ZBORNIK RADOVA
Proceedings

pisanih za 5. Međunarodnu konferenciju o obnovljivim izvorima električne energije

5th International Conference on Renewable Electrical Power Sources

SMEITS

2017

ZBORNIK RADOVA	**PROCEEDINGS**
pisanih za 5. Međunarodnu konferenciju o obnovljivim izvorima električne energije	**5th International Conference on Renewable Electrical Power Sources**
Sava centar 12. i 13. oktobar 2017.	Sava Center 12 and 13 October 2017
Izdavač	**Publisher**
Savez mašinskih i elektrotehničk ihinženjera i tehničara Srbije (SMEITS) Društvo za obnovljive izvore električne energije Kneza Miloša 7a/II, 11000 Beograd	Union of Mechanical and Electrotechnical Engineers and Technicians of Serbia (SMEITS) Society for Renewable Electrical Power Sources Kneza Miloša str. 7a/II, 11000 Beograd
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Za izdavača	**For Publisher**
Vladan Galebović	Vladan Galebović
Štampa	**Printing**
BSIDE d.o.o., Beograd	BSIDE d.o.o., Beograd
Tiraž	**Circulation**
450 primeraka	450 copies

ISBN 978-86-81505-84-7

CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

502.171:620.9(082)(0.034.2)

MEĐUNARODNA konferencija o obnovljivim izvorima električne energije (5 ; 2017 ; Beograd) Zbornik radova pisanih za 5. Međunarodnu konferenciju o obnovljivim izvorima električne energije, [Beograd] Sava centar 12. i 13. oktobar 2017. [Elektronski izvor] = Proceedings / 5th International Conference on Renewable Electrical Power Sources ; [organizator Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS), Društvo za obnovljive izvore električne energije]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije - SMEITS, 2017 (Beograd : BSIDE). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 450. - Abstrakti. - Bibliografija uz svaki rad.

ISBN 978-86-81505-84-7

1. Савез машинских и електротехничких инжењера и техничара Србије (Београд). Друштво за обновљиве изворе електричне енергије

а) Енергетски извори - Одрживи развој - Зборници

COBISS.SR-ID 247351308

GENERALNI POKROVITELJ
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gge

GGE ESCO, Belgrade

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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 5th 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.

This international conference is for the fifth 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 2017

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 5. 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.

Ovaj međunarodni skup po peti 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 2017.

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3. Energetski izvori i skladištenje energije • Energy sources and energy storage

3. Aplikacije i usluge • Applications and services

MAKSIMIZIRANJE PERFORMANSI SOLARNOG SISTEMA ZA ZAGREVANJE SANITARNE TOPLE VODE U FUNKCIJI OPTIMALNOG POLOŽAJA SOLARNOG PRIJEMNIKA

MAXIMIZING PERFORMANCES OF A SOLAR DOMESTIC HOT WATER SYSTEM THROUGH OPTIMUM POSITION OF THE SOLAR COLLECTOR

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https://doi.org/10.24094/mkoiee.017.1.5.139

U Srbiji se najčešće električna energija koristi za zagrevanje sanitarne vode (SV). Kako je oko 70% električne energije dobija korišćenjem uglja koji oslobađa veliki broj gasova sa efektom staklene bašte, korišćenje solarne energije za zagrevanje sanitarne vode u solarnim sistemima za zagrevanje sanitarne vode (STV) ima povoljan uticaj na očuvanje život-ne sredine. Tokom rada solarni sistem za grejanje sanitarne tople vode generiše različite količine toplote iz solarne energije, dobijaju se različite količine izbegnute elekrične energije. U istraživanjma je primenjen softver EnergyPlus. Korišćeni vremenski podaci su iz ovlašćenih meteoroloških stanica.

U ovom radu pokazana je energetska optimizacija solarnog sistema za zagrevanje STV sa solarnim prijemnikom koji funkcioniše tako što koristi ugao nagiba 37.5° i 12 različitih vrednosti ugla azimuta, po jedan za svaki mesec u toku godine. Ovom prilikom je za svaki solarni sistem za grejanje STV izračunat solarni udeo u funkciji ugla nagiba i ugla azimuta i predstavljen odgovarajućim krivama. Takođe je prikazan i mesečni deficit solarnog udela za odstupanja ugla azimuta, kada on u nekim mesecima nije optimalan. Korišćene su odgovarajuće simulacione i optimizacione rutine sa modifikovanom metodologijom Hooke Jeeves algoritma.

Solarni sistemi su poboljšani, tako što je dobijena minimalna potrošnja fosilne energije, smanjena upotreba energetskih resursa, maksimizirana energetska sigurnost, kao minimiziran uticaj na životnu sredinu.

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

In Serbia, it is usually to use electrical energy for domestic hot water (DHW) heating. About 70% of electrical energy is produced by using coal with high greenhouse emission, so it is beneficial to environment to use solar energy for heating of DHW in solar DHW system (SDHWS). During SDHWS operation, different SDHWSs generate different amounts of heat from solar energy, and different amounts of avoided electrical energy are obtained. These investigations use computer software EnergyPlus. The used weather data are from the meteorological station.

In this peper, it is analyzed energy optimization of the solar system for DHW heating with solar collector, which works by using the angle slope 37.5° and 12 different azimuth angle values, for each month during the year. In this occasion, it has been calculated solar fraction for each SDHWS as a function of number of optimum positions of the solar collector in SDHWS during year, for the city of Belgrade, Serbia and represented by the corresponding curves. It is also shown the monthly deficit of solar fraction for deviations the azimuth angle, when it is not optimal. It was used appropriate simulation and optimization routines with the modified methodology of the Hooke Jeeves algorithm.

Solar energy systems have been improved, due to obtaining of minimum fossil energy consumption, reduction of the energy resources use, maximizing energy security, as well as the minimum impact on the environment.

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

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1 Introduction

Basic text should be tagged as Normal style. 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. Also, another important advantage of the usage of solar energy is that it does not pollute the environment with nitrogen oxides and sulfur dioxide.

In Serbian households, the high amount of DHW is used for shower, tap, cloths-washing machines, and dish-washing (machines). It is customary to use electricity for heating of DHW. As around 70% of electricity is produced by using coal with high greenhouse emission, it is important and the most rewarding to use solar energy for DHW heating instead of electrical energy. 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 households, the high amount of domestic hot water (DHW) is used for shower, tap, clothswashing (machines), and dish-washing (machines). If this water is heated by electricity which is generated by coal burning, then the highest amount of CO_2 is released to atmosphere. Accordingly, the most rewarding application of solar energy is when it replaces this type of electrical energy for heating of hot water in households. Then, the highest decrease in CO_2 emissions may be expected. 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. In this peper, it is analyzed energy optimization of the solar system for DHW heating with solar collector, which works by using the angle slope 37.5° and 12 different azimuth angle values, for each month during the year. In this occasion, it has been calculated solar fraction for each SDHWS as a function of number of optimum positions of the solar collector in SDHWS during year, for the city of Belgrade, Serbia and represented by the corresponding curves. It is also shown the monthly deficit of solar fraction for deviations the azimuth angle, when it is not optimal. 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: Simulation Software – EnergyPlus: In this study, the building energy simulation software EnergyPlus 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. 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 [17,20].

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 derivative free optimization algorithms. Hooke Jeeves algorithm is a direct search algorithm. 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 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 [23,24,25].

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. These elements are located in two inner loops of the SDHWS: the solar loop and the use loop. The solar loop is a loop through the solar collector. The use loop is a loop for DHW consumption. The solar loop consists of the solar collector, water pump, and spiral pipe heat exchanger (inside the hot water storage tank). The use loop consists of the splitter, storage water tank, instantaneous water heater, tempering valve, and mixer. Inside the solar loop, the solar collector captures solar energy. This energy heats water that flows through the solar collector. Furthermore, the hot water heats DHW in the storage water tank. In the use loop, the cold DW reaches the splitter. From the splitter, the DW may go to the storage water tank or to the tempering valve. In the storage water tank, DW is heated from the solar loop via the spiral pipe heat exchanger. From the storage water tank, the hot water goes to the instantaneous water heater where can be additionally heated. Then the hot water from the instantaneous water heater and the cold water from the tempering valve go to the mixer and after that as DHW to the consumers. The water temperature in the storage tank may be higher or lower than the needed (hot-water set-up) DHW temperature. If this water temperature is higher than the needed DHW temperature, then this water temperature is lowered in the mixer by using the cold DW through the tempering valve. If this water temperature is lower than the needed DHW temperature, this water is heated by electric energy in the instantaneous water heater to the needed DHW temperature. The investigated solar collector is of flat plate type.

Surface geometry. Calculations require that the solar collector surface is described geometrically. Here, the solar collector is placed to the building roof. The solar collector is rectangular in shape with its length designated as (a) and its width as (b). The building height is designated as h. Finally, the solar collector surface is described by the coordinates of their vertices 1, 2, 3, and 4 in a threedimensional Cartesian coordinate system. This right-hand coordinate system has the X axis pointing east, the Y axis pointing north, and the Z axis pointing up that is characteristics of EnergyPlus Cartesian coordinate system. The vertices are recorded in counter-clockwise sequence (as the surface is viewed from outside its zone).

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 $-180^0 < Ɣ < 180^0$.

The surface of the solar collector is rectangular and defined by 4 vertices. Vertex 1 has coordinates: x_1= b cos β sin Ɣ, y_1 = b cos β cos Ɣ, z_1 = b sin β + h_{12}. Vertex 2 has coordinates x_2=0, y_2=0, z_2=h_{12}. Vertex 3 has coordinates: x_3= a cos Ɣ, y_3= b sin Ɣ, z_3 = h_{12}. Vertex 4 has coordinates: x_4 = b cos β sin Ɣ + a cos Ɣ, y_4 = b cos β cos Ɣ +a sin Ɣ, z_4 = h_{12} + b sin β.

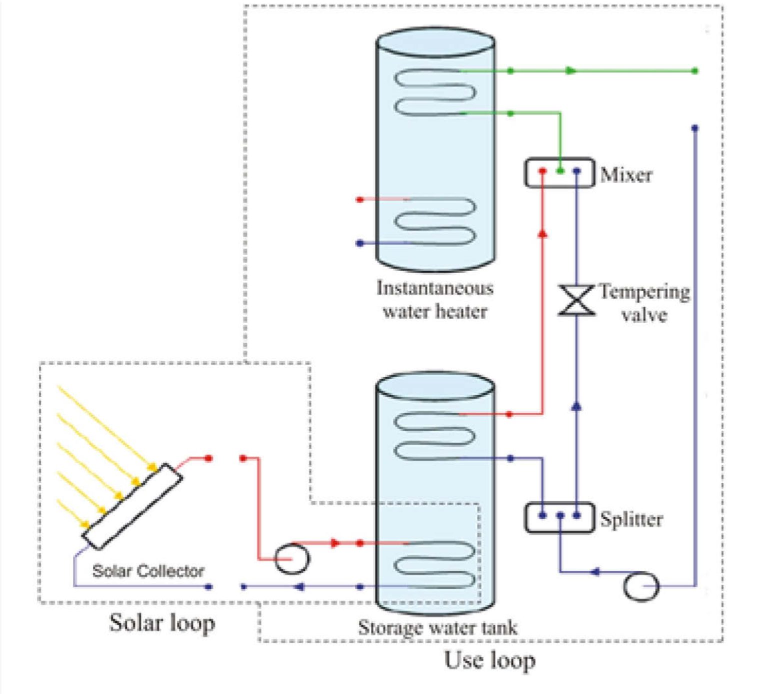

Fig.1 *- Schematics of SDHWS for heating of DHW (adapted from [18])*

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:

$$f = 100\ (R-E)/R = f\,(\beta_i, Ɣ_i)$$

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 $Ɣ_i$. It should be maximized in the constrained region of β_i and $Ɣ_i$. 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 $Ɣ_{i,\ opt}$.

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.

For this case, the deficit solar fraction is defined as

$$D_i = \frac{100(f_{i,tot} - f_{i,max})}{f_{i,max}}. \qquad (1)$$

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.

$$\eta = \frac{\frac{q}{A}}{H_{solar}} \tag{3}$$

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 $H_{solar} > 0$.

An energy balance on a solar collector with double glazing shows relationships between the glazing properties, absorber plate properties, and environmental conditions.

$$\frac{q}{A} = H_{solar}\tau_{g1}\tau_{g2}\alpha_a - \frac{T_{abs}^4 - T_{g2}^4}{R_{rad}} - \frac{T_{abs} - T_{g2}}{R_{conv}} - \frac{T_{abs} - T_{air}}{R_{cond}} \tag{4}$$

where:
τ_{g1} = transmittance of the first glazing layer
τ_{g2} = transmittance of the second glazing layer
α_{abs} = absorptance of the absorber plate
R_{rad} = radiative resistance from absorber to inside glazing
R_{conv} = convective resistance from absorber to inside glazing
R_{cond} = conductive resistance from absorber to outdoor air through the insulation
T_{abs} = temperature of the absorber plate
T_{g2} = temperature of the inside glazing
T_{air} = temperature of the outdoor air

The equation above can be approximated with a simpler formulation as:

$$\frac{q}{A} = F_R\left[I_{sol}(\tau\alpha) - U_L(T_{in} - T_{air})\right] \tag{5}$$

where:
F_R = an empirically determined correction factor
(τα) = the product of all transmittance and absorptance terms
U_L = overall heat loss coefficient combining radiation, convection, and conduction term.
T_{in} = inlet temperature of the working fluid.

$$\eta = F_R(\tau\alpha) - F_R U_L \frac{(T_{in} - T_{air})}{I_{sol}} \tag{6}$$

For η, the following linear correlation can be constructed by treating $F_R(\tau\alpha)$ and $-F_RU_L$ as characteristic and quadratic correlation:

$$\eta = c_0 + c_1 \frac{(T_{in} - T_{air})}{I_{sol}} \tag{7}$$

$$\eta = c_0 + c_1 \frac{(T_{in} - T_{air})}{I_{sol}} + c_2 \frac{(T_{in} - T_{air})^2}{I_{sol}} \tag{8}$$

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:

$$K_{\tau\alpha} = \frac{(\tau\alpha)}{(\tau\alpha)_n} \tag{9}$$

$$K_{\tau\alpha} = 1 + b_0 \left(\frac{1}{\cos\theta} - 1 \right) \tag{10}$$

$$K_{\tau\alpha} = 1 + b_0 \left(\frac{1}{\cos\theta} - 1 \right) + b_1 \left(\frac{1}{\cos\theta} - 1 \right)^2 \tag{11}$$

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:

$$\frac{q}{A} = \dot{m} c_p (T_{out} - T_{in}) \tag{12}$$

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

Solving for T_{out}:

$$T_{out} = T_{in} + \frac{q}{\dot{m} c_p A} \tag{13}$$

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.

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=60^0C), High temperature turn off in solar loop (60^0C), High temperature turn on in solar loop (0^0C), Temperature difference on limit (differential thermostat) (10^0C), Temperature difference off limit (differential thermostat) (2^0C).

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=50^0C) 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 50^0C (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 location of the facility under analysis is critical for the determination of energy consumption. In EnergyPlus, both external (i.e, weather files supplied from others) and internal weather data is used during simulations. The "Site:Location" input object includes parameters that allow EnergyPlus to calculate the solar position (using Latitude, Longitude and Timezone) for any day of the year as well as supply the standard barometric pressure (using elevation). Weather files have hourly or sub-hourly data for each of the critical elements needed during the calculations (i.e., Dry-Bulb Temperature, Dew-Point Temperature, Relative Humidity, Barometric Pressure, Direct Normal Radiation, Diffuse Horizontal Radiation, Total & Opaque Sky Cover, Wind Direction, Wind Speed) as well as some auxiliary data such as Rain or Snow. 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. To familiarize with the Belgrade climate, Figs.2 and 3 are given by using monthly statistics for the Belgrade weather file.

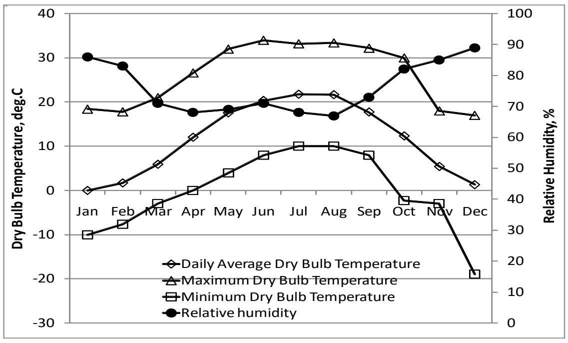

Fig.2 *- Relative humidity and dry bulb temperature (minimum, daily average and maximum) from the monthly statistics for Belgrade, Serbia from Belgrade weather file.*

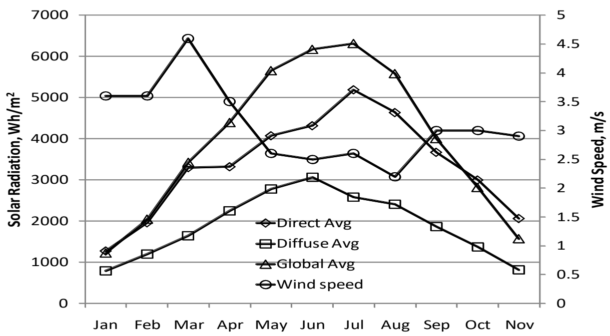

Fig.3 *- Direct, diffuse, and global average solar radiation, and daily average wind speed from the monthly statistics for Belgrade, Serbia from Belgrade weather file.*

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 twelve curves obtained by optimizing fi (βi = βa, opt, ɣi) i.e. when βi = βm, opt = βa, opt = 37.5 ° for SDHWS with SC # 12 operating in Belgrade. The curves represent the solar fraction which are obtained if SC # 12 has a different azimuth to its application. For each month, one is wrong. The curves in Figure 4 were obtained using the calculated results (fi (βi = βa, opt, ɣi), ie when βi = βm, opt = βa, opt = 37.5 ° for SC # 12) in the procedure for determining the approximation to the optimal solution based on the Hooke Jeeves optimization algorithm.

If the solar collector with SC # 12 does not take optimal angles in its application, a smaller amount of electricity will be avoided using a solar heating system for DHW. Their equations are shown in Table 1 as the third-order polynomials. If the solar collector does not have the maximum value of azimuth angles during its operation, we will have losses in generating heat energy. Figure 5 shows the deficit of solar fraction for SDHWS in Belgrade, Serbia in case the azimuth SC # 12 in some months is greater or less than ɣopt by 22.5 °.

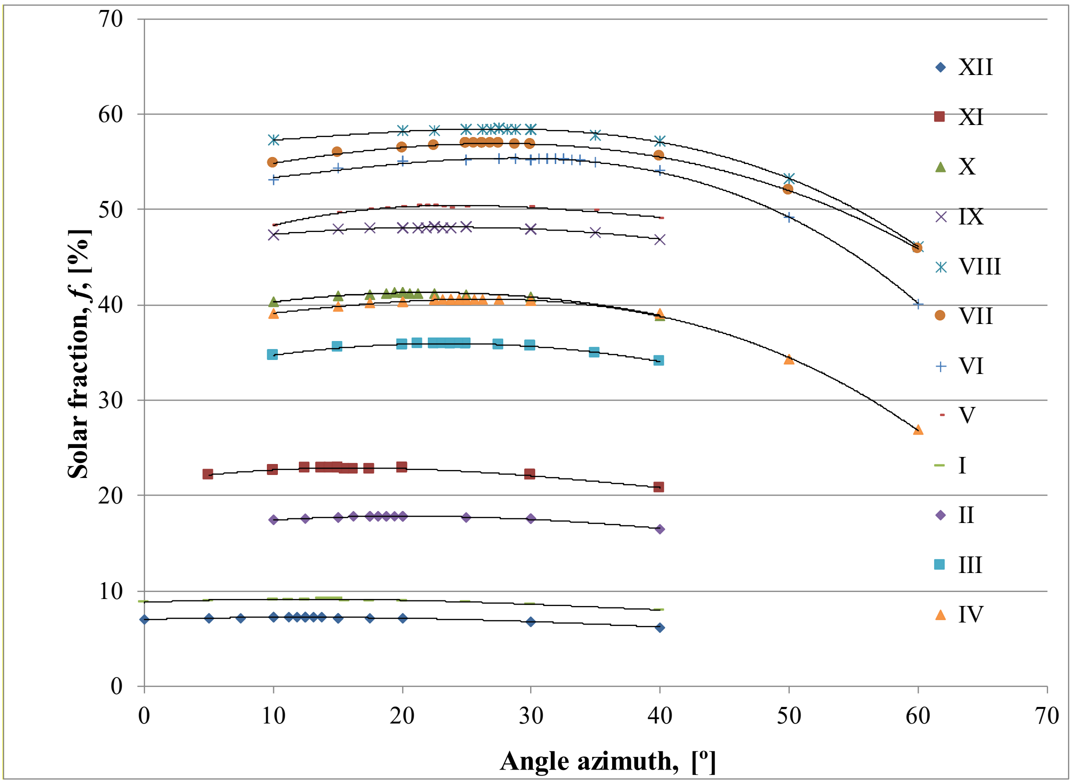

Fig. 4 *– Solar fraction in the function of the angle slope βm, opt = βa, opt = 37.5 ° and azimuth angle for SDHWS with SC # 12 in Belgrade, Serbia*

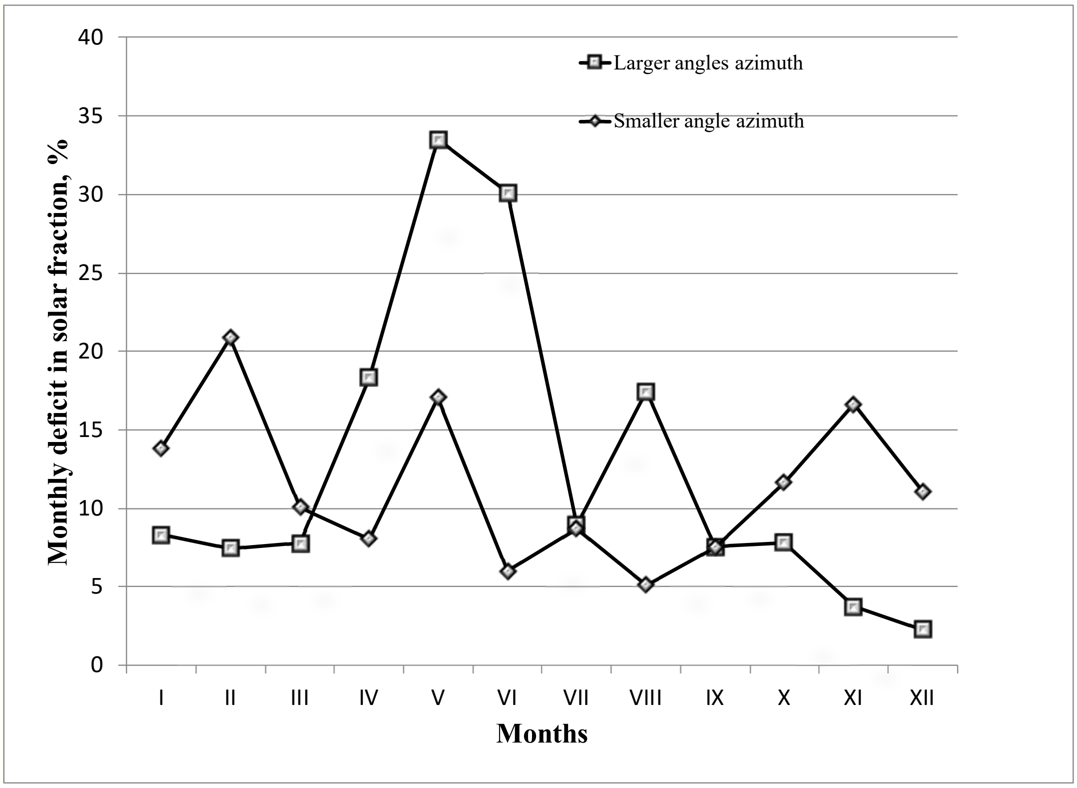

Fig. 5 *- Monthly deficit in solar fraction, deviation of the azimuth angle | Ɣ - Ɣopt | = 22.5 °, obtained by optimization (fi (βi = βa, opt, Ɣi), ie when βi = βm, opt = βa, opt = 37.5 °, for SDHWS with SC # 12 in Belgrade, Serbia*

Table 1 *- The equations of the solar fraction in the function of the azimuth angle, obtained by optimizing fi (βh = βa, opt, Ɣh), i.e. when βm, opt = βa, opt = 37.5 for SDHWS with SC # 12. Equations are given for each month.*

Month	Day	Solar fraction, [%]	Regression coefficient *(R^2)*
I	31	$f = 3 \cdot 10^{-5} \cdot Ɣ^3 - 0.003 \cdot Ɣ^2 + 0.064 \cdot Ɣ + 8.797$	0.975
II	28	$f = 2 \cdot 10^{-5} \cdot Ɣ^3 - 0.004 \cdot Ɣ^2 + 0.173 \cdot Ɣ + 16.18$	0.964
III	31	$f = -4 \cdot 10^{-6} \cdot Ɣ^3 - 0.006 \cdot Ɣ^2 + 0.312 \cdot Ɣ + 32.25$	0.986
IV	30	$f = 10^{-5} \cdot Ɣ^3 + 0.002 \cdot Ɣ^2 + 0.144 \cdot Ɣ + 37.59$	0.994
V	31	$f = 10^{-5} \cdot Ɣ^3 - 0.02 \cdot Ɣ^2 + 0.686 \cdot Ɣ + 43.34$	0.967
VI	30	$f = 10^{-8} \cdot Ɣ^3 + 0.006 \cdot Ɣ^2 + 0.073 \cdot Ɣ + 52.12$	0.988
VII	31	$f = -3 \cdot 10^{-5} \cdot Ɣ^3 - 0.002 \cdot Ɣ^2 + 0.282 \cdot Ɣ + 52.33$	0.998
VIII	31	$f = 0.005 \cdot Ɣ^2 + 0.026 \cdot Ɣ + 56.62$	0.982
IX	30	$f = -2 \cdot 10^{-5} \cdot Ɣ^3 - 0.003 \cdot Ɣ^2 + 0.175 \cdot Ɣ + 45.97$	0.991
X	31	$f = 10^{-5} \cdot Ɣ^3 - 0.006 \cdot Ɣ^2 + 0.293 \cdot Ɣ + 38.01$	0.983
XI	30	$f = 7 \cdot 10^{-5} \cdot Ɣ^3 - 0.008 \cdot Ɣ^2 + 0.223 \cdot Ɣ + 21.26$	0.983
XII	31	$f = 8 \cdot 10^{-6} \cdot Ɣ^3 - 0.001 \cdot Ɣ^2 + 0.039 \cdot Ɣ + 7.015$	0.983

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 and represented by the corresponding curves. Also, it has been calculated the reduction of the solar fractions, as well as a monthly deficit of solar fraction for deviations the azimuth angle, when it is not optimal. The largest difference in the deficit of about 25% exists in the VI month. In months, when Ɣm is 22.5 ° greater than Ɣm, opt, there is a greatest deficit in the value of f of about 15%.

Acknowledgment: This investigation is a part of the project TR 33015 of Technological Development of the Republic of Serbia. We would like to thank to the Ministry of Education and Science of Republic of Serbia for the financial support during this investigation.

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