SIMULATION OF A SOLAR WATER HEATING SYSTEM

SIMULACIJA RADA SOLARNOG SISTEMA ZA ZAGREVANJE VODE

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Introduction

- Energy from fossil fuels has many negative effects on the environment.
- Solar energy has a number of advantages.
- Water heating is one of the most favorable way to use solar energy (location where there is a need, high efficiency, system is simple).

-Sizing of a solar system is a complex problem (includes predictable (components performance characteristics) and unpredictable (weather data) components).

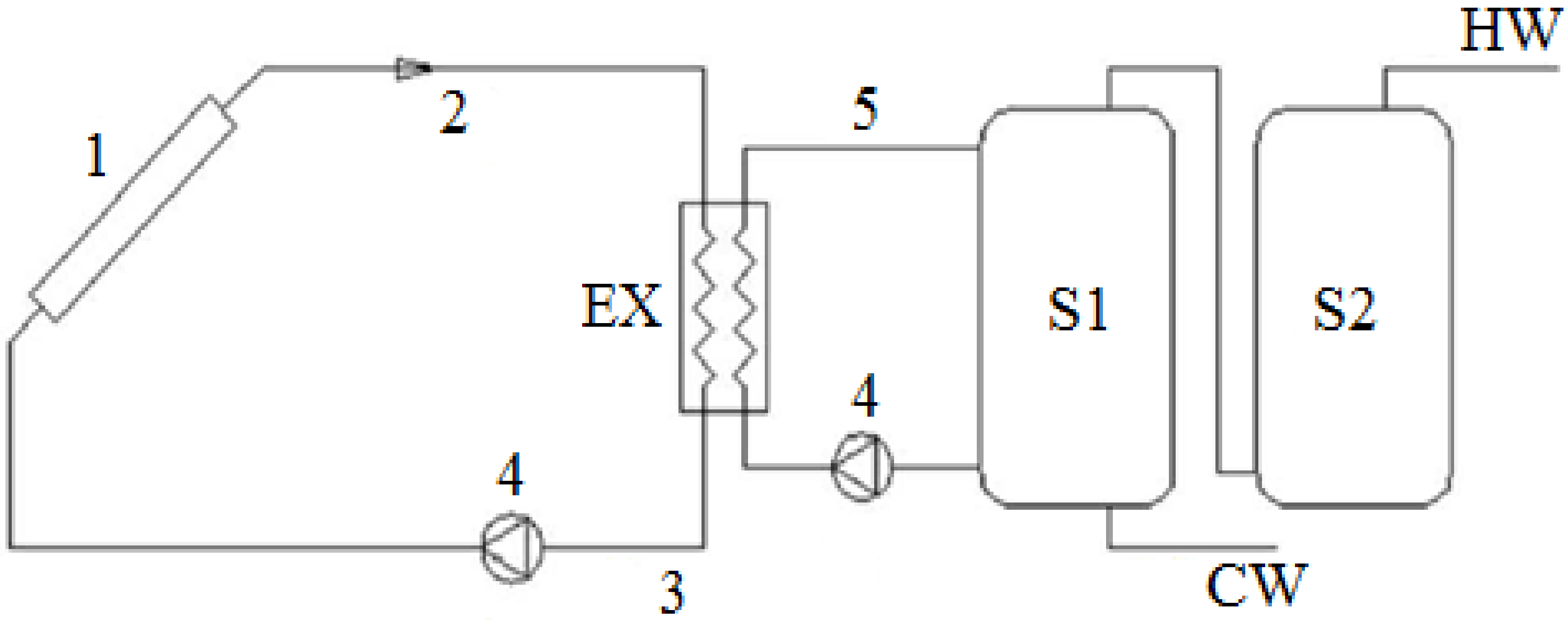
-Computer modeling has many advantages (eliminate the expense prototypes, understanding of system operation, optimize the system components).

-This paper - mathematical model and the results of simulation a solar system for heating sanitary water.

-Model is fully dynamic - daily and annual variations of the temperature of the outside air and solar radiation, and variations in load – in the consumption of hot water.

-Results obtained by numerical simulation were compared with results obtained by using the *f* -chart method of calculation.

Solar System



Schematic diagram of the solar system:
1 – collector's field; 2 - distribution pipe network; 3 - pipe network; 4 – pump; 5 – pipe; EX - heat exchanger; S1,S2 – storage tanks; HW - hot water; CW- cold water.

Mathematical model

The basic energetics parameter of the solar collector is its thermal efficiency. Official test data given by manufacturer contain parameters which define the efficiency of the collector:

$$\eta = \eta_o - a_1 \frac{T_m - T_a}{G} - a_2 G \left(\frac{T_m - T_a}{G} \right)^2$$

Energy balance of the *i* - th solar collector in row is described by equation:

$$C_{c,i} \frac{dT_{m,i}}{dt} = A_{c,i} G \eta_i - \dot{m}_f c_{p,f} (T_{f,out} - T_{f,in})_i$$

Energy balance of the *i* - th element or segment of the solar system (section of the distribution and return pipelines, storage tank) has general form:

$$C_i \frac{dT_{m,i}}{dt} = \sum_{j=1}^{k} (\dot{m}_f c_{p,f} T_f)_{j,in} - \sum_{l=1}^{n} (\dot{m}_f c_{p,f} T_f)_{j,out} - U_i (T_{m,i} - T_{a,i})$$

Energy balance of heat exchanger:

$$\dot{Q}_{ex} = (\dot{m}c_p\Delta T)_{sol} = (\dot{m}c_p\Delta T)_{ac} = \varepsilon(\dot{m}c_p)_{\min}(T_{sol,in} - T_{ac,in})$$

Heat rate delivered by solar system to water: $\dot{Q}_{sol} = \dot{m}_{load}c_p(T_{S2} - T_{cw})$

Total heat rate delivered to the user: $\dot{Q}_{load} = \dot{m}_{load}c_p(T_{load} - T_{cw})$

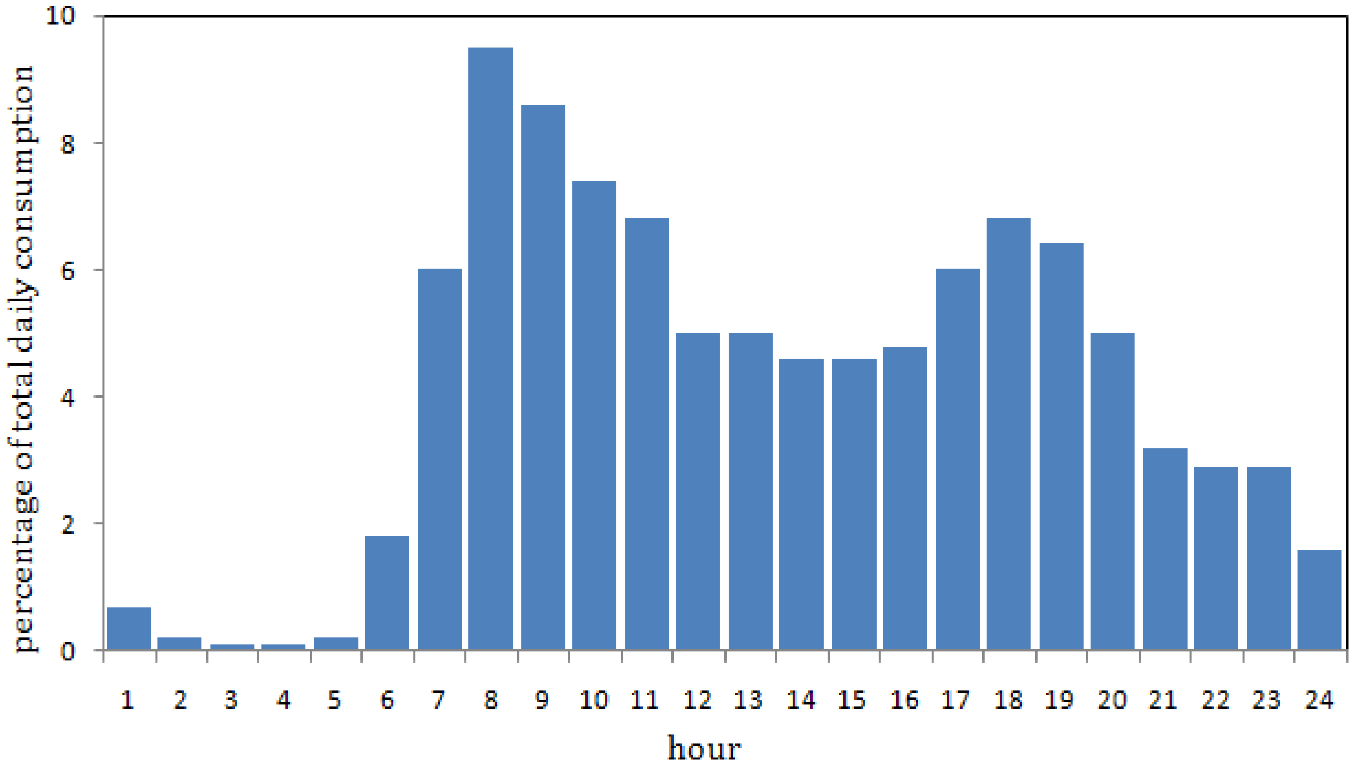
Solar fraction expresses the contribution of solar energy to the total thermal load. For the *i* - th month the solar fraction is:

$$f_i = \frac{Q_{S,i}}{Q_{L,i}} = \frac{\int_{\Delta t} \dot{Q}_{sol}dt}{\int_{\Delta t} \dot{Q}_{load}dt}$$

$Q_{S,i}$ – solar energy delivered to the user during month
$Q_{L,i}$ – energy required to cover the load for given month

Input data and procedure of simulation

-The solar radiation, ambient temperature, cold water temperature, hot water consumption, temperature of the air around pipe network and storage tanks must be known at each time step.



Total hot water consumption 5785 [l/day].

Fig. Daily profile of hot water consumption

Flat solar collectors:

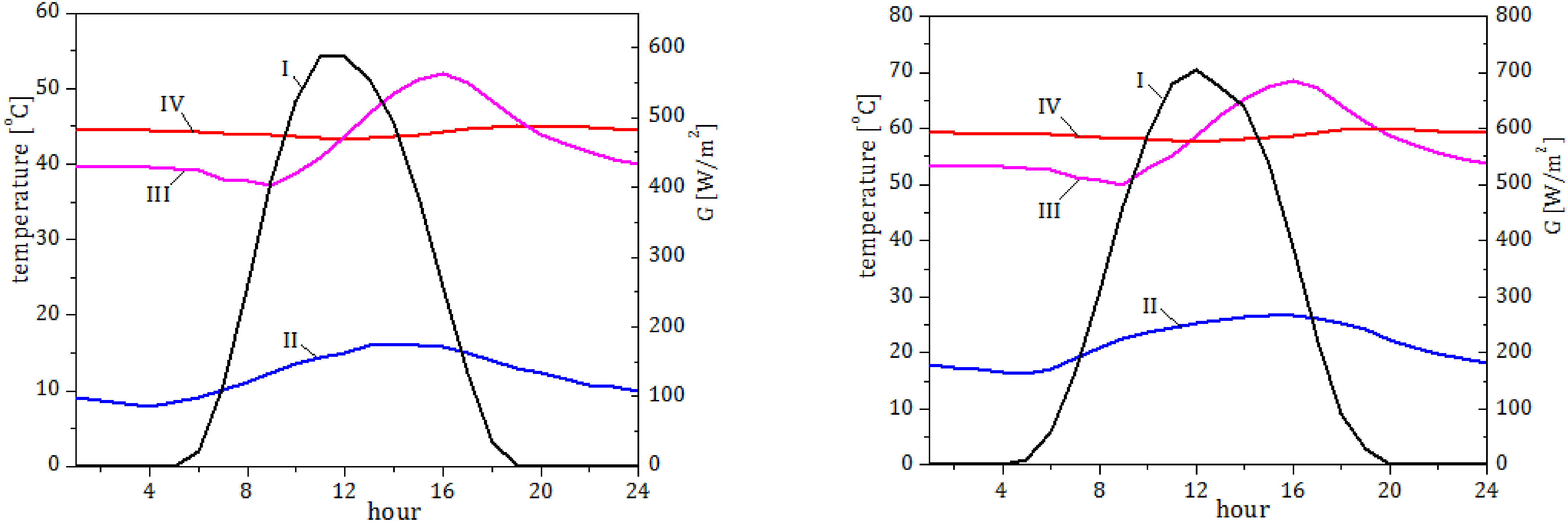
A_c =2,35 m^3, C_c=19 kJ/K, η_o=0,791, a_1=2,41 W/(m^{2}K)), a_2=0,023 W/(m^{2}K^2)).

-Heat loss coefficients for pipelines and storage tanks were calculated.

-Simulation for climate conditions of Belgrade.

-A system of ordinary differential equations which describe dynamic behavior of the solar system was solved numerically.

Results and analysis

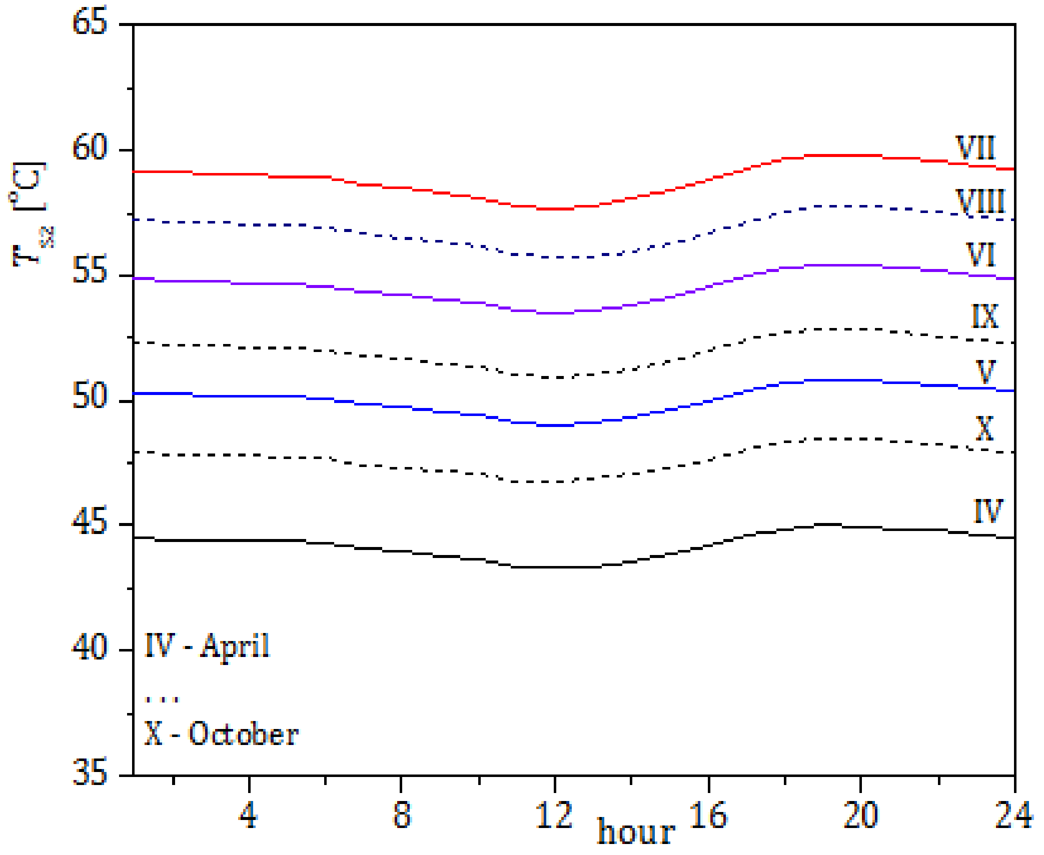


a) April *b)* July

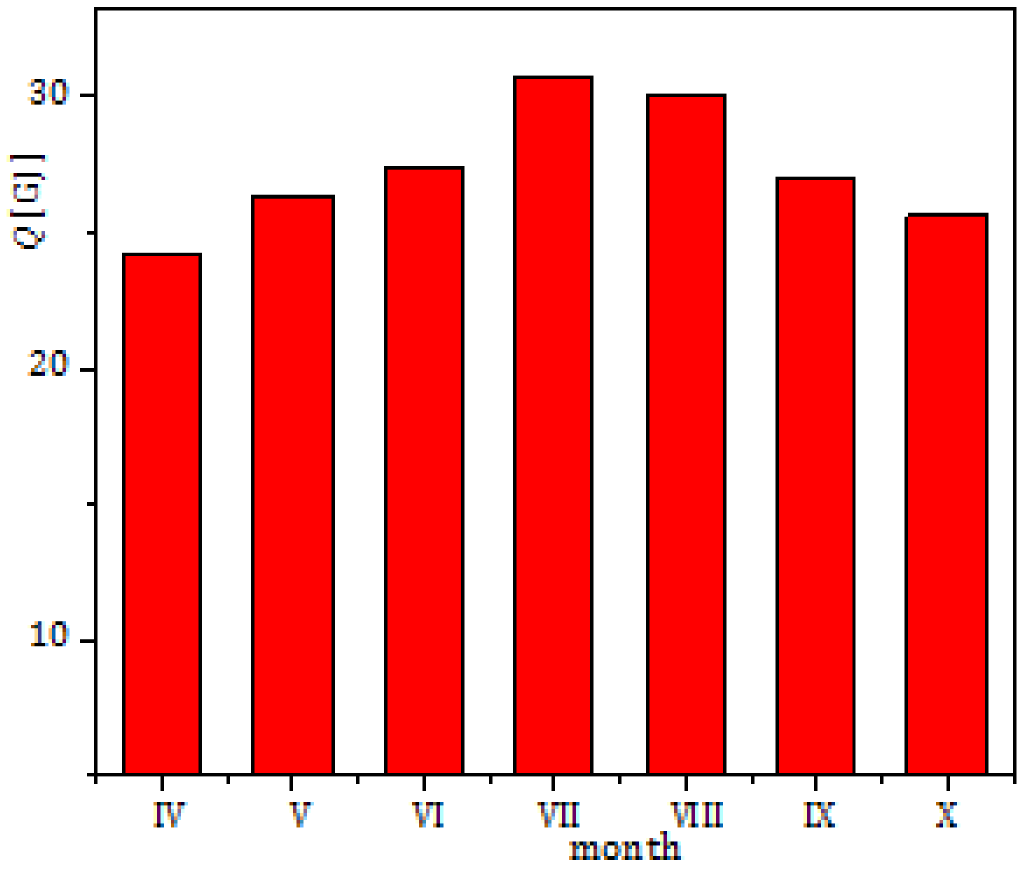
Figure : Daily profile of solar system parameters

I-solar incident radiation; II – ambient air temperature;

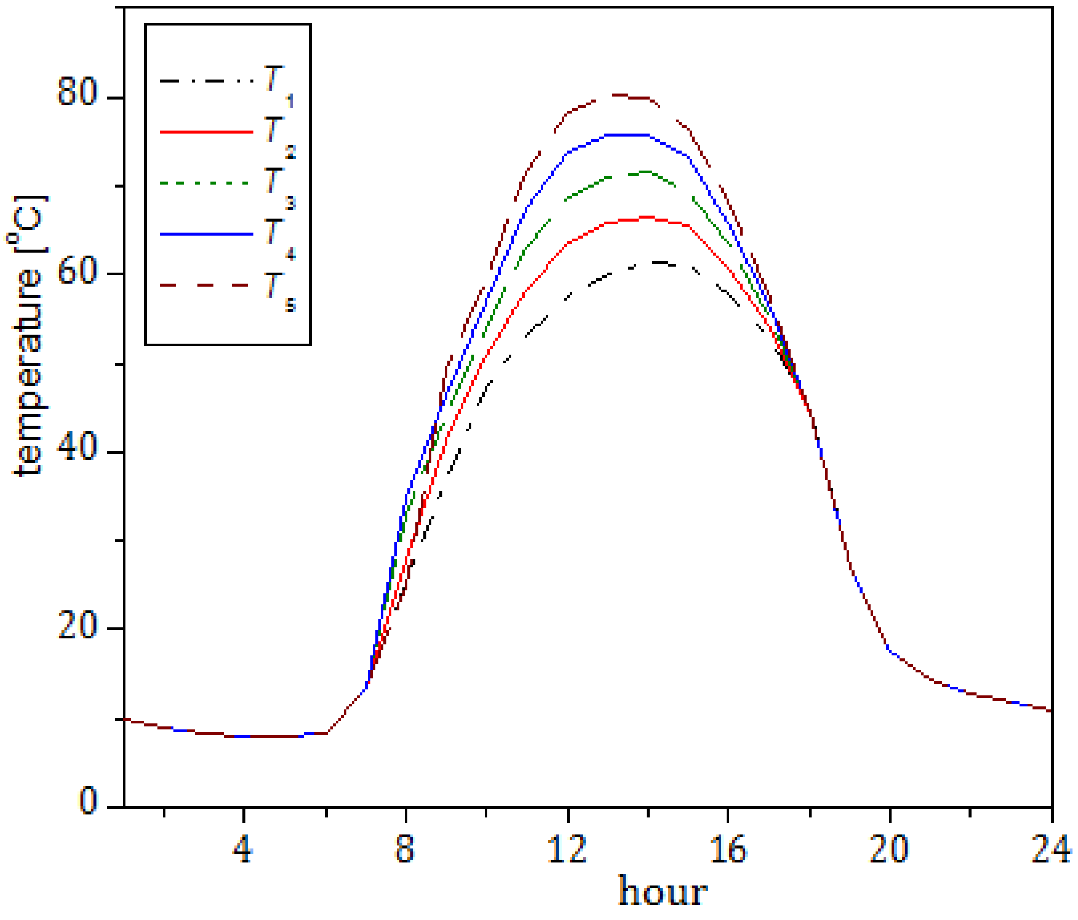
III - water temperature in storage tank S1; IV- water temperature in storage tank S2



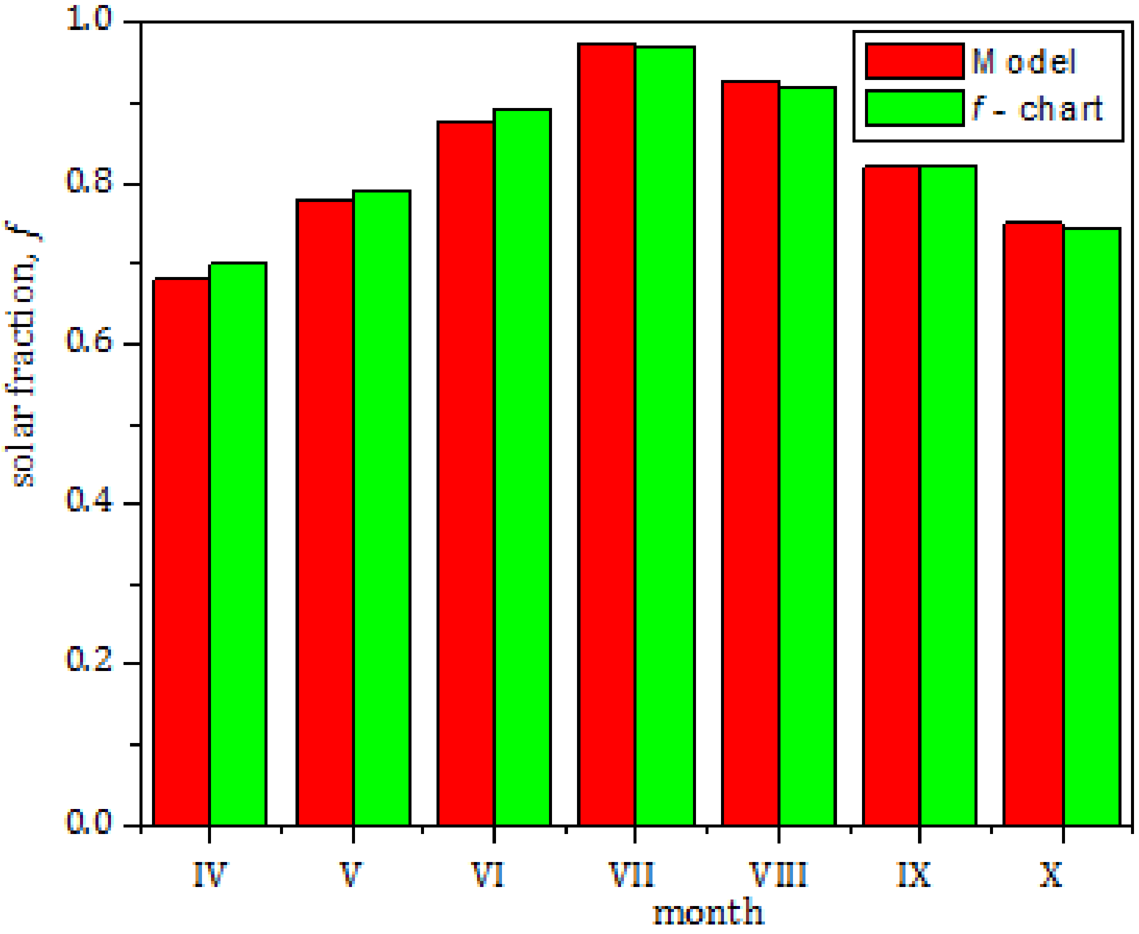
Water temperature in the storage tank S2



Monthly value of useful solar energy



Hourly-averaged temperatures in series connected collectors (from 1 to 5)



Solar fraction

Conclusions

-A dynamic simulation model for thermal solar system was developed;

-The results obtained by the presented model are logical and easy to explain and they are well matching to the results obtained by the *f*-chart method;

-The model provides an opportunity to analyze the influence of different climatic data (different system location), the dynamics of hot water consumption, the characteristics of system components, fluid flow ...

-It can be a good tool for optimization of the operation of solar systems for water heating.