Simulation modeling for Thermal Solar applications

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Abstract

Mathematical treatment of thermal solar applications is a useful tool for investigation and design. Because of irregular conditions, which influence the performance of solar installations (climatic parameters, consumption graphic) it is necessary to make a detailed simulation calculations for all work time of installations.

Computer program was created to make simulation calculations for different thermal application of solar energy. As input information for simulation programs is used data for solar radiation, ambient temperature distribution, constructive and physical parameters of solar elements. Climatic data can be entered as average climatic characteristics for the region, as theoretical estimations or as collected climatic data (from file).

Special mathematical models describe the thermal and mass transfer processes in different elements of installations. The main processes in thermal solar installations are the absorbance of solar radiation, heat conductivity, exchange and accumulation, fluid mass transfer.

Transfer of solar radiation to the heat is the common simulation process for solar simulation models for different applications – solar collectors and hot water installations, dry solar systems, solar pools, passive solar systems et. Procedure for transforming the incident solar radiation on the sloped surface is the main part of program module for calculation of solar radiation.

Accumulation, heat conductivity and heat exchange processes are often used thermal processes in many solar elements. Special mathematical model is composed to simulate the energy transfer in different thermal elements. Special computer modules were developed to solve mathematical models for these processes.

In order to validate the presented models and to analyze performance of different thermal solar applications a special experimental center was created with a monitoring system for long time data registration. Numerous experiments and calculations have been made. After a thorough investigation, appropriate values and formulas for parameters in mathematical equations and parameters of simulation calculation were chosen. A satisfactory coincidence between experimental and theoretical results was achieved.

1. Introduction

In the last years, in view of the limitation of the world's energy resources, the development of thermal solar applications for solar utilization has strongly accelerated. Energy transfer of radiant energy from sun to heat is regulated by physics laws and there are natural limitations of transformation efficiency. For this reason the heat transfer in solar energy equipment is very important and respective field for research. The difficulties arising are due to the complexity of constructive and regime parameters influencing the solar energy utilization processes.

In the base of studying processes in physical systems there are experimental researches, but the essential part in the research process play theoretical studies as well. For solar systems theoretical researches have a greater importance, because their efficiency is defined by typical (statistically average) climatic data for a certain geographical region which cannot be determined in making the experiments. If we should make an assessment of the efficiency of a certain type solar installation through experimental researches, we should accomplish long-year researches whose results should be averaged to achieve typical annual parameters. It is a process connected with a great deal of expenses and the technological innovations permanently change the conditions of the experiments which have been carried out. This is the reason why a basic part for solar systems play theoretical researches using specific software.

A basic method in studying solar systems is a mathematical simulation of their work. The simulation is carried out with the purpose to define optimal parameters of devices and to establish the way the system will react in long-term plan of changing basic parameters of the elements. Simulation computer programs give an opportunity to be determined for a short time a great number of factors and complicated interactions which influence on the efficiency of solar systems.

Mathematical models usually simulate the work of the systems for a year or a season. There exist three basic types of simulation models. They differ from each other with the accuracy of calculating procedures, with the type of the necessary initial information and with the universal and complicated calculating algorithms.

The greatest level of universality have the so called simulation models of the systems with finite elements in which the separate elements (devices) of heat systems are divided in discrete elements and the heat exchange between them is calculated. A drawback of these methods is the complicated algorithms, the difficult completing of the initial information (for example, climatic data for a long period in a short interval of time – 5-10 minutes). Such data is rarely available and for their preparation there are necessary additional models which carry additional incorrectness.

The second group of models is so called simulation models with a module structure. In them the separate elements of heat installations are performed with appropriate models (algebraic or differential equations for the processes carried out). These models are connected in a common system in which the outgoing parameters for a given element are used as incoming parameters for another element connected with it. The simulation calculations are accomplished either for stationary conditions or for a synchronized in the time simulation of boundary parameters for a part of the elements of the heat system. In this case there can be used meteorological parameters for an interval of time 1 hour which are available for standard meteorological services.

The third group of methods is based on different approximation technologies. Such is, for example, F-chart method performed in [1]. These methods use results from real and numeric experiments (simulation models) for achieving correlative (regressive) dependencies between the parameters of the system and its long-term characteristics (utilized energy, thermal efficiency, economic efficiency).

When projecting heat systems even experienced researchers come across a number of problems related to the assessment of long-term characteristics of the exploited systems. In these cases it is of great importance the usage of simulation programming tools and data for typical values of the climatic factors.

The typical programming system based on a module structure is TRANSYS. It contains controlling module called "processor" and modules (elements) for a great range of simulation models for different thermo-technical devices. Programming elements are two basic types:

- elements which do not have physical analogue, but they are necessary for the simulation. These are modules providing inserting the initial information, the preparation of data for the final results, middle mathematical simulators etc.
- elements which model the physical devices.

Despite their great popularity the programming systems of module type have some drawbacks. As a basic drawback of these software products can be pointed the difficult inserting in system untypical elements and devices with specific characteristics. To be able to integrate in the system it should be prepared a special programming interface meeting the requirements of programming system. In some cases the specific character of heat processes can hardly synchronize with the requirements of programming system. That is why standard programming systems for simulation analysis cannot be used efficiently for research purposes.

Another drawback of the universal programming systems with module organization is that it is difficult to make analyses about long-term system characteristics. Apart from that they do not allow to be made analyses about the influence of separate constructive and regime parameters of the devices in the installation scheme. Example for such researches are the experiments carried out in the South-West University in the town of Blagoevgrad about solar installation with stratified accumulator and inserted heat exchanging serpentine. It is difficult to carry out research about the influence of the serpentine position in the volume of the accumulator with a universal programming system.

2. Program SOLAR

It is worked out a software system SOLAR for modeling and simulation calculations of installations for thermal transformation of solar energy. The algorithm and the organization of the interface of the program provides a universal approach for adding new devices for exploring, including an opportunity for variation of parameters for the elements in the system.

The organization of the programming system contains three basic modules. 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.

The second structural part of the programming system is a set of programming modules for simulating heat and mass exchanging processes in different thermo-technical devices for utilizing solar energy. They are organized as separate programming structures according to the common infrastructural part of the programming system.

The third part of the programming system organizes the preservation of results from the calculations and a preparation of the necessary data. It is worked out a universal system for showing results for different periods of the simulation interval. Technical and economical estimations for solar systems can be generated on the base of received results from simulation calculations.

The control of the system is carried out by a main controlling form (panel) which appears when the software system is started – fig.1. Through this panel it can be chosen the source of climatic data about simulation calculations, geographical region to which the researches are related and the type of the installations for utilizing solar energy. In the performed variant of the program there is a possibility to be carried out thermo-technical analyses of devices (water solar collectors, air collectors, solar installations and other), and also additional analyses about the parameters of the solar radiation, optical characteristics of semi-transparent materials and characteristics and processes with wet air.

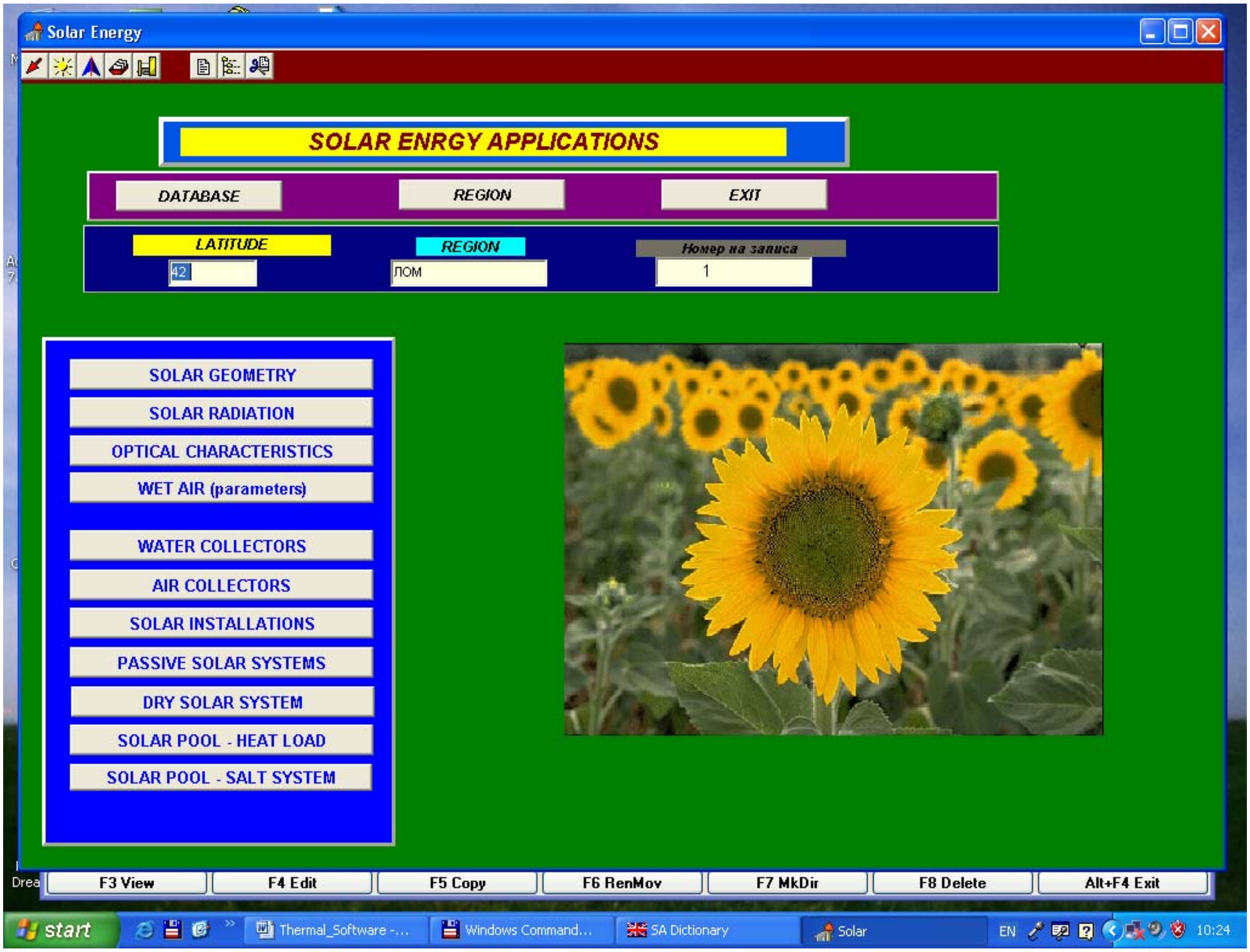

Fig. 1. Main controlling form

3. Programming module for working out climatic data.

It is the basic infrastructural part which provides the organization of the cycles in time and the preparation of climatic data according to the step of discretion in the time for simulation calculations.

The programming system provides three sources for climatic data about different regions (solar radiation and air temperature). The first source provides data about long-term (typical) climatic characteristics for different regions of our country on the base of existing data from the meteorological institute. These data can be expanded.

The second source for climatic data uses values written in specialized files of the solar radiation and air temperature. These data are usually data from measuring for a given period of time for a certain place. These data can be used for validating of the theoretical models through comparisons of the theoretical results with experimental data for a certain period of time. Apart from that through these data there can be explored the devices with different constructive parameters and can be compared with the experimental researches.

The third source of data is provided through using theoretical models for the components of the solar radiation. These data can be used only for limited researches as it cannot model the regime of cloudiness for the certain geographical region. For special regime (absolutely clear or absolutely cloudy day) these models can be successfully used in working out new devices or in comparing the efficiency of the devices with different constructive parameters.

Hundreds of meteorological stations in the world for years have been carrying out actinometrical measurements of the values of solar radiation. For engineering and exploring purposes these values are performed in a possible type. The most reliable and appropriate for work are the statistic data worked out for a sufficiently long period of time for the values of the total solar radiation and its components – direct and diffusive radiation over the horizontal plain. Despite the fast development of actinometry, because of non-sufficient frequency of meteorological stations and comparatively short periods of observing for a great part of them, these data are not sufficient. To achieve certain data for a certain geographical region there are usually used indirect methods.

A main difficulty in the quantity assessment of the real radiation regime of work of the solar systems is due to the great number of factors on which it depends. Apart from the numbered above us should keep in mind the orientation and the angle of inclination of the absorbing surface to the horizontal plain. This requires recalculation of the basic data about the solar radiation to the relative orientation and the angle of the system absorber. In every case it is necessary the total solar radiation to be separated into direct and diffusive components and the two components to be transformed (geometrically) for the given orientation and the angle. Received data for direct and diffuse solar radiation can be treated optically for penetration through the transparent materials and then again summarized the data for total energy.

For Bulgaria, as for a wide range of other countries, there are available long-term measurements only for the duration of sun shining and only particular data for the solar radiation. Data for solar radiation for our country there exist only for Sofia. That is why an important role in this part play different models for transforming the data about the duration of sun shining in values of solar radiation. In software presented here is used transforming model for transforming the data for sun shining duration to the solar radiation presented in [1].

4. Models of solar devices

The basic part of the programming system is a set of independent programming modules describing physical processes in different devices of solar installations. It gives an opportunity to explore separately devices or their work in linked system. There are developed programming modules to explore different devices for solar installations: solar collectors (air and water), accumulators of thermal energy, drying installations, passive solar systems (solar architecture), solar heated swimming pools, water pools with salt and others. Apart from that there can be generated data about solar radiation on different accepting plains (orientation and inclination), data about geometric parameters of sun rays (solar geometry), calculation of optical losses in semi-transparent materials (glass, plastic) when sun rays pass through them, analyzing processes with wet air, etc.

As the construction and the processes carried out in different devices differ too much, the initial information and the organization of calculations are rather different. Therefore constructive and regime parameters of devices for the separate modules are inserted through specific interface for the certain equipment. This is one of the basic differences with the standard module systems for simulating thermo-technical processes. In this way it is provided possibility for working out absolutely independent mathematical models with rather non-linear dependencies and links between parameters.

As an example in fig.2 it is performed screen form with the interface for inserting data about water solar collectors.

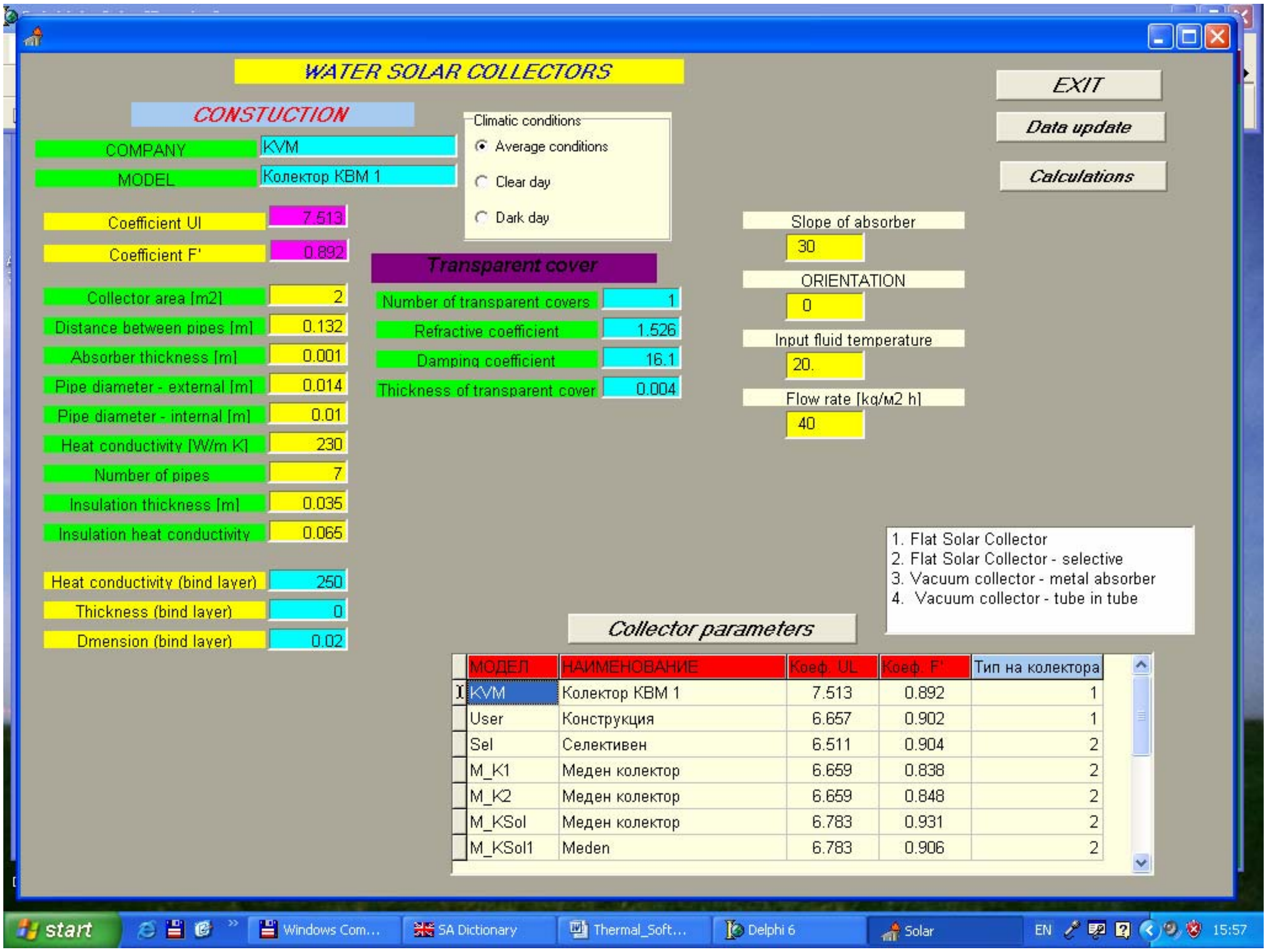

Fig. 2. Form for controlling data for solar collectors

Mathematical models for different devices are based on the description of the physical processes in them. For this reason there are great differences in the complexness and the exactness of the separate programming modules. Some of them perform separate scientific works. For solar installations for hot water there are worked out a few modifications of theoretical models for different types of installation schemes. Analysis of different schemes of solar installations for hot water is made in [2]. A special model for thermo-technical analysis of solar installations with stratified accumulation is described in [3]. Models for exploring passive solar systems are analyzed in [4]. Thermo-technical analysis for common swimming pools and saturated solar ponds, including description of mathematical modeling is performed in [5]. Processes of drying materials with utilizing solar energy are analyzed in [6].

For a certain type of devices in programming modules there are organized inside cycles in time, which gives the opportunity to be made calculations with rather denser calculating net (for example, with a step one or a few minutes in common step in time 1 hour). This seriously increases the accuracy in calculating processes and makes the relevant module independent from the common infrastructural organization of simulation processes. Such are for example the processes of accumulation of heat energy in stratified accumulators of water solar systems, passive solar systems with massive wall (a wall of Tromb), solar salty pools, etc.

5. Conclusion

A software product has been performed for simulation analyses of devices for thermal transformation of solar energy. It has modular structure for completing different installation schemes and it gives the opportunity to generate long-term assessments of thermal efficiency of devices. The main differences from the standard programming systems with modular structure (of the type TRANSYS) is the opportunity of providing different sources of climatic data and bigger freedom in working out mathematical model of describing processes in devices. The programming system allows using modules in which there are realized numeric procedures for the processes of heat carrying, mass exchange, etc., demanding a small step in time. Because of that programming system can be successfully used not only for projecting purposes, but also for solving exploring tasks.

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