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An attempt to increase the performance of a climatizing system using water from boreholes, in an old building

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ABSTRACT

This paper shows part of a broader work made with the aim of studying a climatizing system of an old building. We studied the influence of the temperature variations at the surface, to the temperatures measured in the holes and we conclude that at 0.7 m depth (depth where the pipes are buried) the diurnal variations can be neglected but seasonal temperature variations affect the temperature measured in the holes. We made also a model for the flow and temperature of the fluid in the pipes. Temperatures versus radius of the pipes were obtained for a winter day and a summer day at several distances of the holes. Water temperature in the hole at 30 m depth is 19°C.

With this study we cam say that the temperature of the water in the pipes is influence by air temperatures and a more detailed study must be done in order to increase the efficiency of the system.

INTRODUCTION

This work is done with data obtained in the air conditioning system of the old building of the University of Évora, dating from the 16th century. In order to obtain an adequate temperature in the rooms covered with tiles of the 17th century, a system was built, that uses water obtained in four boreholes made for that purpose. The water retrieved from the reservoir circulates at 70 cm depth, from boreholes traversing the top of the reservoir to a heat pump that heats the water in winter and cools it in summer. After circulating in the building, the water returns to the holes. The device is operational, but the efficiency obtained is low. The aim of our work is to optimize the conditions of transport of the water from the holes to the reservoir, in order to minimize temperature fluctuations.

1.THE DEVICE USED AT ÉVORA UNIVERSITY

1.1 The reservoir

In order to delineate the lateral borders of the aquifer, four holes were drilled approximately 100 meters from each other. The maximum depth of the holes was initially 100 meters , but now is less. The main geologic unit traversed by the holes is granitoid gneiss and sometimes migmatite, amphibolites and halite (Azenha, R.L.,2009). The lithological logs show narrow regions of fractured material at some depths.

Flow tests performed in the holes show flow rates between 600l/hour (hole RA4) and 9000l/hour (hole RA2). The studies of flow and those obtained using the device, show hydraulic interaction between holes RA1 and RA2. The amount of water that passes from RA1 to RA2 is about 6300l/hour and the amount that passes from RA2 to RA1 is about 5300l/hour. This fact may be related with the different values of hydraulic transmissivity obtained in holes RA1 and RA2. No hydraulic connection was found between the hole RA4 and the other holes. The hydraulic transmissivity values obtained are 0.30 m^2/day in hole RA4 0.41 m^2/day in hole RA3,0.80 m^2/day in hole RA2 and 2.64 m^2/day in hole RA1(Montes,V.,2009). This low values of transmissivity indicates that the flow is made mainly through fissures.

1.2 Soil and air temperatures found in Évora

Mean air temperature values obtained in Évora in January vary between 5.8ºC and 12.8ºC. In July and August we have mean air temperature values between 16.3ºC and 30.2ºC. Sometimes we have temperatures of 1 or 2ºC in winter and 40ºC in summer. The pipes through which water circulates are at 70 cm depth. Temperature values obtained in soil, covered with grass, in 2012, near the city of Évora, show values of 13ºC at 70 cm depth in January and 24ºC in August. Temperature variations at 70 cm depth are of the order of 0.2ºC. Although the penetration depth depends on the thermal conductivity of the material being studied, and the thermal conductivity of the gneiss is higher than the thermal conductivity of the soil, we can use, as a first approach the temperatures measured. Another factor that makes temperatures less elevated is that the soil surface is covered with grass that sometimes is watered. The soil in the area of the holes is stripped of vegetation. Figure 1 shows temperatures obtained at different depths during one day in January. We can see that temperatures of the soil at 0,70 m depth are near 13ºC.

With the aim of studying the temperature in the holes, we put, in hole RA4, temperature sensors at depths of

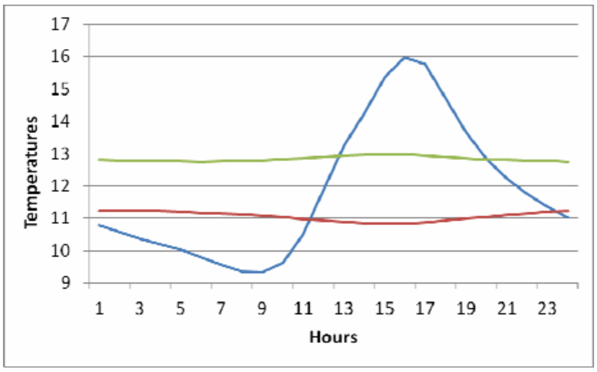

Figure 1: Temperatures obtained in the soil at depths of 0m (blue), 0.30 m (red) and 0,70 m (green).

sensor at the depth of 75 meters, only worked for a few days, and now is damaged. Figure 2 shows temperature values obtained at 0.2,0.7 meters and at the surface, during one day. If we compare these values with those presented in Figure 1 we conclude that temperature at 0.7 m depth in the hole presents a higher variation in Figure 2 than in Figure 1. This fact may be related with the absence of water at this depth and the probe to be measuring the air temperature. In Figure 3 we can see temperature values obtained in the same hole since January 2013, at the same depths.

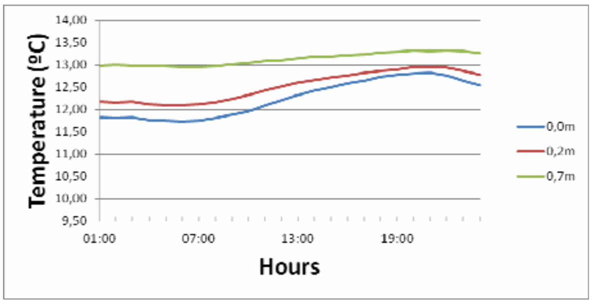

Figure 2: Temperatures obtained at three different depths in borehole RA4 during one day of January 2013.

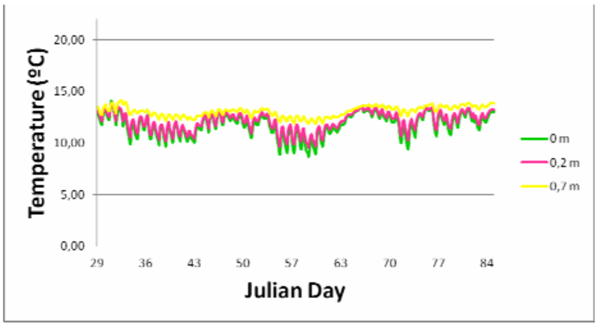

Figure 3: Temperature values obtained in borehole RA4 since January 2013, at three different depths.

In this graph we can see clearly temperature variations at 0.7 meters depth. We can see also that temperature values are increasing due to atmospheric temperature values more elevated.

Temperatures obtained at 0.70 m depth in holes nearby Évora show values of 30°C. This means that seasonal temperature variations must affect the temperature values at 0.7 m depth and the temperature values of the water inside the pipes.

Figure 4 shows temperature versus depth values obtained in borehole RA4 in a day of January 2013, at three different hours. We can see that temperature values are around 19°C and at 50 m depth we can see that temperature values are different at different hours. The lithological log shows at 49 m depth a narrow zone with small fractures. The thermal gradient obtained from 30 to 90 m is very small (11.7°C/km). If we use the value of 3.0 W $K^{-1}m^{-1}$ for the thermal conductivity of the Gneiss (Jaupart and Mareschal,2011) we obtain a value of 36 mW $m^{-2}$for the heat flow. This lower value means that water in the hole is not in thermal equilibrium with the surrounding medium. In Figure 5 we can see temperature values obtained in the same hole at 30, 50 and 90 m depth, since January to March 2013. We can

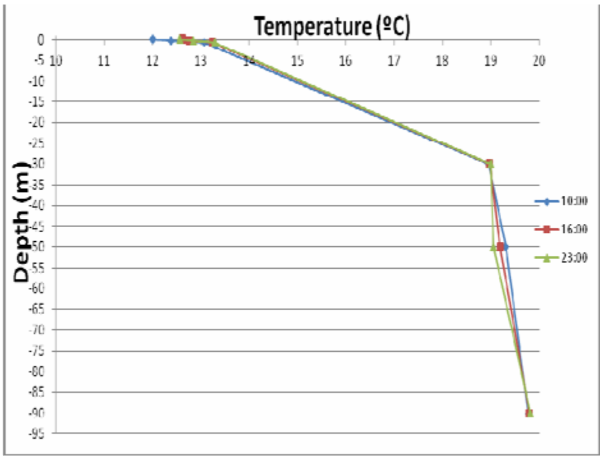

Figure 4: Temperature versus depth values obtained in borehole RA4 at three different hours of a day in February of 2013.

see the temperature variation at 90 meters depth (yellow) due to temperature variation at the surface. The temperature at 90 m depth is increasing from January to March During the time interval in which the measurements were made no entry of rainwater was detected in the hole, although the month of March have been extremely wet.

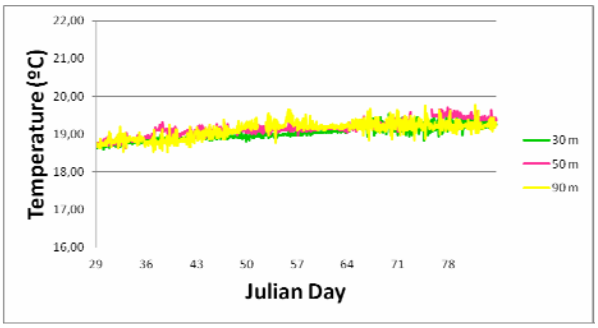

Figure 5: Temperature values obtained at 30, 50 and 90 m depth since January to March 2013.

2. TEMPERATURE OF THE WATER IN THE PIPES

When the water arrives to the reservoir in winter, its temperature is lower than the temperature in the borehole. In summer the temperature is higher than the temperature at the borehole. In order to study the variation of the temperature in the pipes, we used a model involving both fluid flow and heat transfer (Turcotte and Schubert, 2012).

2.1 The model used

If the flow is steady so that the temperatures of the fluid does not change in time and if axial heat conduction is unimportant compared with heat advection by the flow, the net effects of radial heat conduction and axial heat convection must balance. The equation studied is

$$\rho u_m c(\delta T/\delta x) = K [(\delta^2 T/\delta x^2) +[(1/r)(\delta T/\delta r)]] \quad [1]$$

T he boundary conditions used were

$T = T_w$ at $r = R$ (internal boundary of the pipe)

with $T_{w=} C_1 X + C_2$ and the other boundary condition is $q_r = 0$ at $r = 0$ because there is no line source or sink of heat along the axis of the pipe.

The solution of equation [1] with these boundary conditions is

$$T = C_1 X + C_2 + \theta(r) \quad [2]$$

where C_1 and C_2 are constants, and

$$\theta(r) = - [(\rho c u C_1 R^2)/(8K)] x \{3-4 (r^2/R^2)+(r^4/R^4)\} \quad [3]$$

The flow.-weighted average excess fluid temperature is

$$\Theta_m = - (11 \rho c u_m C_1 R^2)/(48 K) \quad [4]$$

2.2 Values used and results obtained

The values used for water and rock properties are summarized in Table 1.

Table 1: Properties and values used in the model

Property	Value
Water density	$\rho = 1000$ kg/m^3
Water specific heat	c = 4180 J/kg
Mean velocity of water	u_m= 0.85 m/s
Pipe radius	R=25 X10^{-3}m

Constant values C_1 and C_2 used for winter days are C_1= -0.004 and C_2 =13. For summer days we used C_1=0.008 and C_2=30. These values were calculated based on measured temperature values located near the city of Évora. The value used for the distance between the boreholes and the water deposit is 250 m.

Figure 6 and figure 7 show temperature values as a function of radius for a few points along the path of the water, between the holes and the deposit of the heat pump.

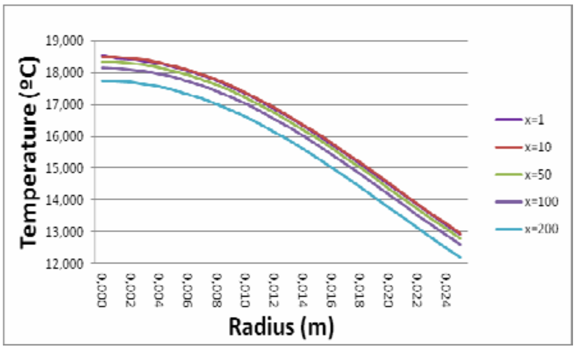

Figure 6: Temperature values versus radius in a winter day.

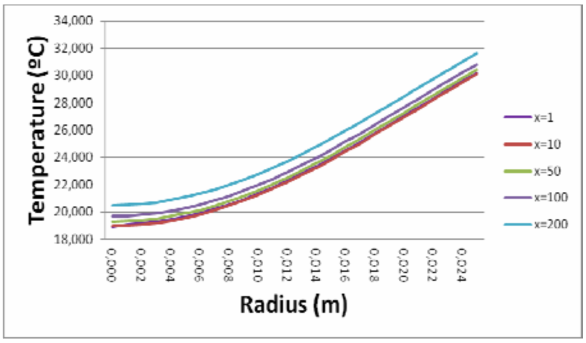

Figure 7: Temperature values versus radius in a summer day.

Table 2 shows mean temperature values obtained near the hole and near the deposit of the heat pump.

Table 2: Average temperature values in the beginning and at the end of the pipe

Location	Winter	Summer
X= 1m (near the hole)	16.4	23.2
X=250 m (near the deposit)	15.4	22.2

3. CONCLUSIONS

Temperature values in the holes and in the pipes is influenced by seasonal temperature variations observed at the surface. The model used to obtain the distribution of the temperature as a function of the radius show that water temperature increases in a summer day and decreases in a winter day. A more detailed study must be done in order to obtain a better agreement between the values obtained and data measured.

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