6. Međunarodna konferencija o obnovljivim izvorima električne energije

6th International Conference on Renewable Electrical Power Sources

Beograd, 11. i 12. oktobar 2018.
Belgrade, October 11 and 12, 2018

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PROGRAM

ČETVRTAK • THURSDAY, October 11, 2018		
09.00–10.00 h	Prijavljivanje učesnika	Registration
10.00–10.30 h	Otvaranje Konferencije	Opening ceremony
10.30–11.30 h	Plenarna predavanja	Plenary session
11.30–13.30 h	Izlaganje radova I tematske grupe	First session
13.30–14.00 h	Pauza	Break
14.00–16.15 h	Izlaganje radova II tematske grupe	Second session
16.15–16.30 h	Pauza	Break
16.30–18.45 h	Izlaganje radova III tematske grupe	Third session

PETAK • FRIDAY, October 12, 2018		
12.00–16.00 h	Fotonaponski sistemi u gradovima	Seminar

FOREWORD

Intensive technological development, improved standard of living and population growth on Earth demand an increasing consumption of all forms of energy and, on the other hand, cause negative effects on the environment. Having this in mind, the United Nations have defined the sustainable economic development in the Millennium Development Goals, and the presidents of seven most developed countries, so called G7 Group, signed the declaration in Brussels, in which, inter alia, they emphasised the following goals:

- *reduction of greenhouse gas (GHG) emissions,*
- *improvement of energy efficiency, and*
- *promotion of the use of clean and sustainable energy technologies and continuation of investment in innovations.*

Particularly negative effects on the environment come from the electricity generation plants, taking into account that they are fuelled by fossil fuels. Therefore, the increased use of renewable electrical power sources is expected in the following period, both globally and in this country.

The main goal of the 6th international conference on renewable electrical power sources is to analyse the comparative advantages and disadvantages of modern solutions in the field of renewable electrical power sources used globally and in this country, and to provide a constructive platform for the exchange of competent opinions and ideas related to the development and use of these sources.

The 6th Conference is accredited by the Institute for Education Promotion.

This international conference is for the sixt time organised by the Society for Renewable Electrical Power Sources, which has been a part of SMEITS (Serbian Union of Mechanical and Electrical Engineers and Technicians) since 2010.

Belgrade,
October 2018

PREDGOVOR

Intenzivan tehnološki razvoj, rast životnog standarda i porast broja ljudi na Zemlji, zahtevaju sve veću potrošnju svih vidova energije, dok se na drugoj strani kao posledica, javljaju negativni efekti po životnu sredinu. Imajući ovo u vidu, UN su definisale održiv ekonomski razvoj u Milenijumskim ciljevima a predsednici sedam najrazvijenih država, takozvane Grupe G7, potpisali su deklaraciju u Briselu u kojoj su, između ostalih, istakli i sledeće ciljeve:

- *smanjenje emisije gasova staklene bašte,*
- *unapređenje energetske efikasnosti, i*
- *promovisanje primene čistih i održivih energetskih tehnologija i nastavak ulaganja u istraživanja i inovacije.*

Posebno negativan uticaj na životnu sredinu imaju postrojenja za proizvodnju električne energije imajući u vidu da kao pogonsko gorivo uglavnom koriste fosilna goriva.

Zbog toga se u svetu, kao i kod nas, u narednom periodu očekuje povećanje primene obnovljivih izvora električne energije.

Osnovni cilj 6. Međunarodne konferencije o obnovljivim izvorima električne energije jeste da se analiziraju uporedne prednosti i nedostaci savremenih rešenja u oblasti obnovljivih izvora električne energije koja se primenjuju u svetu i kod nas, i da se obezbedi plodotvorna razmena kompetentnih mišljenja i ideja vezanih za razvoj i primenu ovih izvora.

Zavod za unapređenje obrazovanja Republike Srbije akreditovao je šestu Konferenciju.

Ovaj međunarodni skup po šesti put organizuje Društvo za obnovljive izvore električne energije koje u okviru Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS) postoji od 2010. godine.

U Beogradu,
oktobra 2018.

SADRŽAJ

2. Energetska efikasnost u kontekstu primene OIEE

3. Aplikacije i usluge

OCENJIVANJE SOLARNIH ENERGETSKIH SISTEMA MODERNIM METODAMA

ASSESSMENT OF SOLAR ENERGY SYSTEMS USING MODERN METHODS

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Dragan CVETKOVIĆ, Jasna RADULOVIĆ
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Energetski resursi i njihova upotreba povezani su sa održivim razvojem. U postizanju održivog razvoja, važnu ulogu igra povećanje energetske efikasnosti procesa u kojima se koriste održivi izvori energije. Energetska analiza se uveliko koristi u projektovanju, simulaciji i proceni karakteristika sistema za solarnu energiju. Solarna energija je čista, ima je u izobilju i lako je dostupna obnovljiva energija. Ovaj rad predstavlja optimizaciju dizajna, implementaciju u praksi i rad solarnih kolektora u prostoru i vremenu, kao elementa solarnih instalacija. Kako bi se utvrdila izvodljivost predloženog koncepta korišćene su moderne metode energomonitoringa i energodijagnostike. U istraživanjima je korišćen softver EnergiPlus. Vremenski podaci korišćeni su iz meteorološke stanice.U radu je pokazan maksimalni iznos generisane toplotne energije, kao i maksimalne vrednosti solarnog udela optimizovanjem fi(βi) u fi(βi,Ɣi,) tokom godine za Beograd, Srbija, za solarni sistem za zagrevanje STV sa CK#12. Ovom prilikom je pokazan i procentualni gubitak generisanja toplotne energije i razlike solarnog udela optimizovanjem fi(βi) i fi(βi,Ɣi,), što govori da optimalno pozicioniranje mora biti na osnovu rigoroznih proračuna, a ne na bazi iskustava. Ovakvi proračuni dovode do unapređenja rada solarnih energetskih sistema.Ovo vrlo korisno znanje je takođe neophodno za utvrđivanje energetske efikasnosti i/ili mogućnosti očuvanja energije, kao i za formulisanje pravih strategija države za upravljanje energijom.

Ključne reči: *Optimizacija; solarni sistem za zagrevanje STV; solarni udeo; simulacija; solarni prijemnik;*

Energy resources and their utilization relate to sustainable development. In attaining sustainable development, increasing the energy efficiencies of processes utilizing sustainable energy resources plays an important role. Energy analysis has been widely used in the design, simulation and performance evaluation of solar energy systems. Solar energy is clean, abundant and easily available renewable energy. This paper represents the optimization of design, implementation in practice and operation of the solar collectors in space and time, as elements of solar installations, in order to determine the feasibility of the proposed concept modern methods of energy monitoring and energy diagnostics. These investigations use computer software EnergyPlus. The used weather data are from the meteorological station. The paper presents the maximum amount of generated heat energy as well as the maximum values of the solar fraction by optimizing fi (βi) and fi (βi, Ɣi,) during the year for SDHWS with SC # 12, operating in Belgrade, Serbia. This is shown the percentage loss of the generation of heat energy and the difference in the solar fraction was also shown by optimizing fi (βi) and fi (βi, Ɣi,), which suggests that optimal positioning must be based on rigorous calculations and not on the basis of experience. Such calculations lead to the improvement of the operation of solar energy systems.This very useful knowledge is also needed for identifying energy efficiency and/or energy conservation opportunities, as well as for dictating the right energy and exergy management strategies of a country.

Key words: *Optimization, SDHWS, Solar fraction, Simulation, Solar collector*

1 Introduction

Long-term potential actions for sustainable development are needed if we want to achieve solution to environmental problems that we face today. In comparison to conventional energy sources,

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renewable energy sources are inexhaustible and offer many environmental benefits At the moment conventional sources meet most of the energy demand, however the role of renewable energy resources and their current advances have to take more relevance in order to contribute to energy supply and support the energy conservation (or efficiency) strategy by establishing energy management systems. Numerous benefits including a decrease in external energy dependence; a boost to local and regional component manufacturing industries; decrease in impact of electricity production and transformation; promotion of regional engineering and consultancy services specializing in the utilization of renewable energy;

During the first years of the twenty-first century, extensive efforts have been undertaken to alleviate global warming of the earth caused by emission of CO_2 in atmosphere. These emissions are generated by intensive burning of fossil fuels to satisfy the growing energy needs of humanity. The emissions may be mitigated when part of energy needs is satisfied by using non-polluting energy sources such as solar energy, instead of fossil fuels.

In Serbian households, customary to use electricity for heating of DHW. Accordingly, in Serbia and worldwide, the most rewarding application of solar energy is when it replaces electrical energy for heating of DHW in households. In addition it is important to have a high efficiency of this use. In renewable energy field, SDHWS have arisen a great research interest [1,2]. To use SDHWS with the greatest benefit, SDHWS must have adequate design, installation, and operation.

The solar collectors can be placed in an optimal stationary position. However, it has been proven that this position is not optimal during the year. Therefore, in order to obtain a higher amount of energy from solar energy, solar collectors can be positioned in several different positions during the year. It was necessary that appropriate simulation and optimization of routers that will support this application using the solar collector. These algorithms enabled the determination of the position of the solar collector in the space, as well as the optimal start and end time for the use of a certain spatial position, all depending on the characteristics of the solar collectors, the characteristics of their installations, as well as the meteorological conditions of the place where it is installed this solar installation and house with net-zero energy consumption.

The paper presents the maximum amount of heat from solar energy as well as the maximum values of the solar fraction by optimizing fi (βi) and fi (βi, Ɣi,) during the year for SDHWS with SC # 12, operating in Belgrade, Serbia. This is shown the percentage loss of the heat from solar energy and the difference in the solar fraction was also shown by optimizing fi (βi) and fi (βi, Ɣi,). The solar collectors of the SDHWSs are placed in north-south direction at roofs of houses. The used weather data were from the meteorological stations and software Meteonorm. These investigations use the computer codes: EnergyPlus and GenOpt and HJ search algorithm [3-16].

2 Modelling and Simulation

In this investigation, simulation, and optimization are performed by using two separate software packages. The research of these installations was performed by using simulation by EnergyPlus and optimization by using Hooke-Jevees method. In this investigation, the Hooke-Jevees method was used to optimize energy flows in SDHWS.

Simulation Software – EnergyPlus: In this study, the building energy simulation software EnergyPlus (Version 7.0) was used to predict solar energy and electrical energy use in solar installation for heating of DHW in Serbia. Then, the solar fraction was determined for its different design, installation and operation parameters. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [18]. The software serves to simulate building energy behavior and use of renewable energy in buildings. The software has been tested using the IEA HVAC BESTEST E100-E200 series of tests [19,20]. Modeling of the SDHWS in EnergyPlus environment required models of different components embedded in EnergyPlus[20].

Genopt Software: GenOpt is an optimization program for the minimization of a cost function that is evaluated by an external simulation program [21]. It has been developed for optimization problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. GenOpt can be coupled to any simulation program that reads its input from text files and writes its output to text files. The independent variables can be continuous variables (possibly with lower and upper bounds), discrete variables, or both, continuous and discrete variables. Constraints on dependent variables can be implemented using penalty or barrier functions. GenOpt has a library with local and global multi-dimensional and one dimensional optimization algorithms, and algorithms for doing parametric runs [22]. An algorithm interface allows adding new minimization algorithms without knowing the details of the program structure. GenOpt is written in Java so that it is platform independent. The platform independence and the general interface make GenOpt applicable to a wide range of optimization problems. GenOpt has not been designed for linear programming problems, quadratic programming problems, and problems where the gradient of the cost function is available. For such problems, as well as for other problems, special tailored software exists that is more efficient.

Optimization Algorithm: For optimization, the Hooke–Jeeves algorithm is used together with EnergyPlus simulation. These two programs are connected together by using Genopt software [21]. In this research, the adaptive precision Hooke-Jeeves algorithm is used. Hooke Jeeves algorithm is a direct search algorithm [23,24]. In direct search methods, only the objective functions and the constraint values are used to guide the search strategy. The methodology of search is given in [25,26] in sufficient details. The used Hooke Jeeves algorithm is the adaptive precision algorithm. This algorithm progressively increase the precision of the approximating cost functions as the sequence of iterates approaches a stationary point. In addition, the algorithm only accepts iterates that reduces the cost sufficiently. It reduces the computation time up to a factor of four compared to the standard Hooke–Jeeves algorithm.

3 Mathematical Model

To obtain performance of SDHWS, the operation of the SDHWS was investigated by using simulation and optimization. The mathematical model was developed in EnergyPlus simulation environment and the optimization was performed by using Hooke-Jeeves search algorithm.

This part of the paper provides the mathematical model used to simulate the energy behavior of SDHWS and different parts of its installation: solar collector, thermal tanks (storage & heaters), tempering valve, and SDHWS-control devices.

EnergyPlus Model for SDHWS: The SDHWS heats DHW by using solar and electric energy. The DHW is used as water for sink, bath, shower, dish washing and cloth washing. The SDHWS is schematically shown in Fig.1 in EnergyPlus environment. The SDHWS consists of the following main elements explained separately in the text below: the solar collector, storage water tank, instantaneous water heater, tempering valve, and temperature controls. The investigated solar collector is of flat plate type.

Calculations require that the solar collector surface is described geometrically. Here, the solar collector is placed to the building roof. The solar collector is south facing. Its tilt angle (β) is the angle between the Z-axis and the normal to the surface of the solar collector (or between the solar collector surface and the horizontal). The convention assumed here is that $-90^0<\beta<90^0$. The surfaces with positive β face south and with negative β face north. Its azimuth angle (Ɣ) is defined as the displacement angle between the projection on a horizontal plane of the normal to the collector surface and due north. The convention assumed here is that $-180^0 < \gamma < 180^0$.

If $f=f_i$ is larger, the SDHWS better protects the environment. Variable f_i is a function of tilt β_i and azimuth angle γ_i. It should be maximized in the constrained region of β_i and γ_i. As a result of the optimization, we obtain the maximum solar fraction $f_{i,max}$, and the optimum tilt $\beta_{i,opt}$, and optimum azimuth angle $\gamma_{i,\ opt}$.

Each solar collector that stays at optimal position generates the highest amount of heat from the incident solar energy. Then, the SDHWS uses this heat for the DHW heating instead of the electrical energy from the electricity network. This means that such a SDHWS avoids use of the highest amount of electrical energy from the electricity grid for the DHW heating. In addition, this avoids the highest amount of electrical energy generation by the national power plants.

If the solar collector of a SDHWS does not stay at the optimum position due to some reason, then it will generate smaller amount of exergy for the DHW heating than the maximum amount it would generate when it stays at the optimum position. As the heating of DHW uses the electrical energy, the SDHWS will use more electrical energy for the DHW heating than that when the SDHWS has its solar collector at the optimum position.

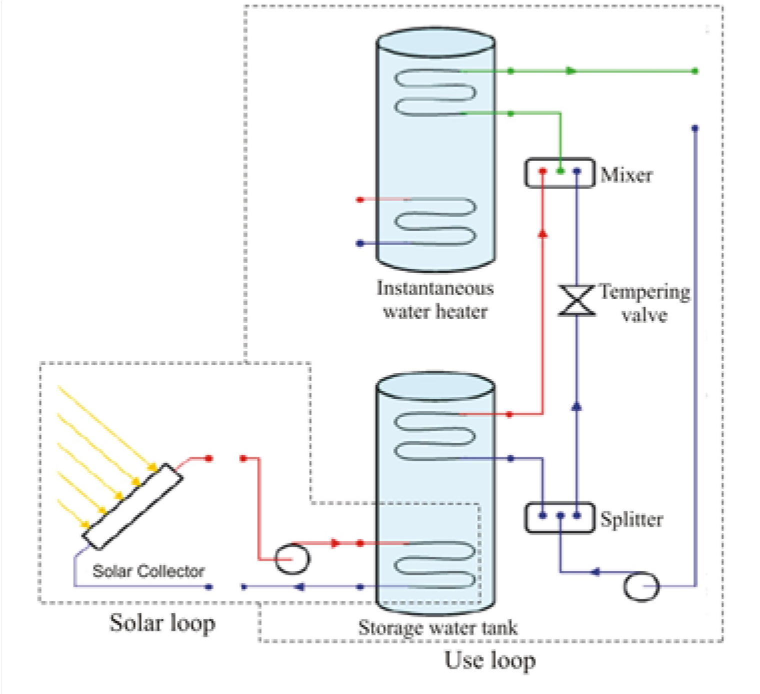

Fig.1 *- Schematics of SDHWS for heating of DHW (adapted from [19])*

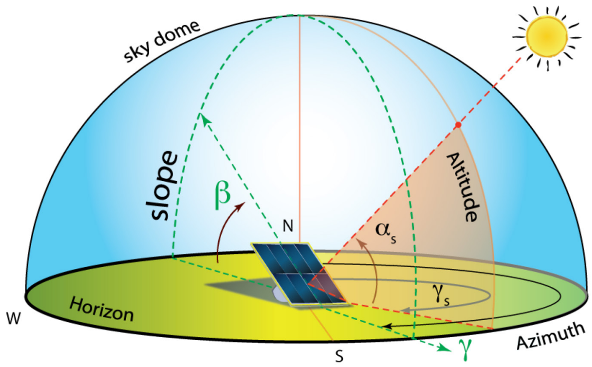

Fig. 2*- Collector-Sun_Orientation [14]*

Calculation of energy consumption: Calculation of energy consumption during the calculation period gives two electrical energies *E* and *R* consumed for DHW production. The energy *E* is consumed by the electric heater when the solar collector is present and operating, and energy *R* is consumed when no solar collector is employed. The objective function is the performance of the installation is evaluated by calculating the solar fraction (*f*) by:

$$f = 100\ (R-E)/R = f\,(\beta_i, \gamma_i) \qquad (1)$$

Solar Collector (Thermal Performance): Solar Collector is of Flat Plate type produced by, Alternate Energy Technologies (AE-32) with length of 3.66m and width of 2.43m.

The thermal efficiency of a collector is defined as the ratio of the useful heat gain of the collector fluid versus the total incident solar radiation on the gross surface area of the collector.

$$\eta = \frac{(q/A)}{H_{solar}} \qquad (2)$$

where:q = useful heat gain

A = 8.89m^2 = gross area of the collector

H_{solar} = total incident solar radiation

Notice that the efficiency η is only defined for $H_{solar} > 0$.

$$\eta = c_0 + c_1 \frac{(T_{in} - T_{air})}{I_{sol}} + c_2 \frac{(T_{in} - T_{air})^2}{I_{sol}} \qquad (3)$$

Both first- and second-order efficiency equation coefficients from [20] are given as $c_0 = 0.691$, $c_0 = 3.396$ W/m^2-K, and $c_0 = 0.00193$ W/m^{2}K^2.

Solar Collector (Incident Angle Modifiers): As with regular windows the transmittance of the collector glazing varies with the incidence angle of radiation. Usually the transmittance is highest when the incident radiation is normal to the glazing surface. Test conditions determine the efficiency coefficients for normal incidence. For off-normal angles, the transmittance of the glazing is modified by incident angle modifier coefficients by the equation:

$$K_{\tau\alpha} = 1 + b_0 \left(\frac{1}{\cos\theta} - 1 \right) + b_1 \left(\frac{1}{\cos\theta} - 1 \right)^2 \tag{4}$$

The incident angle modifier coefficients b_0= -0.1939 and b_1= -0.0055 are usually negative [20]. and only valid for incident angles of 60 degrees or less. Because these curves can be valid yet behave poorly for angles greater than 60 degrees, the EnergyPlus model cuts off collector gains for incident angles greater than 60 degrees.

Solar Collector (Outlet temperature): Outlet temperature is calculated using the useful heat gain q, the inlet fluid temperature T_{in}, and the mass flow rate available from the plant simulation:

$$\frac{q}{A} = \dot{m} c_p (T_{out} - T_{in}) \tag{5}$$

where:
$\dot{m}$ = fluid mass flow rate through the collector
c_p = specific heat of the working fluid

Solving for T_{out}:

$$T_{out} = T_{in} + \frac{q}{\dot{m} c_p A} \tag{6}$$

Thermal tanks (storage & heaters): Water thermal tanks are devices for storing thermal energy in water from the SDHWS. The input object of EnergyPlus (WaterHeater:Mixed) provides a model that simulates a storage water tank (well-mixed water tank), and also instantaneous water tank (tankless water heater). The storage water tank has volume of 0.75 m^3.

Tempering Valve: In certain solar hot water and heat recovery situations, a thermal storage tank may become warmer than is necessary or allowable for safe use of the hot water. The tempering valve acts to divert flow through the branch it is on in order to adjust the temperature at the outlet of the mixer (see Fig. 3).

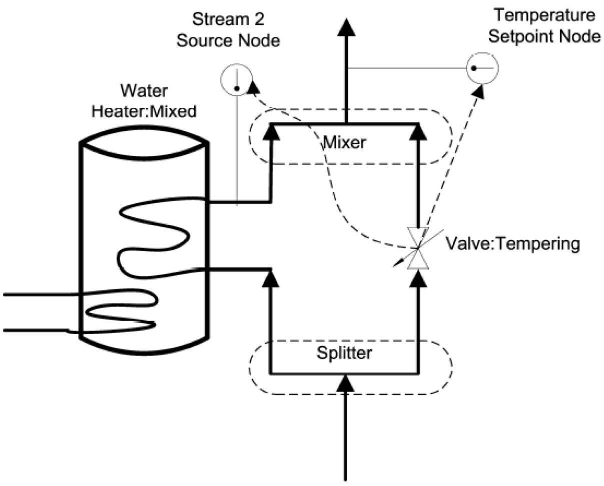

***Fig. 3**- SDHWS –tempering valve (adapted from [19])*

SDHWS-Control temperatures for solar loop: To control use of this installation, several temperatures will be supported in the solar loop by using the control equipment inside this installation. Its maximum flow rate is 0.00006 m3/s. Main parameters of solar heating installation for water loop through the solar collector are the following Loop temperature (TL=60^{0}C), High temperature turn off in solar loop (60^{0}C), High temperature turn on in solar loop (0^{0}C), Temperature difference on limit (differential thermostat) (10^{0}C), Temperature difference off limit (differential thermostat) (2^{0}C).

SDHWS-Control temperatures for use loop: To control use of this installation, several temperatures will be supported in the use loop by using the control equipment inside this installation. Main supported temperatures are are the hot water setpoint temperature (TH=50^{0}C) and the maximum temperature limit for storage tank (82.2 ^{0}C).

4 Simulation and Optimization

For simulation and optimization to run, it is necessary to know the hot water consumption and climate.

Hot Water Consumption: This installation generates four different types of hot water: that of tap, shower, dish-washer, and cloth-washer. Regarding its application, the water would be heated to two temperatures: 43.3 (tap and shower with the maximum flow rate of 0.0000945 m^3/s) and 50^{0}C (dish and clothes washer with the maximum flow rate of (0.000063 m^3/s). For water with lower temperature and for water with higher temperature used in dish washer, the daily schedule is the same for each day throughout entire summer. The cloth washer operates only on Sunday. For water with higher temperature used in the cloth washer, the daily schedule is the same for each Sunday throughout the entire summer.

Weather data: The investigated SDHWS is located in the city of Belgrade. Their meteorological data are used in the form of EnergyPlus weather files. These are either measured by the meteorological stations or calculated by the software Meteonorm for sites where data from meteorological stations are not available.

Belgrade has the average height above sea-level of 99 m. Its latitude is 44.82°N, longitude 20.27°E, and time zone GMT +1.0 Hours.

5 Results and Discussion

To use SDHWS adequately, it must be satisfactory designed, installed, and operated. In this paper, we report how the optimal installation of the SDHWS can be achieved by using EnergyPlus software with the modified Hooke Jeeves direct search algorithm. As an example, these software tools are applied to SDHWS in Belgrade, Serbia.

Figure 4 shows the maximum amount of heat from solar energy by optimizing fi (βi, Ɣi) for solar heating system STV with SK#12 for Belgrade, Serbia. Values are everyday and are given for each month. Also, given the differences, the percentage loss of heat from solar energy. If the solar collector is set to the optimum position, we get larger daily values of the heat from solar energy compared to the values of the heat from solar energy by months, when we optimize fi (βi, Ɣi). The loss ranges from 6.5% to 15.5%.

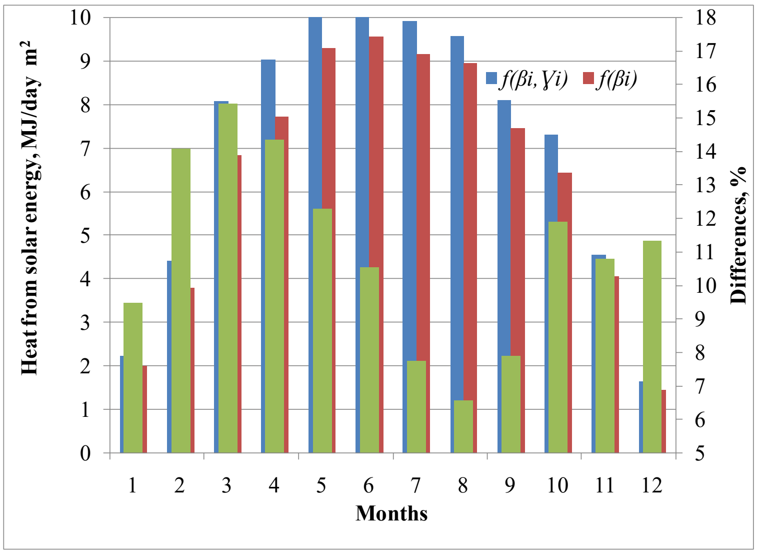

***Fig 4.**- Maximum amount of heat from solar energy and loss in heat from solar energy by optimizing fi (βi, Ɣi,) for SDHWS with SC # 12, obtained by optimizing fi (βi) and optimizing fi (βi, Ɣi), operating in Belgrade, Serbia.*

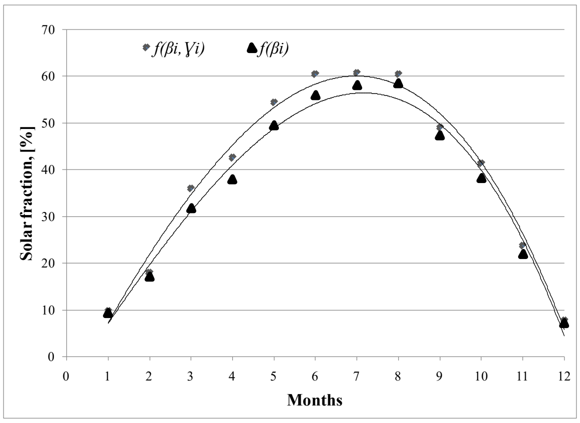

Fig 5. *- Optimal values fm,opt optimizing fi (βi) and optimizing fi (βi, Ɣi) for SDHWS with SC # 12, operating in Belgrade, Serbia*

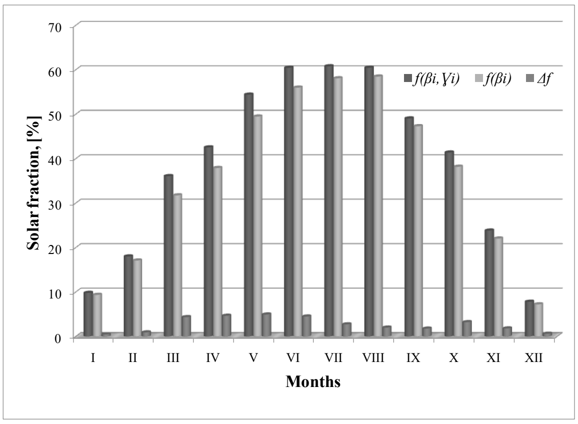

Fig 6. *-Differences solar fraction, optimizing fi (βi) and optimizing fi (βi, Ɣi) for SDHWS with SC # 12, operating in Belgrade, Serbia*

Figure 5 shows the maximum values of the solar fraction, where one curve is obtained for the case fm in the function of the angle slope βm and the azimuth angle Ɣm, and the second curve for the case fm in the function of the angle slope βm. It has been shown that the values obtained in the case of fi (βi, Ɣi,) give higher values of solar fraction by months. Figure 6 graphically shows the monthly difference in solar fraction, for SDHWS with SC # 12, operating in Belgrade, Serbia. The highest values of the differences are in May Δfm = 5%, and at least in December Δfm = 0.5%.

Table 1. *shows the values of the percentage loss of optimization fm (βm, Ɣm) compared to the optimization of fm (βm).*

SDHWS with SC # 12	$f_i(\beta_i)$, [%]	$f_i(\beta_i, Ɣ_i)$ [%]	percentage loss of optimization, [%]
I	9.3	9.8	4.9
II	17.1	18.0	5.3
III	31.7	36	13.6
IV	37.9	43.5	12.2
V	49.5	54.4	9.9
VI	55.9	60.4	7.9
VII	58.1	60.8	4.6
VIII	58.4	60.4	3.4
IX	47.3	49.0	3.7
X	38.2	41.4	8.4
XI	22.0	23.8	8.2
XII	7.2	7.8	8.2

6 Conclusion

To use SDHWS with benefit, it has to be optimally designed, installed, and operated. In this paper, it is analyzed how the SDHWS can be optimally installed by using EnergyPlus software with the modified Hooke Jeeves direct search methodology. As an example, Hooke-Jeeves algorithm is used to obtain the maximum amounts of these performances for different SDHWS as a function of number of optimum positions of the solar collector in SDHWS during year for the city of Belgrade, Serbia. The paper presents the maximum amount of heat from solar energy as well as the maximum values of the solar fraction by optimizing fi (βi) and fi (βi, Ɣi,) during the year for SDHWS with SC # 12, for Belgrade, Serbia. This is shown the percentage loss of the heat from solar energy (the loss ranges from 6.5% to 15.5%) and the difference in the solar fraction (the highest values of the differences are in May Δfm = 5%, and at least in December Δfm = 0.5%) was also shown by optimizing fi (βi) and fi (βi, Ɣi), which suggests that optimal positioning must be based on rigorous calculations and not on the basis of experience. The paper presents losses optimization, which also speaks of the necessity of rigorous calculations for the optimal positioning of solar collectors in order to achieve the best performance.Such calculations lead to the improvement of the operation of solar energy systems.

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