Some comments about the use of GHP in Alentejo (Portugal)

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ABSTRACT

In this work we advocate the use of geothermal pumps to cool the isolated houses that can be observed in the plain of Alentejo. Passive cooling of the houses, made for centuries, becomes insufficient when it aims to promote tourism in the region. The climatic characteristics of the region and the relatively high values of the thermal conductivity of the ground favour this type of use. The available land around the houses provide places where you can drill or make trenches to put the pipes under the surface . Some values of pipe lengths were obtained using values appropriate for the region. The need to try to preserve the shape of the typical houses of the region discourages the use of solar panels placed on the roofs. The length and time of use of the equipment is another factor to take into account in the analysis of the costs.

1.INTRODUCTION

The South of Portugal is known to be one of the regions of the world with high number of hours of sunshine and cloudless days. Local inhabitants live in very old cities with a rich historical and architectural heritage or in small villages. In the countryside we can find small clusters of typical houses called "montes alentejanos"(see Figure 1). These houses have been used by farmers and cattle farmers, but , in the last years, some of them have been used as guest houses or habitation tourism. Historically these houses have been heated in winter, using wood burned in fireplaces with a typical chimney. The heat of the fire can be used to heat water that can be distributed over selected parts of the house. In the summer, this system cannot be used because air temperatures outside the houses are relatively high, and despite the typical characteristics of the houses in the region, a cooling system is desirable. In this work, the advantages of the use of GHP in these houses are presented, especially as cooling systems, during hot days.

2. REGION CHARACTERISTICS

Geologically speaking, the region is very old and very eroded. The main altitude of the region is around 200 m above sea level. Sometimes this region is

Figure 1. A typical house named "monte alentejano".

designated by Alentejo Plain, but this is the result of an elevated erosion rate during an elevated number of years, that originated the present topography.

2.1 Climate of the region

This region has a very special climate. In summer it is very hot and dry, reaching high air temperatures (maximum values above 40°C can be measured in some places, during several consecutive days). In the coldest season (Autumn and Winter) occurs heavy precipitation, with the possibility of flooding. We can see on Figure 2 a graph of the average monthly values of air temperatures measured in the locality

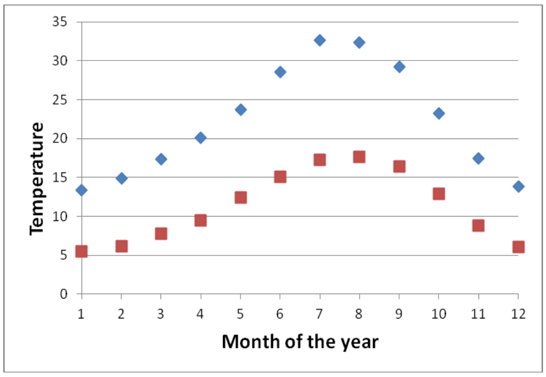

Figure 2. Graph of average (maximum and minimum) monthly temperatures obtained in different months of the year in Amareleja

Amareleja. This is the place where the highest temperature values were measured in Portugal. We can see that average maximum temperature values are obtained in July and August and lowest minimum temperatures are obtained in January. The difference between the highest and the minimum average temperature value is 14.6 °C, in Amareleja. Using values obtained in another places in the region, we can find values between 12.8 °C (Ourique) and 15.6 °C (Santo Aleixo da Restauração).

The lower amount of precipitation occurs in July and August, with values of 2 or 3 mm per month. The largest values of precipitation occurs in November, December and January. The amounts obtained belongs to the interval between 73-74 mm , in Amareleja, and 86 mm, in Castro Verde and Ourique. The average annual precipitation in Amareleja is 533 mm. This is the small value of precipitation found in the region.

2.2 Thermal properties of the soil

Heat flow density data obtained in the region (Duque and Mendes-Victor,1993; Correia, 2015) present elevated values, due to high thermal gradient values (between 20 and 30 °C) and high thermal conductivity values (between 3.03 and 4.65 W K^{-1} m^{-1}). These values were obtained using samples taken from boreholes at different depths. Although the values near the surface are relatively lower, it appears that during the dry season (June, July and August), due to the very low values of precipitation, the thermal conductivity values must decrease near the surface and the upper soil acts as an obstacle to the propagation of heat, from the air to the soil, resulting in soil temperatures lower than those expected with the air temperatures measured in the region. Temperature measurements in boreholes show that it is easy to find temperature values around or over 20°C at 60 m depth, in the region.

2.3 Water in the region

The houses located in the middle of the plain do not have lakes in the surroundings, with the dimensions needed to be used in open refrigeration systems. For this reason, it is necessary to work with underground aquifers located near the houses or to introduce water in the soil during the assembly of the system that works as a closed system. It is common to find near the houses boreholes with water for household use, that in many cases could be used in the cooling system.

2.4 Typical houses in the region

Typical houses in the region have only one floor. The external walls are painted white, with yellow or blue bars. The doors of the houses are made of wood and the windows are protected by wooden doors. The roofs are covered with tiles made with clay. In the warm season, the local inhabitants close the doors of the houses and the protecting doors of the windows during the day, preventing the heat input from the outside. During the night, the windows are opened for ventilation. This system, used for centuries, does not work if the houses have people inside during the day, and/or the doors and windows are opened. This makes the need of artificial cooling methods.

3. GEOTHEMAL HEAT PUMPS

Geothermal heat pumps are one of the most energy efficient and lower cost effective cooling and heating systems available. They use much less energy than conventional heating/cooling systems and they deliver 3 to 5 times the energy they consume. Ground Heat pump (GHP) design is based on soil properties, the type of ground material, moisture content and ground temperature.

The heating efficiency of a ground-source heat pump is indicated by the coefficient of performance (COP), which is the ratio of heat provided per energy input. The cooling efficiency is indicated by the Energy Efficiency Ratio (EER), which is the ratio of the heat removed per hour to the electricity required (in Watt) to run the unit. COP values associated to ground source heat pumps are between 3.0 and 5.0. The EER values for ground source heat pumps are, generally, in the range of 15 to 25.

3.1 Ground loop systems

The ground loop systems can be closed systems (they can be horizontal, vertical and pond/lake systems) and open systems.

In most closed-loop geothermal heat pumps circulate an antifreeze solution through a closed loop that is buried in the ground or under water. Due to the soil temperatures in Alentejo we don't need to use the antifreeze, using only water. A heat exchanger transfers heat between the refrigerant of the pump and the water in the closed loop. Because we have isolated houses we do not have the problem of sufficient land available and it is possible to install vertical and horizontal heat systems. Pond/lake systems or open-loop systems are not recommended for this region due to the scarcity of water resources.

Placing the vertical loops in the ground requires more expensive drilling than horizontal systems. However, as the pipes are buried deeper in the ground (50 to 100 m) they are in a more stable thermal zone (the temperature in the ground at 50 m does not vary during seasons).Vertical systems can be a good option in the region. Horizontal systems are cheaper to install as the loops are installed in a trench (1 or 2 meters below the surface) and trenching is cheaper than drilling. They are also a better option with soils including hard rocks. A disadvantage of the horizontal systems is that they are more affected by weather and air temperature fluctuations because of their proximity to the surface.

The length of the pipes needed depends on the properties of the soil, borehole geometry, the operation of the heat pump and the characteristics of the loop tubes. The thermal properties of the soil and grout, the borehole spacing, the shank space and the ratio of heating load to cooling load are the most important factors.

3.2 Vertical systems

In vertical GSHP systems, the ground heat exchangers consists of one to several boreholes containing one or two U-tubes through which the heat exchange fluid circulate. On figure 3 we can see a schematic representation of a cooling cycle of a GSHP. We can

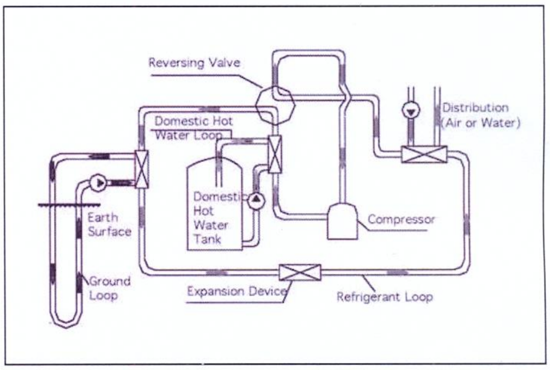

Figure 3. Schematic representation of the cooling cycle of a GSHP (adapted from Ping et al, 2007).

see on the figure three system loops (a ground loop, a refrigerant loop and a distribution loop). In order to optimize the design of a GSHP it is necessary to study the particular properties of the three loops. We are talking about the ground loop. Using the model presented by Ping at al (2007), we can see on Figure 4

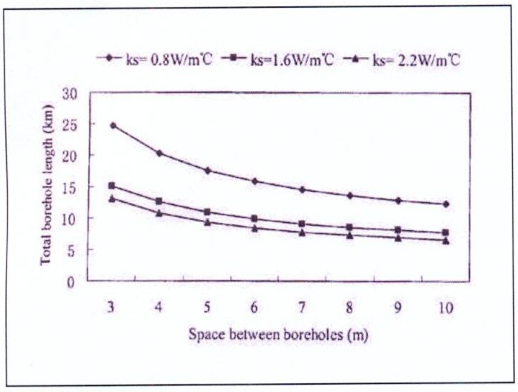

Figure 4. With high soil thermal conductivity values the total borehole length obtained is lowest for the same space between boreholes (adapted from Ping et al, 2007).

a graph showing the total borehole length as a function of the space between boreholes, using different values for the thermal conductivity of the ground. We can see that borehole length decreases for higher thermal conductivity values. The thermal conductivity of 2.0 W m^{-1} K^{-1} allows a 45% reduction in the total borehole length over a thermal conductivity of 0.8 W m^{-1} K^{-1}.

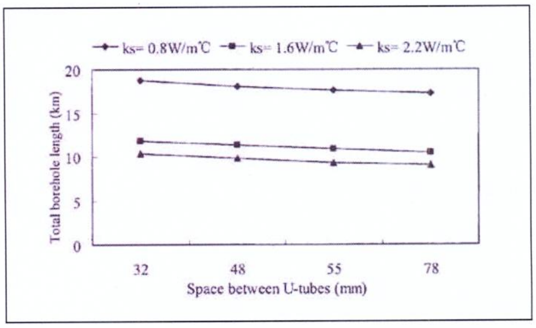

Figure 5 . Effect of the space between U-tube pipes in borehole length for three soil thermal conductivity values (adapted from Ping et al, 2007).

On figure 5 we can see that the space between the U-tubes is smaller for high thermal conductivity values of the soil. Using these results, we can say that the high thermal conductivity values found in the ground of Alentejo can be associated to a lower length of boreholes and small space between U-tube pipes.

Another important parameter related with the length of underground piping needed are the heating and cooling loads (energy demands of the houses) and the amount of time the load demand will be imposed to the system. The heating and cooling loads of the ground heat exchanger are related to the house loads and performance characteristics of the heat pump.

3.3 Horizontal systems

In order to have an estimation of the pipe length needed to cool our houses we use the model presented by Glassley (2010) using the equation [1], where L_C is

$$L_c = \{ (C_c)x\ [(EER+3.412)/EER]x[R_P+(R_s x F_c)]\} / (T_{max} - T_H) \quad [1]$$

the length of the pipe needed, R_P is the thermal resistance of the pipe, R_s is the thermal resistance of the ground, T_{max} is the maximum fluid temperature for the selected pump, T_H is the maximum soil temperature at the depth of the installation, F_c is the fraction time the cooling period will be operating and C_c is the cooling load. Taking into account the temperature data recorded in the region (see Figure 2) we can say that it is justified cooling the houses during four months of the year and heating during another four months. In spring and autumn, given the characteristics of the houses, natural climate will suffice. The heating and cooling loads depends on the area occupied by the house, the number of rooms and number of people living inside the house, particularly during the day. We are going to take as a reference the minimum value of 1 KW and the maximum value of 10 KW. The COP value of the heat pump used is 3.6 and the EER value is 17.5. Pipe thermal conductivity is 14.8 W K^{-1} m^{1} (thermal resistance R_p=1/14.8= 0.0676 W^{-1}K m). The results obtained for different thermal conductivity values of the ground are summarized in Table 1 and Figure 6.

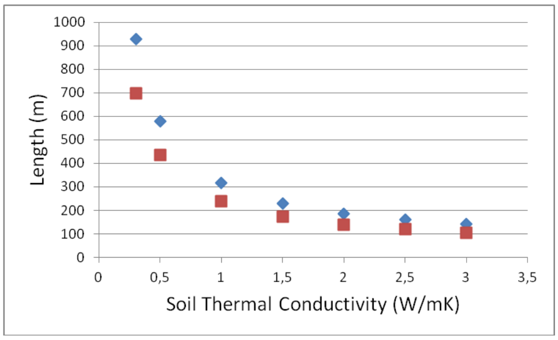

Figure 6.Computed loop length for cooling, closed-loop ground source heat pump systems. T_{max}-T_H values of 15°C (blue) and 20°C (red).

The values in the graph were obtained for a cooling load of 10 KW and a EER of 17.5. The values obtained for ground thermal conductivities between 1.5 and 3.0 belongs to the interval between 100 and 200m. The values obtained using a EER value of 15.0 are shown on Table 1. L_1 and L_2 are values obtained for C_c value of 1 KW and T_{max}-T_H values of 15°C and 20°C, respectively. L_3 and L_4 values are obtained using C_c of 10 KW.

Table 1. Length values obtained for a closed-loop ground source using an EER of 15.0

R_s	L_1 (m)	L_2 (m)	L_3 (m)	L_4 (m)
0.33	14.5	10.9	145.0	108.6
0.40	16.4	12.3	163.7	122.7
0.50	19.1	14.3	190.7	143.0
0.67	23.7	17.8	236.6	177.4
1.00	32.6	24.4	325.7	244.3
2.00	59.6	44.7	595.7	446.8
3.33	95.5	71.6	955.0	716.2

The results show clearly that in grounds with thermal conductivity values of 0.3 or 0.5 W $K^{-1}m^{-1}$the lengths obtained are too elevated. This is not the case in the region studied.

4. MORE REASONS TO MAKE OUR CHOICE

We could use solar energy for heating and cooling homes but there is a problem alteration the landscape and the external appearance of the traditional houses of the area with the placement of solar panels on the roofs. The placement of solar panels on the ground close the housing, it is not recommended due to possible vandalism problems or problems caused by weather events. The high temperature values that sometimes are measured in the region, can decrease performance and the life time of the equipment.

With ground source heat pumps, the piece of equipment that is out of the house is buried in the ground and the remaining part is placed indoors. There is no equipment on the ground that may be subject to problems of vandalism or weather events. The lifetime, supplied by manufacturers, for equipment placed inside house is from 20 to 25 years, and the material placed on the ground is from 25 to 50 years.

Although a significant portion of the electricity used in Portugal be obtained in hydro and wind power plants and in the short term all the coal plants will be closed, the use of methods such as proposed may contribute to a reduction in the emission of greenhouse gases in the region. On the other hand, the electricity in Portugal continues to have relatively high prices, and so we need to try to use methods that reduce the consumption of electricity.

5. CONCLUSIONS

The reasons found for the use of GSHP in the study area are related to the need to preserve the characteristics and appearance of typical houses in the region, as well as equipment safety. The thermal properties of the soil (high values of thermal conductivity) and the temperatures recorded in the region contribute to the length of the tubes in the ground be relatively low. The relatively high value of the electricity network in the region and the equipment lifetime are reasons to encourage the use of the proposed equipment.

The installation price of a geothermal system can be higher than conventional cooling systems with the same cooling capacity, but additional costs are returned, due to the lifetime of some equipment and the electricity saved.

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