ANALYSIS ON ENERGY AVAILABLE IN SOIL TO BE USED FOR HEATING DWELLING PLACES

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Abstrac: This paper proposes an analysis on the soil's available thermal power that can be used for heating dwelling places. The calculation of this resource's size, for various types of soil, using the numerical model introduced here, permits the simulation of the thermal energy available in soil production dynamics for specific values of time delay and depth.

Keywords: energy, temperature, power, soil, heat

1. INTRODUCTION

The need of reducing carbon dioxide emissions as well al the increasing oil price obliged the scientific research to find and valorize new energetic resources having relatively low temperatures to be used for dwelling places heating. An important energetic resource is the soil's heat. As can be seen in figure 1, at depths exceeding 5…15 m the temperature in soil remains unchanged by the energy influences from the soil's surface. Starting from a depth of approximately 10 m, the temperature in soil increases linearly with depth (1° for each 33 m) due to a thermal flux given off by the earth which is estimated, for Central Europe, at 0.05…0.12 W/m^2.

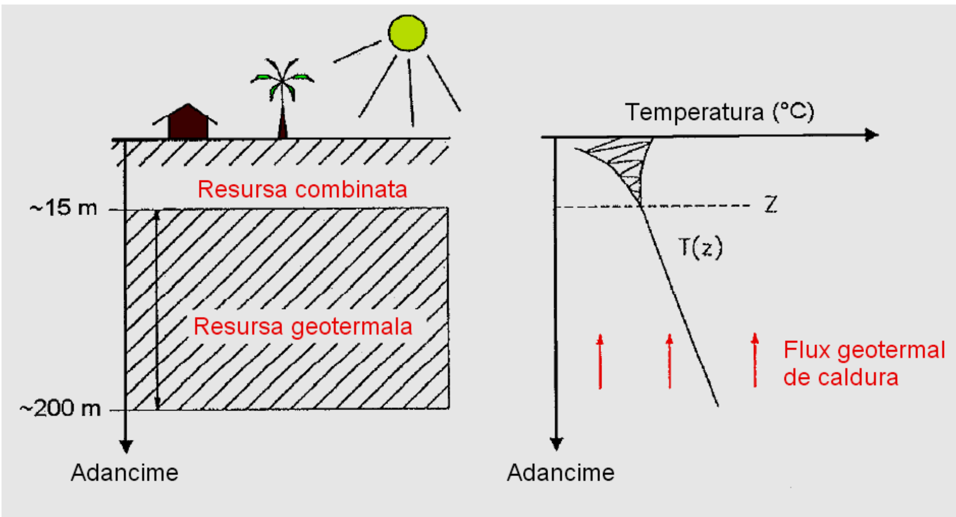

Fig. 1

The use of this energetic resource is mainly based on the increased soil temperature at depths greater than 10…15 m and on the soil's high thermal inertia. Using a heat pump, the heat can be extracted from the soil during winter, in order to be used for heating dwelling places, and in summer the heat can be "introduced" in the soil to cool houses.

This work deals with the analysis of the size of this energetic resource for various types of soil, based on a numerical model described afterwards. The temperature was set to a constant 5 °C value because the depth of the region thermally influenced by the atmosphere is not well defined by the model. On the basis of this model the available thermal energy corresponding to a cylindrical well having the depth of 1 m and the diameter of 0.3 m was established.

2. NUMERICAL ANALYSIS OF THERMAL FLUX VARIATION WITH TIME

For evaluating the potential of the soil's geothermal resource, a two-dimensional numerical model which permits the simulation of the heat exchange phenomena around a cylindrical hole was build.
It was accepted that the extraction of heat from the soil is achieved through a cylindrical well having the diameter $D = 2r_0$. The soil around the well is admitted to be homogeneous and isotropic, characterized by the properties of the considered rocks (clay, sandstone etc.). These hypotheses allowed the use of an axial symmetrical geometry. The space around the well was divided in annular volume elements geometrically equal, having the height dz and the thickness dr.

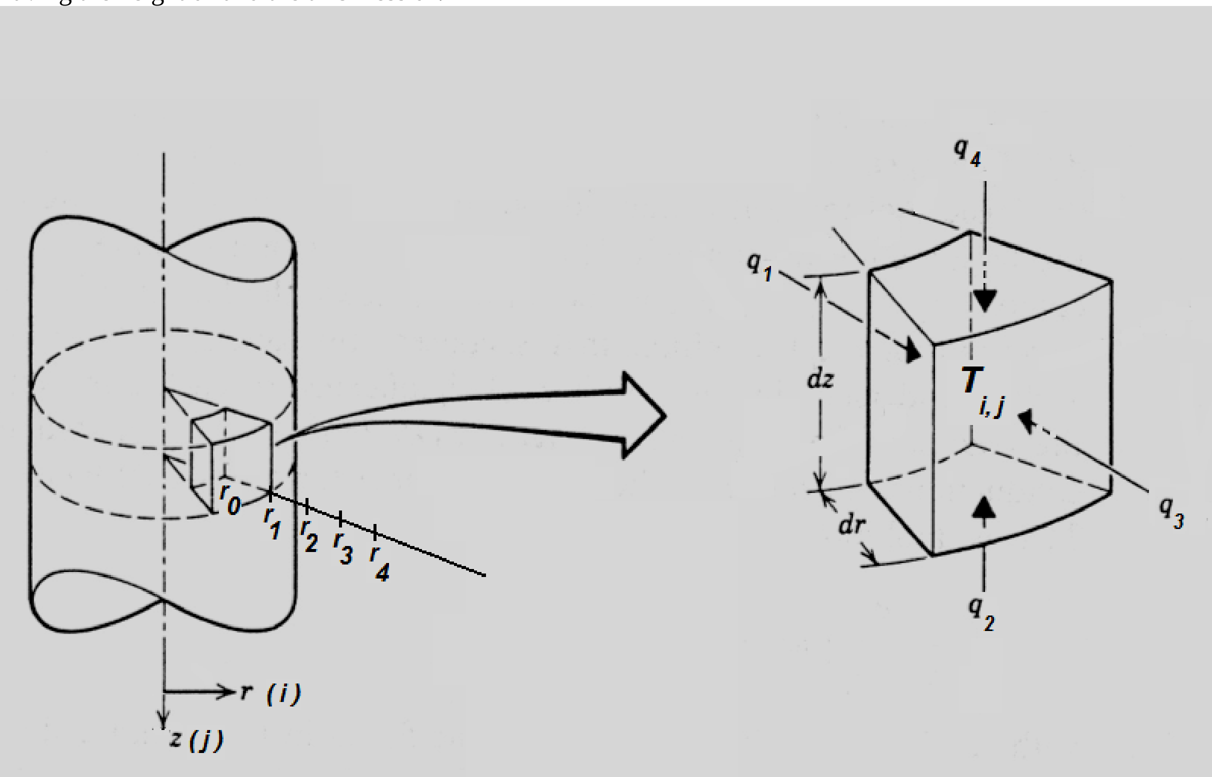

Fig. 2

The element i is defined against the well's axis by two radiuses expressed by the relationships (1), (2) and it has the basis area defined by the formula (3).

Thus we have the relationships

$$r_1 = r_0 + \left(1 - \frac{1}{2}\right)\Delta r \tag{1}$$

$$r_2 = r_0 + \left(1 + \frac{1}{2}\right)\Delta r \tag{2}$$

The elementary area of the *i* element basis is given by the expression

$$\Delta A = \pi\left(r_2^2 - r_1^2\right) \tag{3}$$

For an elementary volume we define the thermal fluxes as follows

$$\dot{q}_1 = 2\pi\,\lambda\, r_1\,\Delta y \frac{T_{i-1,j} - T_{i,j}}{\Delta r} \tag{4}$$

$$\dot{q}_2 = \lambda\,\Delta A \frac{T_{i-1,j} - T_{i,j}}{\Delta r} \tag{5}$$

$$\dot{q}_3 = 2\pi\,\lambda\, r_2\,\Delta y \frac{T_{i+1,j} - T_{i,j}}{\Delta r} \tag{6}$$

$$\dot{q}_4 = \lambda\,\Delta A \frac{T_{i+1,j} - T_{i,j}}{\Delta y} \tag{7}$$

The heat accumulated in the element is expressed as

$$\dot{q}_{ac} = m\,c_p \frac{\partial\Gamma}{\partial\zeta} = \Delta A \Delta y \rho c_p \frac{T_{i,j}^{n+1} - T_{i,j}^{n}}{\Delta\zeta} \tag{8}$$

The balance equation of the thermal power is

$$\dot{q}_1 + \dot{q}_2 + \dot{q}_3 + \dot{q}_4 = \dot{q}_{ac} \tag{9}$$

and leads to the following scheme

$$T_{i,j}^{n+1} = \alpha_1\,T_{i-1,j} + \alpha_2\,T_{i+1,j} + \beta\left(T_{i,j-1} + T_{i,j+1}\right) + \left(1 - \alpha_1 - \alpha_2 - 2\beta\right)T_{i,j} \tag{10}$$

If we consider the temperatures in the right side at the time step *n*, we get an explicit scheme, and if we take these temperatures at the time step *n*+1 we obtain an implicit scheme.

The following notations were used:

$$\alpha_1 = \frac{2\pi\,r_1\,\Delta\zeta}{\Delta A\,\Delta r}a \tag{11}$$

$$\alpha_2 = \frac{2\pi\,r_2\,\Delta\zeta}{\Delta A\,\Delta r}a \tag{12}$$

$$\beta = \frac{\Delta\zeta}{\Delta y^2}a \tag{13}$$

where *a* is the soil's diffusivity.

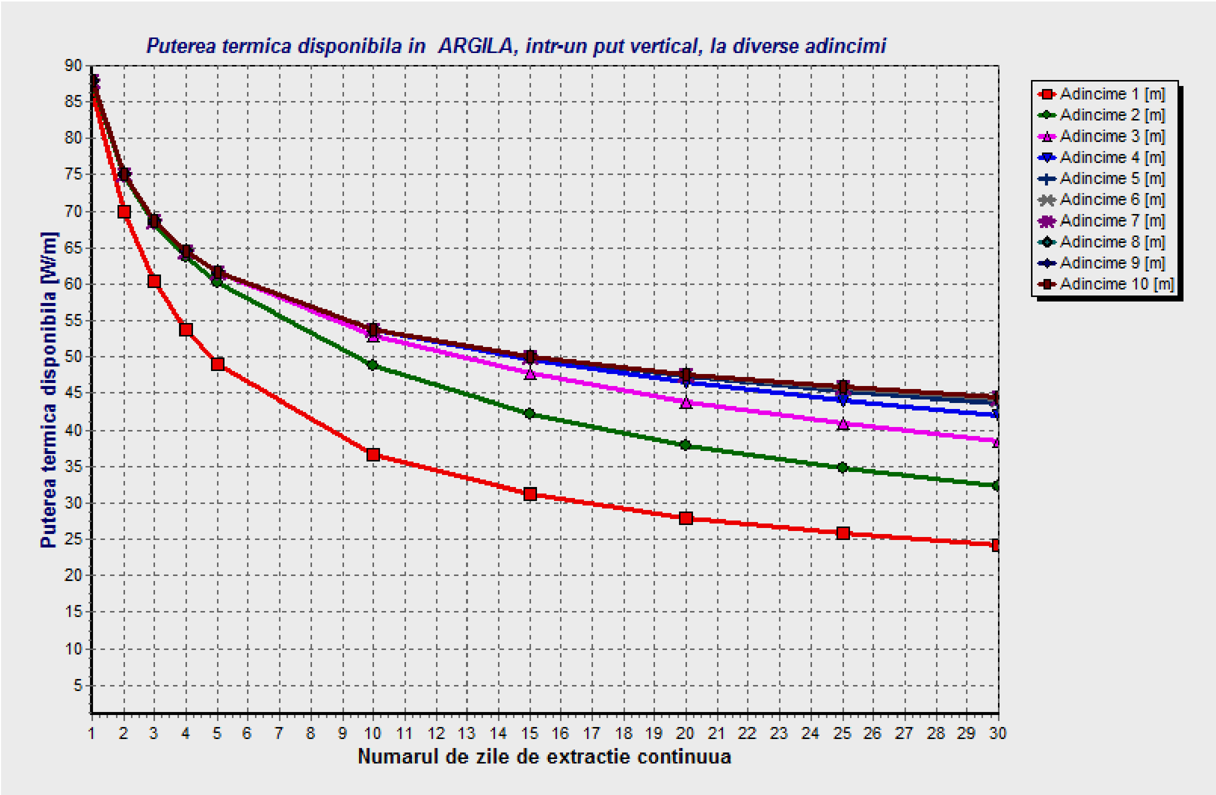
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Fig. 3

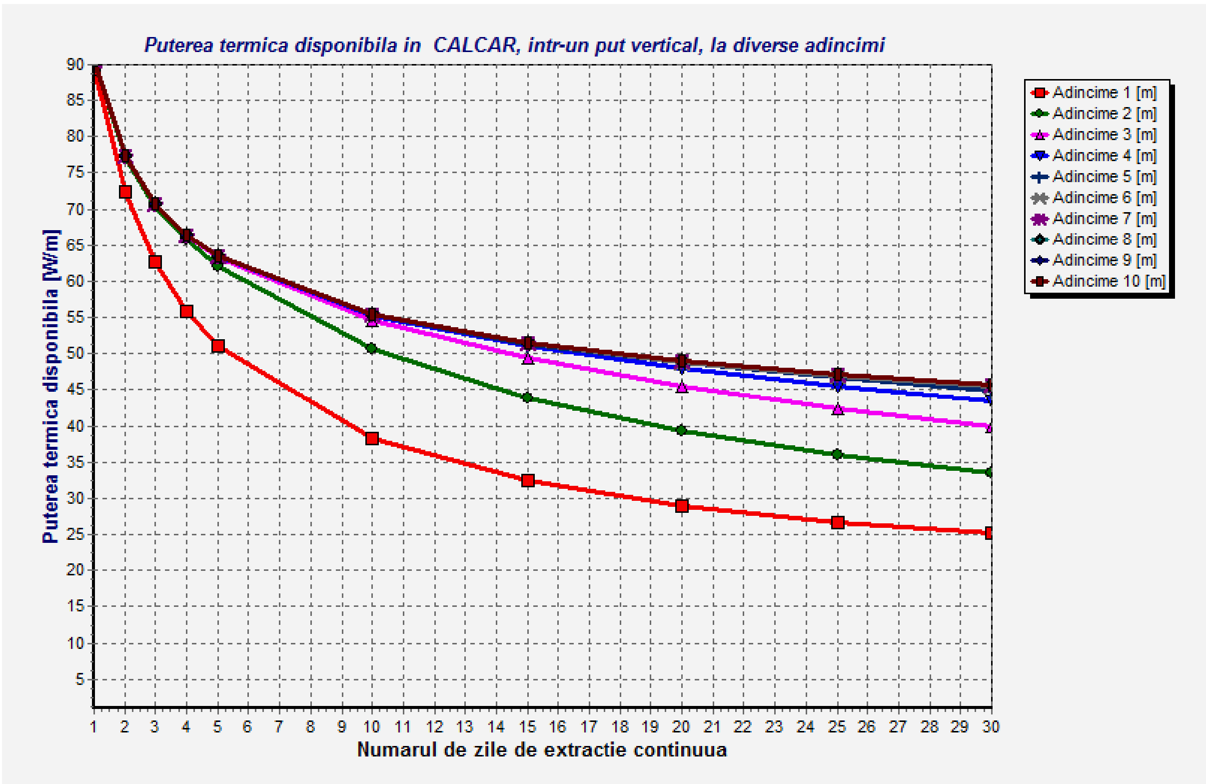
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Fig. 4

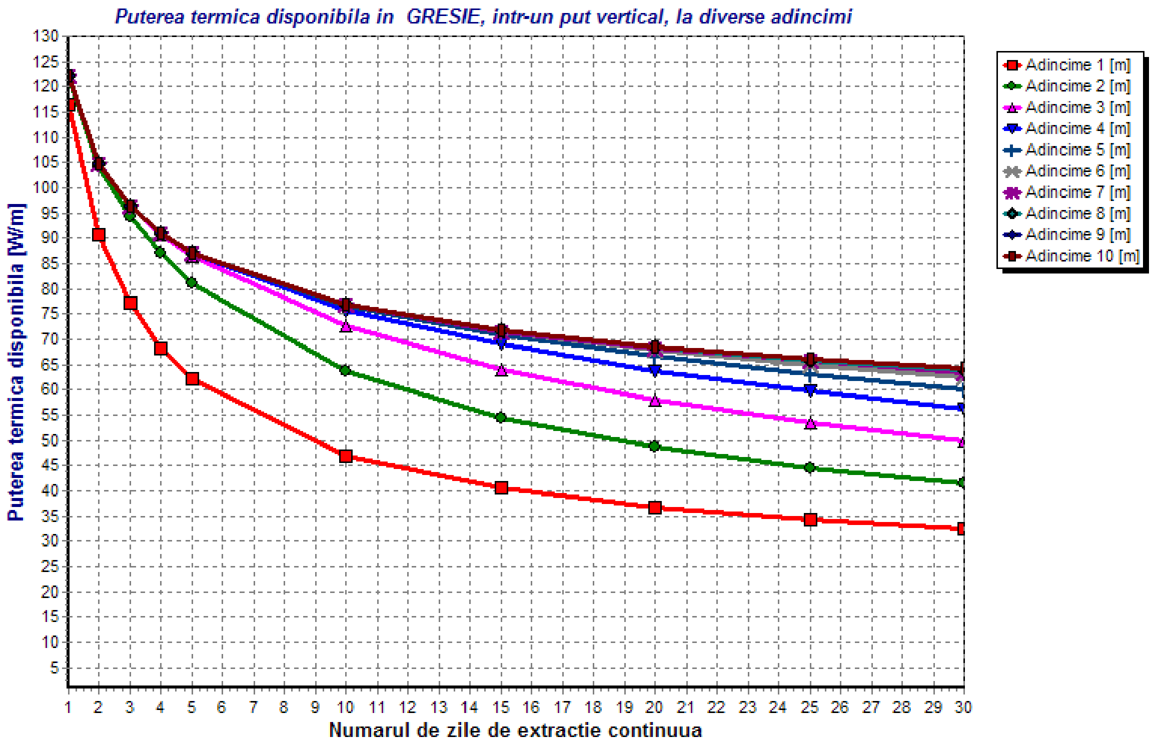
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Fig. 5

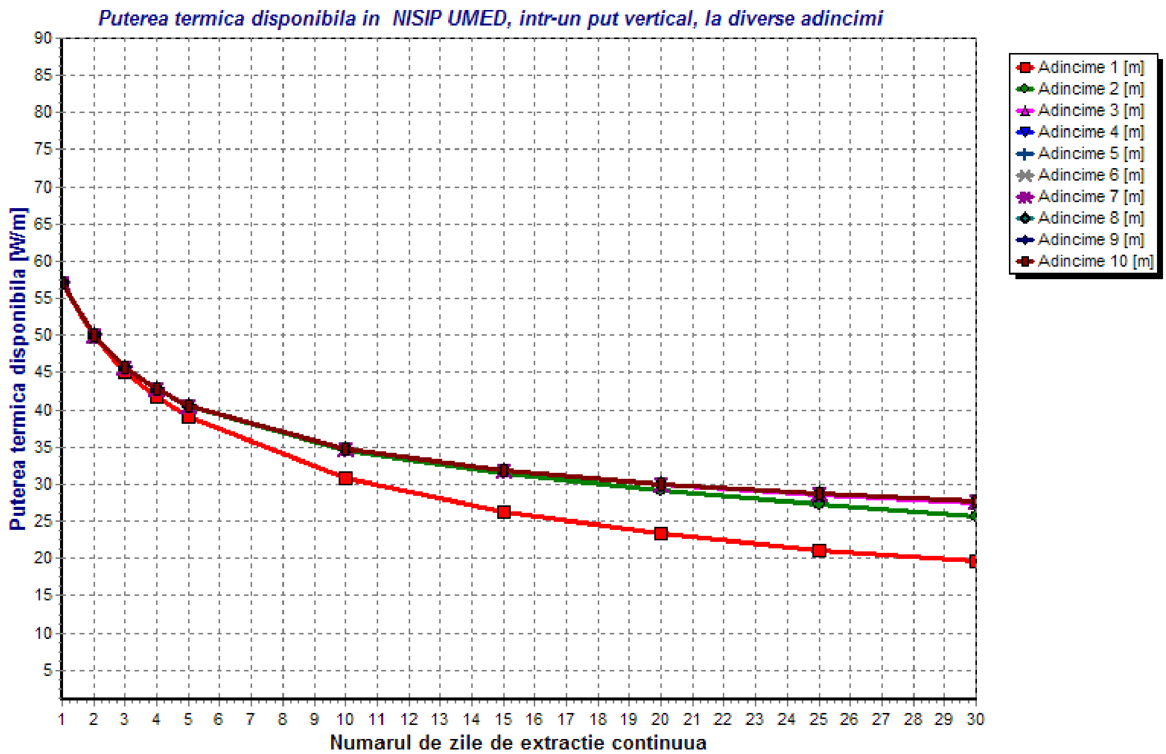
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Fig. 6

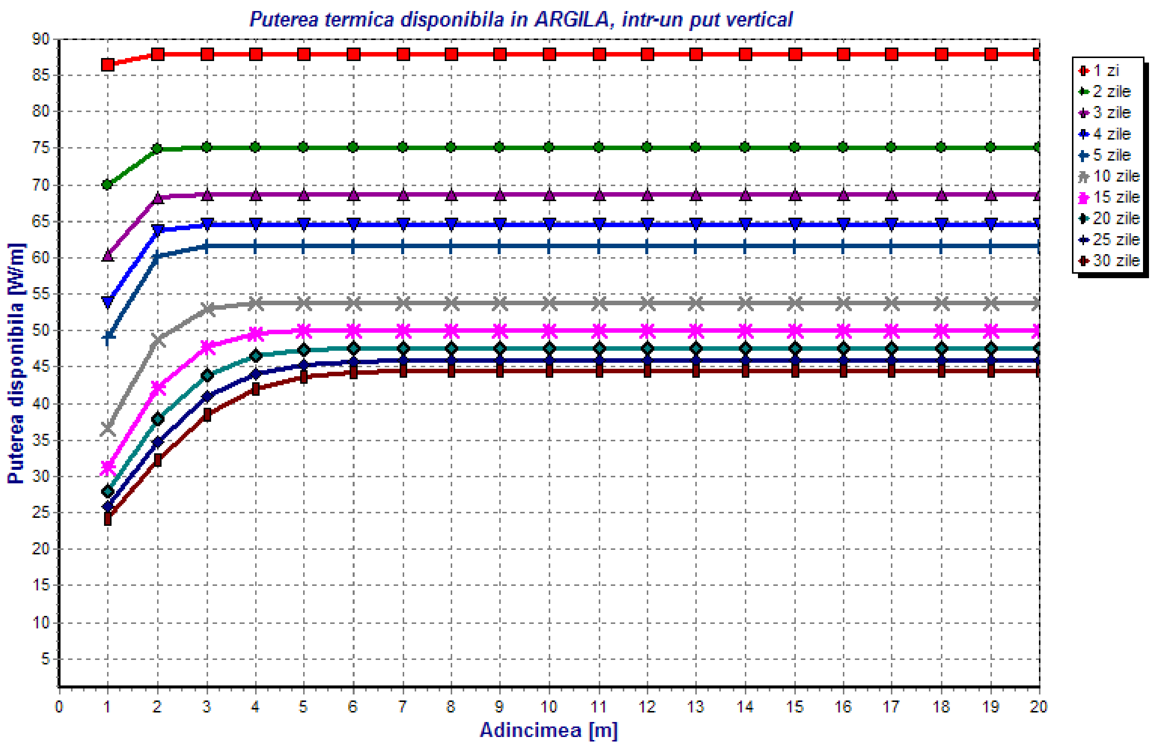
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Fig. 7

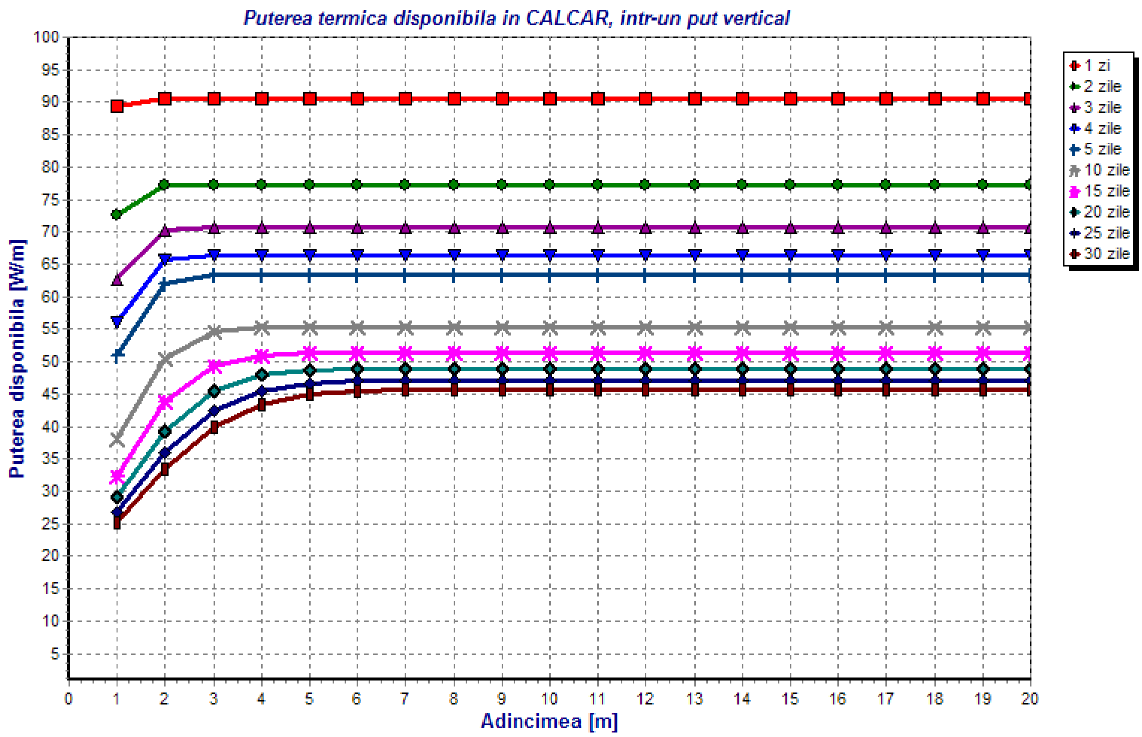
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Fig. 8

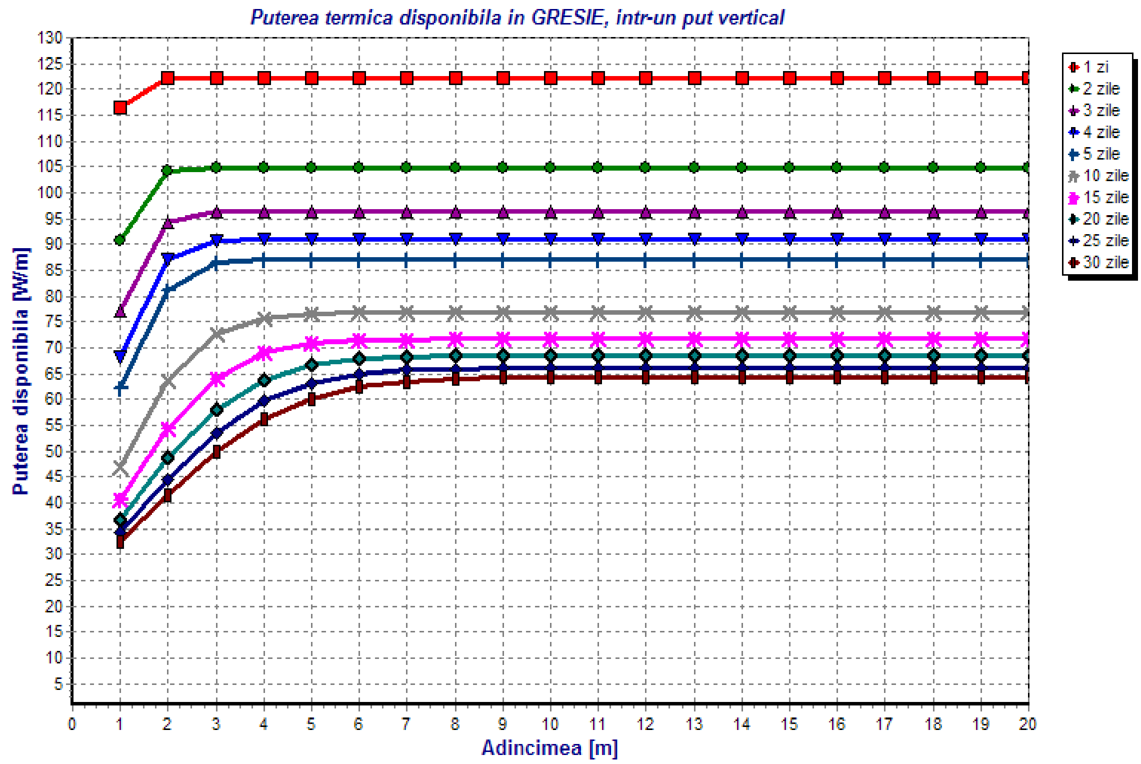
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Fig. 9

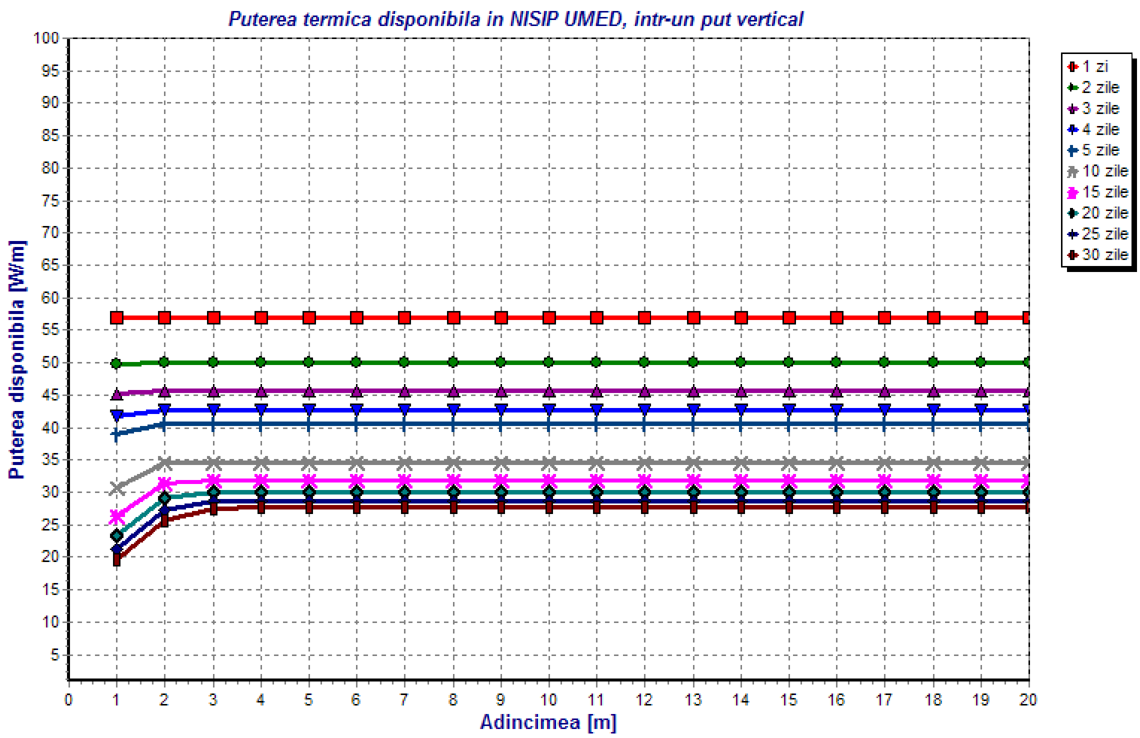
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Fig. 10

The numerical model described was used to perform a temporal analysis, for various types of soil, of the available thermal power, supposing that the exploitation is continuous for a 30 days delay.
Due to the soil's diffusivity, which is in the 10^{-6} m^2/s range, to the long heat extraction delay (tenths of days) and to the great volume of soil involved, the available thermal power is variable in time, as shown in figures 2…5.

3. ANALYSIS OF THE AVAILABLE THERMAL POWER AS A FUNCTION OF DEPTH

One can observe that, during the first few days, the available thermal power decreases relatively accelerated, and after some 10 days it reaches a tendency of constancy. The nature of soil influences the available thermal power. Thus, for the sandstone the available thermal power is greater than for the wet unconsolidated sand.
Another interesting remark is that the time variation of the available thermal power is similar; the curves are very close for depths exceeding 5 m. The large variation of the available thermal power for depths between 1 and 5 m can be explained by the influence of both atmospheric air temperature and solar radiation. The shape of the curves in figures 3…6 is mainly determined by the thermal inertia of the medium around the wells used to extract the heat.
The variation of the available thermal power as a function of depth, which is shown in figures 7…10, indicate a limit of the surface phenomena influence, which, for a delay of 30 days, corresponds to the depth of about 7 m. This depth limit depends on the time, so that, during the first days of heat extraction from the vertical well, it is of only 1…2 m. The dispersion of the curves in figures 7…10 is determined by the diffusivity of the medium around the well.
The linearity of the available thermal power curves reflects its constancy with depth, which is useful in heat extraction well design. Practically, in the design phase, well's depth can be determined as a function of both required and available powers.

4. CONCLUSIONS

The thermal energy accumulated in soil is an important energetic resource that can be used for heating dwelling spaces. The model introduced by this paper allows the simulation of soil available thermal energy extraction dynamics for a 30 days delay and for depths less than 30 m.
Two important conclusions can be drawn. The first: there is a decline of the available thermal power as a function of time, due to the thermal inertia. The second: the thermal properties of the soil (thermal conductivity, density, specific heat) determine the effective values of the available thermal power.
We have to observe that the heat pumps used for house heating do not run continuously, as we admitted in this paper, but discontinuously. This fact increases the available thermal power of the soil because this is regenerated during the pause intervals.

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