yr)	(€/m²)	Percent of total (%)
HVAC components			
Electric	22.558	2,715	13.6
Natural gas	9.415	1,133	5.7
HVAC sub-total	31.974	3,849	19.2
Non-HVAC components			
Electric	134.409	16,178	80.8
Non-HVAC sub-total	134.409	16,178	80.8
Grand total	166.383	20,027	100.0

Table 6 Annual energy costs, savings and payback (Porto region).

	Geothermal Energy Option	Natural Gas Boiler and Chiller option	Annual saving
Heating costs (€)	3078	9415	6337
Cooling costs (€)	4873	6362	1489
BHE total costs (€)	120750		
Payback (years)		15.5	

heating and cooling costs are 9415€ and 6362€ respectively. Considering the geothermal heat pump with a COP of 5 and an EER of 4 and a heating useful energy of 152375 kWh and for cooling 192992 kWh, the comparison of costs and payback period for heating and cooling are presented in Table 6.

Same calculations were made for other locations. The pay back times are: Bragança, 10.9 years; Lisbon, 14.7 years; Evora 12.1 years. The payback times correspond to the high values. To decrease the payback time in this kind of applications, the heating and cooling system by GSHP should to be integrated into to the refrigeration system. It was also studied the decrease of primary energy consummation (kgep), using the conversion factors of the Portuguese regulation (0.29 kgep/k Whelect and 0.086 Kgep/kWh fossil fuels) and the decrease of CO_2 emissions. The decrease of primary energy consummations varies between 28% and 32% (cooling about 25% and heating about 40%), highest value for Bragança, lowest value for Lisbon. The decreases of CO_2 emissions proportional, therefore it is from 28% to 32%. Some studies show that it is possible to achieve higher global energy saves in the supermarket, if the GSHP is integrated with also the refrigeration display cases energy system of the supermarket. One of the most important studies in the market was made by EGEC (Sanner, 2008) in the European project IGEA.

4. Conclusions

This study shows that it is possible to use GSHP in supermarkets, especially substituting boilers in heating, integrated with chiller and ice banks dedicated to cooling needs. This application can achieve very important energy savings (decrease of primary energy consummations between 28% and 32%, cooling about 25% and heating about 40%), contributing also with important CO_2 emissions reductions (from 28% to 32%).

One of the most interesting developing field in this area, is the integration of the cooling demands of the refrigeration display cases in the system. It was shown that elsewhere the payback period will probably vary between 10 and 15 years depending of the specific supermarket.

So we can conclude that GSHP can be very important in reduction of energy consumption in supermarkets, but its application should be carefully studied, case by case, and if possible integrated with other system, as a way to reduce payback period and increase economic viability.

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