Program system for investigation of heat physics applications

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Abstract: *Software application for heat analysis of technical devices and systems is developed and experimented. It is based on detailed algorithm for numerical solving of transient three dimensional heat transfer equation with various types of boundary condition. The program application 'Eart_Hea't is developed for using in solving different research problems (energy balance in buildings, heat transfer in earth layers, heat accumulators, solar applications, greenhouses e.g.).*

Keywords: *Heat transfer modeling, finite difference method, numerical analysis.*

1. INTRODUCTION

Maintaining a comfortable temperature inside buildings or other objects, like greenhouses and pools, require a significant amount of energy. Considering that 46% of sun's energy is absorbed by the earth, a good option is to use this abundant energy to heat and cool buildings and other objects. In contrast to many other sources of heating and cooling energy which need to be transported over long distances, Earth Energy is available on-site, and in massive quantities.

Because the ground transports heat slowly and has a high heat storage capacity, its temperature changes slowly—on the order of months or even years, depending on the depth of the measurement. As a consequence of this low *thermal conductivity*, the soil can transfer some heat from the cooling season to the heating season; heat absorbed by the earth during the summer effectively gets used in the winter.

This warm earth and groundwater below the surface provides a free renewable source of energy that can easily provide enough energy year-round to heat and cool an average suburban residential home, for example.

The main problem for assessing the heat transfer equipment for Earth Energy utilization is very complicated heat transfer mechanism. In charge and discharge phase of the process there is continuous change of heat flux. This mean that the energy extracted and accumulated in soil will vary. Variation of extracted or accumulated heat can be calculated only by using tree-dimensional transient mathematical model with distributed heat sources (heating or cooling). Computer programming for such a calculation problems require serious algorithmic organization for achieving the needed universality for different tasks.

2. THEORETICAL MODEL

Mathematical model of processes in ground layers can be derived on the base of theoretical treating of heat conductivity, heat transfer to the working fluid and heat losses to the ambient. The main mathematical equation in this problem is the heat conductivity equation, written in orthogonal coordinate system:

$$\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+\frac{q_V}{\lambda}=\frac{1}{a}\frac{\partial T}{\partial t} \tag{1}$$

where **T** is the temperature in the walls, ***x, y*** and ***z*** – space variables, ***λ*** – heat conductivity coefficient [W/m K], $\boldsymbol{q_V}$ - source member [W/m^3] and $a=\lambda/\rho\cdot c_p$ is thermal diffusivity.

This equation is first order in time and second order in space, so it require one boundary condition in time (called an initial condition) and surrounding boundary conditions in space - 6 boundary conditions for 3D problem. In dependency of boundary condition there can be defined different tasks describing real heat processes. For example, there can be solved the one-dimensional problem for temperature distribution in massive building walls, which are the base conception of so-called passive solar systems. Two and three-dimensional models can be used for accumulating and extracting the heat from massive earth volume.

The mathematical problem is defined on a rectangular domain [0; L_x]x[0; L_y]x[0; L_z]x[0; T] and is assumed that L_x, L_y, L_z and T are chosen properly for practical purposes.

3. BOUNDARY CONDITIONS

In general, boundary conditions for objects considered in this work, can be written in next form:

$$\beta\frac{\partial T}{\partial n}+\gamma T+\sigma=0 \tag{2}$$

where ***β,γ*** and ***σ*** are coefficients, which present heat conductivity, heat convective coefficient to the free space, and heat sources (for example solar radiation); ***n*** - normal direction to the boundary surface.

The main problem in supporting the boundary condition data for the model is connected with the weather parameters (solar radiation, ambient temperature). Base concept for weather data is the availability of temperature bins for daytime and nighttime's hours for the selected location. Additionally, bin data for the coldest and hottest months (corresponding to design heating and cooling conditions) are required for the ground loop calculation. Such a heavy user-data requirement would render the model impractical. Alternatively, storing the data within the model would translate into an excessively large file if even a moderate number of locations around the world were to be included.

To circumvent this problem, an hourly weather data generator is included in the model. This generator is based on empirical correlations between statistically derived daily maximal and minimal ambient temperature and hourly weather data, as defined in ASHRAE (1997). Usage of a generator does not restrict the generality of the method. If appropriate bin data are available, they could be used in the model without any change to the other algorithms.

4. FINITE DIFFERENCE APPROXIMATION

Because of the importance of the diffusion/heat equation to a wide variety of fields, there are many analytical solutions of that equation for a wide variety of initial and boundary conditions. However, one very often runs into a problem whose particular conditions have no analytical solution, or where the analytical solution is even more difficult to implement than a suitably accurate numerical solution. The finite difference method begins with the discretization of space and time such that there are an integer number of points in space and an integer number of times at which is calculated the field variable(s), in this case just the temperature. The resulting approximation is shown schematically in figure 1. For simplicity here is described only one dimension mesh with intervals of size $\boldsymbol{\Delta x = x_{i+1} - x_i}$.

The finite-difference form of differential equation (1) is derived by integration over control volume surrounded the typical node ***i, n*** in solution grid (Fig.1). The indexes ***I,j,k*** and ***n*** refer to the thickness (***x,y,z***) and the time (τ). An implicit time approximation, which is stable for forward integration in time, is developed for transient differential equations. If the time interval is named $\nabla\tau = (\tau_n, \tau_n + \nabla\tau_{n+1})$, the time derivative can be written using forward Euler formula for discretization:

$$\frac{\partial T}{\partial \tau} = \frac{T^{n+1} - T^n}{2\nabla\tau} \tag{3}$$

For the space derivative is applied a second order nonlinearly implicit Crank-Nicholson method, which is solved by iteration.

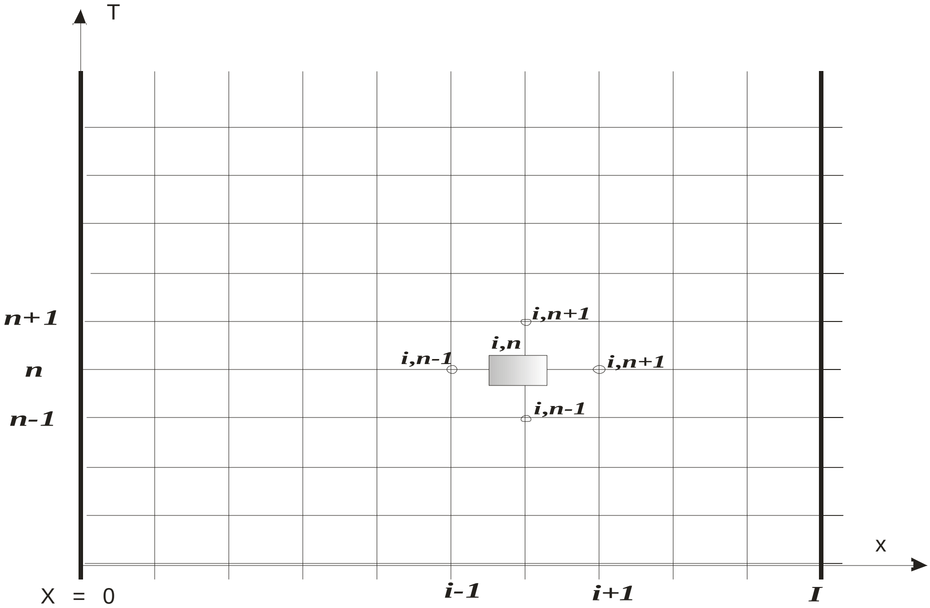

Fig. 1 The mesh in time and space

$$\frac{\partial^2 T}{\partial x^2} = \sigma \frac{T^{n+1}_{i+1,j,k} - 2T^{n+1}_{i,j,k} + T^{n+1}_{i-1,j,k}}{\Delta x^2} + (1-\sigma)\frac{T^{n}_{i+1,j,k} - 2T^{n}_{i,j,k} + T^{n}_{i-1,j,k}}{\Delta x^2} \tag{4}$$

where σ is a weight coefficient.

This is a system of (***I***-2) algebraic equations with ***I*** (***i*** = 1,2....***I***) unknown node temperatures (with upper index ***n+1***). Temperatures with upper index ***n*** are considered as known (received from calculation, made in former time step or from initial conditions in the first time step). Boundary conditions (2) must be added to complete the system.

Such equations can be written for Y and Z directions (j and k indexes respectively).

Equations (4) can be solved by standard algebraic methods. For solving the three dimensional problem is needed to add equations like (4) for other directions Y and Z. This is made by using so called fractional steps method. It is equivalent to separate solving the one-dimensional task for each time step.

5. PROGRAM EARTH_HEA T

It is developed a software system EARTH_HEAT for modeling and simulation calculations of thermal processes of heat extracting and accumulation in earth. The algorithm and the organization of the interface of the program provides a universal approach for adding new type of devices, including an opportunity for variation of parameters for the elements in the system.

The various algorithms are used to calculate, on a month-by-month basis, the energy transfer in systems, utilizatied heat from earth. A flowchart of the algorithm used in EARTH_HEAT system is shown in Figure 2.

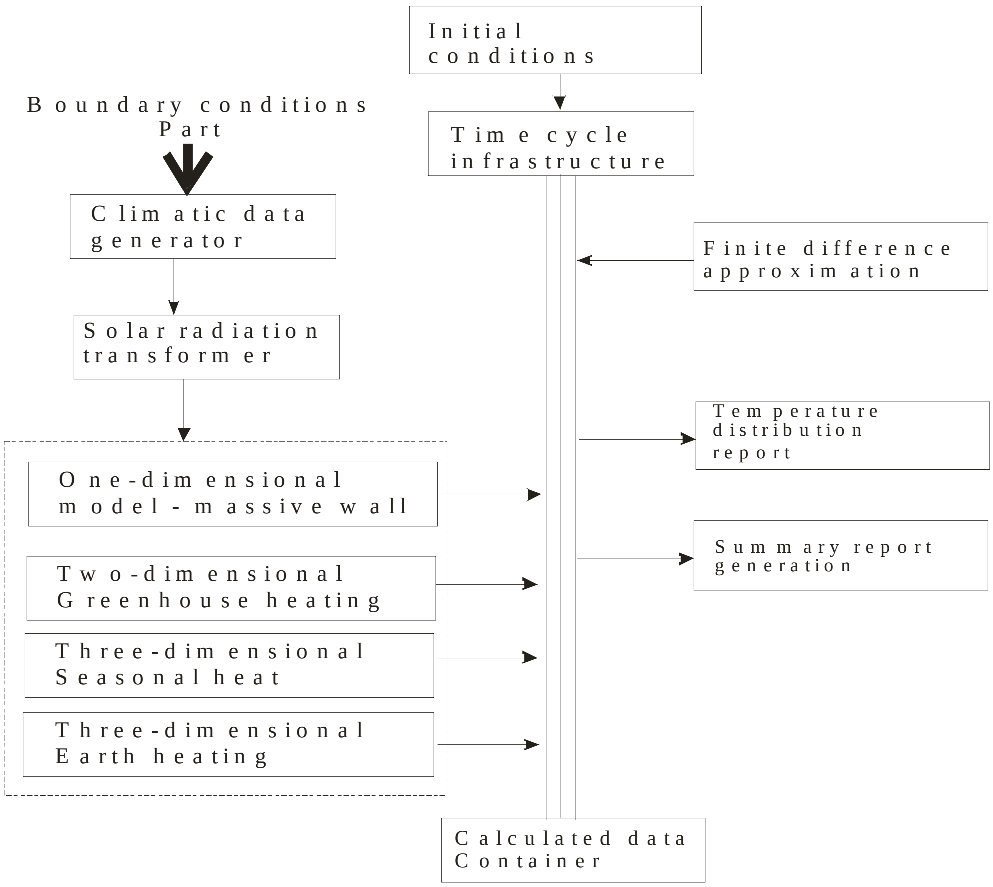

Fig. 2. Scheme of the program algorithm

The heat transfer in Earth_Heat systems is relatively complex because of great number of factors influencing the boundary condition data. It is dependent upon the solar radiation, temperature and wind speed surrounding the system. Most heating analyses tools use an hourly time step to follow the changing solar and weather conditions.

The organization of the programming system contains three basic functional parts (Fig. 1). As a basic infrastructural part of the system it appears the module of controlling simulation cycles in time and providing necessary climatic parameters in relation to discretion of the processes in time. In this time it is included the deliverance of data about the solar radiation and the air temperature for different geographical regions. In this functional part it is included special solar radiation' processor, which recalculate solar radiation for given slope and orientation of the received surface, and optical parameters for solar radiation penetration through the transparent covers.

The control of the system is carried out by a main controlling form (panel) which delivery the boundary condition data (fig.2). Through this panel it can be chosen the source of climatic data about simulation calculations and the type of the installations for utilizing earth energy. In the performed variant of the program there is a possibility to be carried out thermotechnical analyses of devices (heating of building, heat accumulator in soil greenhouse heating, passive solar system), and also additional analyses about the parameters of the temperature distribution in earth.

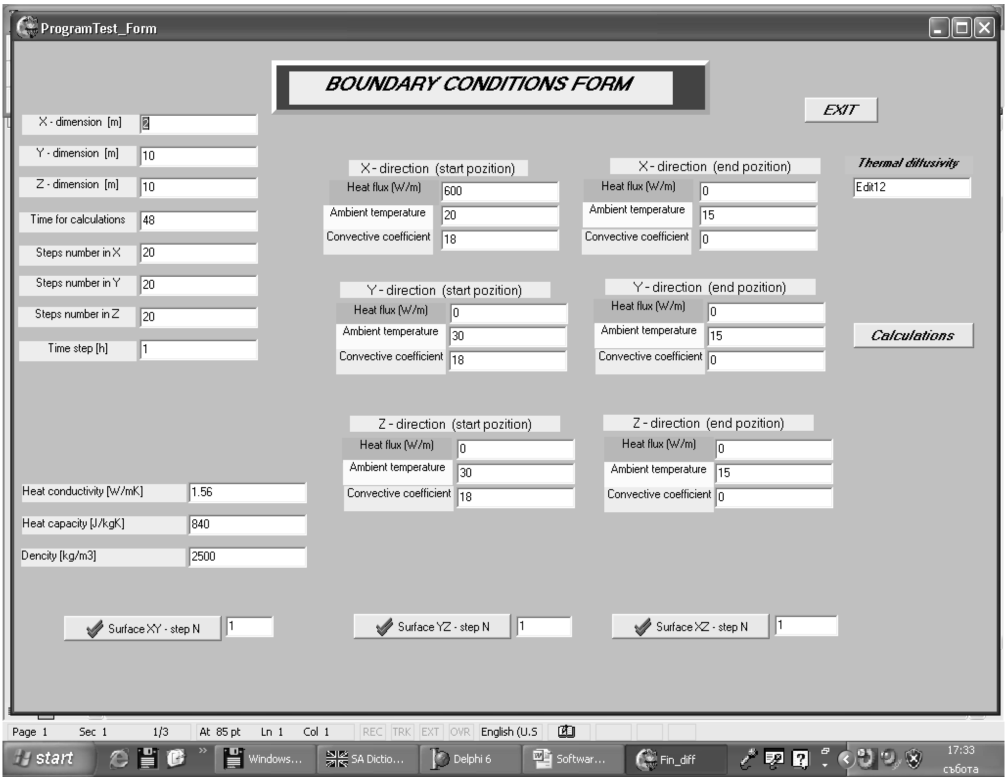

Fig. 2 Program form "Boundary conditions"

6. CONCLUSIONS

A software product has been performed for simulation analyses of devices for thermal transformation of energy from earth. It has modular structure for completing different installation schemes and it gives the opportunity to generate long-term assessments of thermal efficiency of devices. Program system can be successfully used not only for projecting purposes, but also for solving exploring tasks.

7. REFERENCES

1. Akbarzadeh A., W.S.Charters and D.A. Lesslie, Thermocirculation characteristics of a Trombe wall passive test cell. Solar Energy, 28(6), 461-468 (1992).
2. Cranc J., P.Nicolson. A practical method for numerical evaluation of solution of partial differential equations of heat-conduction type. Proc.Cambridge Philos.Sos.,1974, N 43
3. Duffie J.A. and W.A. Beckman, Solar Energy Thermal Processes. Wiley, New York (1974)
4. Richtmayer R.D.,K.W. Morton, Difference method for initial-value problems. Interscience Publishers, 1997.