

# ZBORNIK RADOVA Proceedings

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obnovljivim izvorima električne energije**

**5th International Conference on Renewable  
Electrical Power Sources**



2017

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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*

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## 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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# SADRŽAJ

## 1. Plenarna predavanja • Plenary session

1. PRIMENA LOW-COST SENZORA I SISTEMA ZA MONITORING AEROZAGAĐENJA  
USING LOW-COST SENSORS AND SYSTEMS FOR AIR POLLUTION MONITORING  
Viša TASIĆ . . . . . 11
2. UTICAJ EMISIJE EKSTREMNO NISKOFREKVENTNOG MAGNETNOG POLJA  
NA KORISNIKE PRENOSNIH RAČUNARA  
THE INFLUENCE OF THE EXTREMELY LOW FREQUENCY MAGNETIC FIELD EMISSION TO THE  
ENVIROMENTAL NEIGHBORHOOD OF THE LAPTOP USERS  
Darko BRODIĆ . . . . . 21

## 2. Životna sredina, održivost i politika • Environment, sustainability and policy

3. EKOLOŠKA SVEST I EKOLOŠKO OBRAZOVANJE U SREDINAMA  
SA INDUSTRIJSKIM IZVORIMA ZAGAĐENJA  
ENVIRONMENTAL AWARENESS AND ENVIRONMENTAL EDUCATION  
IN COMMUNITIES WITH INDUSTRIAL SOURCES OF POLLUTION  
Snežana UROŠEVIĆ, Dejan RIZNIĆ, Zoran STEVIĆ . . . . . 29
4. SOM KLASIFIKACIJA SA PRIMENOM NA EMISIJU ZRAČENJA MAGNETNOG POLJA  
U OKOLINI LAPTOP ISPRAVLJAČA  
SELF-ORGANIZING MAPS CLASSIFICATION WITH APPLICATION TO  
LAPTOP'S ADAPTERS MAGNETIC FIELD  
Darko BRODIĆ, Alessia AMELIO . . . . . 37
5. ANAEROBNA DIGESTIJA ORGANSKOG ČVRSTOG OTPADA:  
PERSPEKTIVE I ISTRAŽIVAČKA DOSTIGNUĆA ANAEROBIC DIFESTION OF ORGANIC WASTE:  
PERSPECTIVES AND RESEARCH ACHIEVEMENTS  
Andrijana STOJANOVIĆ, Dragoljub ŽIVKOVIĆ, Marko MANČIĆ . . . . . 45
6. STANJE I PERSPEKTIVE SOLARNE ENERGETIKE U SRBIJI  
CURRENT STATE AND PROSPECTS OF SOLAR ENERGY IN SERBIA  
Tomislav M. PAVLOVIĆ, Dragana D. MILOSAVLJEVIĆ . . . . . 51
7. PORODIČNA KUĆA NULTE POTROŠNJE ELEKTRIČNE ENERGIJE U SRBIJI  
THE ZERO ELECTRIC ENERGY FAMILY HOUSE IN SERBIA  
Zoran NIKOLIĆ, Dušan NIKOLIĆ . . . . . 59
8. DUALNO OBRAZOVANJE U OBLASTI OBNOVLJIVIH IZVORA ENERGIJE I ENERGETSKE  
EFIKASNOSTI U OBRAZOVNOM SISTEMU REPUBLIKE SRBIJIE  
DUAL EDUCATION IN THE AREA OF RENEWABLE ENERGY SOURCES AND ENERGY EFFICIENCY  
IN THE EDUCATION SYSTEM OF THE REPUBLIC OF SERBIA  
Marjan Lj. IVANOV, Saša SKOKO, Violeta DIMIĆ, Marina ČURIĆ,  
Aleksandra HERCEG-ROKNIĆ, Aleksandar SAVIĆ, Mirjana ĐURIŠIĆ . . . . . 65

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

9. ZGRADE NETO-NULTE POTROŠNJE ENERGIJE SA ASPEKTA KORIŠĆENJA  
FOTONAPONSKIH PANELA  
ZERO-NET ENERGY BUILDINGS FROM ASPECT OF PV USAGE  
Jasna RADULOVIĆ, Danijela NIKOLIĆ, Jasmina SKERLIĆ, Mina VASKOVIĆ, Vesna RANKOVIĆ . . . . . 75
10. ANALIZA PONAŠANJA MALE HIDROELEKTRANE TERVOL  
U ELEKTRODISTRIBUTIVNOM SISTEMU  
ANALYSIS OF TERVOL SMALL HYDROPOWER PLANT AT A REGION OF DISTRIBUTION SYSTEM  
Astrit BARDHI, Flamur BIDAJ, Alfred PJETRI . . . . . 81
11. ANALITIČKI MODEL ZA ODREĐIVANJE TEMPERATURE FOTONAPONSKOG MODULA ZASNOVAN  
NA PRINCIPU ODRŽANJA ENERGIJE  
AN ANALYTICAL MODEL FOR ESTIMATING THE TEMPERATURE OF A PHOTOVOLTAIC MODULE  
BASED ON THE PRINCIPLE OF ENERGY BALANCE  
Bojan PEROVIĆ, Dardan KLIMENTA, Mirosljub JEVTIĆ, Miloš MILOVANOVIĆ . . . . . 89

12.	ANALIZA UTICAJA PARAMETARA MONOKRISTALNIH I POLIKRISTALNIH SILICIJUMSKIH SOLARNIH ČELIJA STUDY OF THE INFLUENCE OF PARAMETERS ON SILICON MONOCRYSTALLINE POLYCRYSTALLINE IN SOLAR CONVERTERS Mohammed Abdelkader OUARIDHENE, Mohammed BENATALLAH, Abderrahim BENMOUSSAT . . . . .	97
13.	ANALIZA STABILNOSTI FREKVENTNO ZAVISNIH KOMPONENATA U SISTEMIMA SOLARNIH I VETROGENERATORA ANALYSIS OF STABILITY FREQUENCY-DEPENDENT COMPONENTS INCLUDED IN THE SYSTEM'S WORK OPTIMIZATION OF SOLAR AND WIND ENERGY GENERATION Hanna UKHINA, Tykhon SYTNIKOV, Valeriy SYTNIKOV . . . . .	105
14.	SISTEM ZA HRONOLOŠKO PRAĆENJE SUNCA IMPLEMENTIRAN NA MOBILNOM SOLARNOM GENERATORU THE CHRONOLOGICAL SYSTEM FOR SOLAR TRACKING IMPLEMENTED ON MOBILE SOLAR GENERATOR Miloš JOVANOVIĆ, Željko DESPOTOVIĆ, Đorđe URUKALO . . . . .	107
15.	MATERIJALI ZA APSORPCIJU SVETLOSNOG ZRAČENJA I PRETVARANJE U TOPLOTNU ILI ELEKTRIČNU ENERGIJU MATERIALS FOR ABSORPTION OF LIGHT AND CONVERSION INTO HEAT OR ELECTRICAL ENERGY Zoran KARASTOJKOVIĆ, Milesa SREČKOVIĆ, Nikola BAJIĆ, Zoran JANJUŠEVIĆ . . . . .	115
16.	PUNJAČ BATERIJE SUPERKONDENZATORA SA IZJEDNAČENJEM NAPONA SUPERCAPACITOR BATTERY CHARGER WITH VOLTAGE EQUILIZING Yuliia KOZHUSHKO, Tetiana RYZHAKOVA, Oleksandr BONDARENKO, Zoran STEVIĆ . . . . .	127
17.	PRIMENA SUPERKONDENZATORA ZA SKLADIŠTENJE ENERGIJE KOD SOLARNIH SISTEMA APPLICATION OF SUPERCAPACITORS FOR ENERGY STORAGE IN SOLAR SYSTEMS Zoran STEVIĆ, Mirjana RAJČIĆ-VUJASINOVIĆ, Miša STEVIĆ, Ilija RADOVANOVIĆ . . . . .	135
18.	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 Jasmina SKERLIĆ, Danijela NIKOLIĆ, Dubravka ŽIVKOVIĆ, Jasna RADULOVIĆ . . . . .	139
19.	SOLARNA ENERGIJA KAO ODRŽIVI IZVOR ENERGIJE SOLAR POWER AS SUSTAINABLE ENERGY SOURCE Sanja PETROVIĆ, Mirjana RAJČIĆ-VUJASINOVIĆ, Zoran STEVIĆ, Ivana JOVANOVIĆ, Slađana KRSTIĆ . . . . .	149

### 3. Aplikacije i usluge • Applications and services

20.	NANOMATERIJALI I NANOFLUIDI – NOVI MATERIJALI ZA SOLARNE SISTEME INTEGRISANE U OMOTAČ ZGRADE NANOMATERIALS AND NANOFLUIDS – NEW MATERIALS FOR BUILDING INTEGRATED SOLAR THERMAL SYSTEMS Danijela NIKOLIĆ, Jasmina SKERLIĆ, Jasna RADULOVIĆ, Dubravka ŽIVKOVIĆ, Blaža STOJANOVIĆ . . . . .	155
21.	MOGUĆNOSTI KORIŠENJA SOLARNE ENERGIJE POSTAVLJANJEM PV PANELA NA RAVNIM KROVOVIMA JAVNIH OBJEKATA. STUDIJA SLUČAJA: PIJACA U BLOKU 44 NA NOVOM BEOGRADU – MODELSKI PRISTUP POSSIBILITY OF USING THE SOLAR ENERGY BY INSTALLING THE PV PANELS ON FLAT ROOFS OF PUBLIC BUILDINGS. CASE STUDY: MARKET IN BLOCK 44 IN NEW BELGRADE – MODEL-BASED APPROACH Mila PUCAR, Borjan BRANKOV . . . . .	163
22.	RAČUNARSKI SISTEM ZA TERMALNU ANALIZU MATERIJALA COMPUTER CONTROLLED SYSTEM FOR THERMAL ANALYSIS OF MATERIALS Milan RADIVOJEVIĆ, Misa STEVIĆ, Zoran STEVIĆ . . . . .	169
23.	RAZVOJ I PRIMENA 3D ŠTAMPAČA DEVELOPMENT AND APPLICATION OF 3D PRINTERS Misa STEVIĆ, Milan RADIVOJEVIĆ, Zoran STEVIĆ . . . . .	175

24.	ENERGETSKI EFIKASNI PULSNO-REVERZNI REŽIMI GALVANIZACIJE ENERGY EFFICIENT PULSE-REVERSE REGIMES OF ELECTRODEPOSITION Zoran STEVIĆ, Milica VLAHOVIĆ, Sanja MARTINOVIĆ, Stevan DIMITRIJEVIĆ, Miša STEVIĆ . . . . .	179
25.	ISPITIVANJE VREMENA VEZIVANJA CEMENTNIH MEŠAVINA KOJE SADRŽE LETEĆI PEPEO TESTING THE SETTING TIME OF CEMENT MIXTURES CONTAINING FLY ASH Ivana JOVANOVIĆ, Sanja PETROVIĆ, Zoran STEVIĆ, Daniel KRŽANOVIĆ, Srđana MAGDALINOVIĆ, Ljiljana MILIČIĆ . . . . .	185
26.	DOBIJANJE BEZKADMIJUMSKIH LEGURA SREBRA ZA TVDRO LEMLJENJE RECIKLAŽOM ELEKTRONSKOG ŠKARTA OBTAINING OF THE CADMIUM-FREE SILVER BRAZING ALLOYS FROM E-SCRAP Stevan P. DIMITRIJEVIĆ, Silvana B. DIMITRIJEVIĆ, Zoran M. STEVIĆ, Biserka T. TRUMIĆ, Aleksandra T. IVANOVIĆ . . . . .	191
27.	ISTORIJA PREVLAKA ZLATA HISTORY OF GOLD COATINGS Silvana B. DIMITRIJEVIĆ, Mirjana RAJČIĆ-VUJASINOVIĆ, Zoran M. STEVIĆ, Biserka T. TRUMIĆ, Aleksandra T. IVANOVIĆ, Stevan P. DIMITRIJEVIĆ . . . . .	197
28.	ANALIZA INDIKATORA ENERGETSKE EFIKASNOSTI I OBNOVLJIVIH IZVORA ENERGIJE KOD POSTOJEĆIH ZGRADA THE ANALYSIS OF ENERGY EFFICIENCY INDICATORS AND RENEWABLE ENERGY SOURCES FOR EXISTING BUILDINGS Mimica MILOŠEVIĆ, Dušan MILOŠEVIĆ, Violeta DIMIĆ, Dragan STEVIĆ, Ana STANOJEVIĆ . . . . .	205
29.	EDUKATIVNA LABORATORIJSKA POSTAVKA KASKADNE REGULACIJE MOTORA JEDNOSMERNE STRUJE BAZIRANE NA DSPACE1104 PLATFORMI EDUCATIONAL LABORATORY SETUP OF DC MOTOR CASCADE CONTROL BASED ON DSPACE1104 PLATFORM Marko ROSIĆ, Sanja ANTIĆ, Miroslav BJEKIĆ, Vojislav VUJIČIĆ . . . . .	213
30.	MONITORING MALIH HIDROELEKTRANA PRIMENOM TERMOVIZIJE MONITORING OF SMALL HYDROPOWER PLANTS USING THERMOGRAPHY Dragan MILENKOVIĆ, Dejan TANIKIĆ, Zoran STEVIĆ . . . . .	223
31.	SINTEZA OPTIMIZOVANE KONTROLE ZA VENTILACIONI SISTEM PUTNIČKIH VOZILA SYNTHESIS OF OPTIMIZED CONTROL FOR VENTILATION SYSTEM OF PASSENGER CARS Victor BUSHER, Valery SYTNIKOV, Victoriya YARMOLOVICH . . . . .	229
32.	IOT OSNOVE: LORA MREŽE THE IOT BASES: LORA NETWORKS Vojkan NIKOLIĆ, Nada BEGENIŠIĆ . . . . .	235
33.	METODA I UREĐAJ ZA TRANSFORMACIJU SIGNALA PARAMETARSKIH SENZORA METHOD AND DEVICE FOR TRANSFORMING SIGNALS FROM PARAMETRIC TYPE SENSORS Elena PONOMARYOVA . . . . .	239
34.	KONTROLA PRITISKA U IRIGACIONOM “OFF-GRID” FOTONAPONSKOM SISTEMU BAZIRANOM NA MOBILNOM SOLARNOM GENERATORU THE PRESSURE CONTROL IN IRRIGATION “OFF-GRID” PHOTOVOLTAIC SYSTEM BASED ON MOBILE SOLAR GENERATOR Željko DESPOTOVIĆ, Milovan MAJSTOROVIĆ, Miloš JOVANOVIĆ, Ilija STEVANOVIĆ . . . . .	245
35.	POSTUPCI OJAČAVANJA POVRŠINE TURBINSKIH LOPATICA IZ TERMOELEKTRANA SURFACE HARDENING METHODS OF STEAM TURBINE BLADES Zoran KARASTOJKOVIĆ, Momo DERETA, Milesa SREČKOVIĆ, Nikola BAJIĆ, Zoran JANJUŠEVIĆ, Dragan STOJILJKOVIĆ . . . . .	253
36.	PRIMENA NAUKE O PODACIMA U RADU SA OBNOVLJIVIM IZVORIMA ENERGIJE USE OF DATA SCIENCE IN THE RENEWABLE ENERGY RESOURCES Predrag STOLIĆ, Danijela MILOŠEVIĆ, Zoran STEVIĆ . . . . .	263



37.	VIŠEKANALNA SENZORSKA MERENJA U FOG COMPUTING ARHITEKTURI ZA MONITORING SISTEMA OBNOVLJIVIH IZVORA ENERGIJE MULTI CHANNEL SENSOR MEASUREMENTS IN FOG COMPUTING ARCHITECTURE FOR RENEWABLE ENERGY SOURCES SYSTEMS MONITORING Ilija RADOVANOVIĆ, Đorđe KLISIĆ, Ivan POPOVIĆ . . . . .	269
38.	FAZI EKSPERTSKI OPTIMIZACIONI MODEL KAO MATEMATIČKA PODRŠKA UPRAVLJANJU PROJEKTIMA VODNIH RESURSA FUZZY EXPERT OPTIMIZATION MODEL AS MATHEMATICAL SUPPORT IN PROJECT MANAGEMENT ON WATER RESOURCES Svetlana STEVOVIĆ . . . . .	275
39.	TERMODINAMIČKA ANALIZA GEOTERMALNE TERMoeLEKTRANE NA BAZI RANKINOVOG CIKLUSA S ORGANSKIM FLUIDOM-PRIMJER GEOTERMALNOG POLJA REČICE BLIZU KARLOVCA THERMODYNAMIC ANALYSIS OF ORGANIC RANKINE CYCLE BASED ON GEOTHERMAL POWER PLANT – CASE STUDY OF GEOTHERMAL FIELD REČICA NEAR KARLOVAC Nenad MUSTAPIĆ, Marko DRAGIĆ, Marko VREŠ . . . . .	287
40.	EKONOMSKI ASPEKTI INTERREG-IPA CBC PROJEKATA MAĐARSKA - SRBIJA ECONOMIC ASPECTS OF INTERREG-IPA CBC HUNGARY- SERBIA PROJECTS Erika Cs. SZABO . . . . .	299

# 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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*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 električne energije. U istraživanjima 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 modifikovanim metodologijom Hooke Jeeves algoritma.*

*Solarni sistemi su poboljšani, tako što je dobijena minimalna potrošnja fosilne energije, smanjena upotreba energetske 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 paper, 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<sub>2</sub> 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, clotheswashing (machines), and dish-washing (machines). If this water is heated by electricity which is generated by coal burning, then the highest amount of CO<sub>2</sub> 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<sub>2</sub> 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 paper, 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-Jeeves method. In this investigation, the Hooke-Jeeves 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.

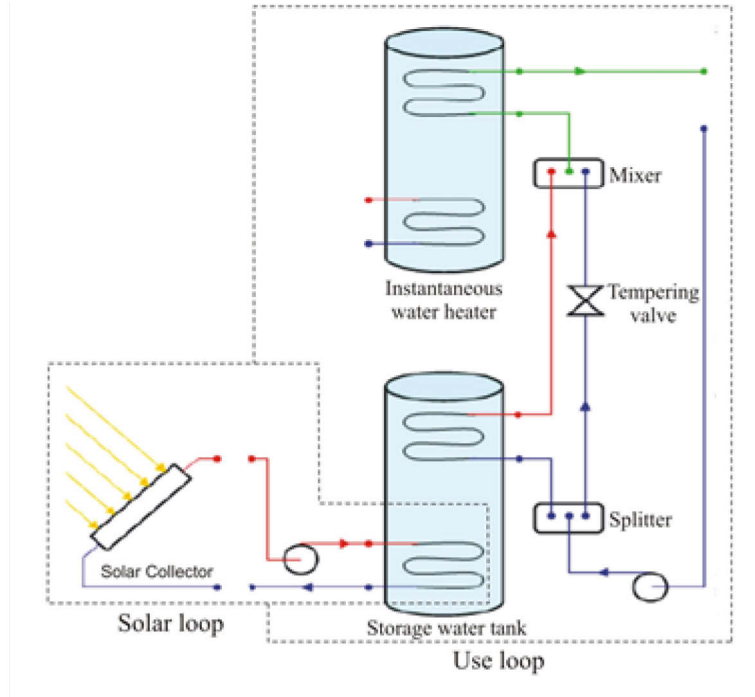
This part of the paper provides the mathematical model used to simulate the energy behavior of SDHWS and different parts of its installation: solar collector, thermal tanks (storage & heaters), tempering valve, and SDHWS-control devices.

**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 three-dimensional 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 ( $\beta$ ) 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  $-90^{\circ} < \beta < 90^{\circ}$ . The surfaces with positive  $\beta$  face south and with negative  $\beta$  face north. Its azimuth angle ( $\gamma$ ) 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  $-180^{\circ} < \gamma < 180^{\circ}$ .

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



**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:

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

If  $f = f_i$  is larger, the SDHWS better protects the environment. Variable  $f_i$  is a function of tilt  $\beta_i$  and azimuth angle  $\Upsilon_i$ . It should be maximized in the constrained region of  $\beta_i$  and  $\Upsilon_i$ . 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  $\Upsilon_{i,opt}$ .

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

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

**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.

$$\eta = \frac{\frac{q}{A}}{H_{solar}} \quad (3)$$

where:  $q$  = useful heat gain

$A = 8.89\text{m}^2$  = gross area of the collector

$H_{solar}$  = total incident solar radiation

Notice that the efficiency  $\eta$  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.

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

where:

$\tau_{g1}$  = transmittance of the first glazing layer

$\tau_{g2}$  = transmittance of the second glazing layer

$\alpha_{abs}$  = 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:

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

where:

$F_R$  = an empirically determined correction factor

$(\tau\alpha)$  = 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.

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

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

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

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

Both first- and second-order efficiency equation coefficients from [20] are given as  $c_0 = 0.691$ ,  $c_1 = 3.396 \text{ W/m}^2\text{-K}$ , and  $c_2 = 0.00193 \text{ W/m}^2\text{K}^2$ .

**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:

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

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

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

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:

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

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

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

**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 (tank-less water heater). The storage water tank has volume of 0.75 m<sup>3</sup>.

**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 m<sup>3</sup>/s. Main parameters of solar heating installation for water loop through the solar collector are the following Loop temperature (TL=60<sup>0</sup>C), High temperature turn off in solar loop (60<sup>0</sup>C), High temperature turn on in solar loop (0<sup>0</sup>C), Temperature difference on limit (differential thermostat) (10<sup>0</sup>C), Temperature difference off limit (differential thermostat) (2<sup>0</sup>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 the hot water setpoint temperature (TH=50<sup>0</sup>C) and the maximum temperature limit for storage tank (82.2<sup>0</sup>C).

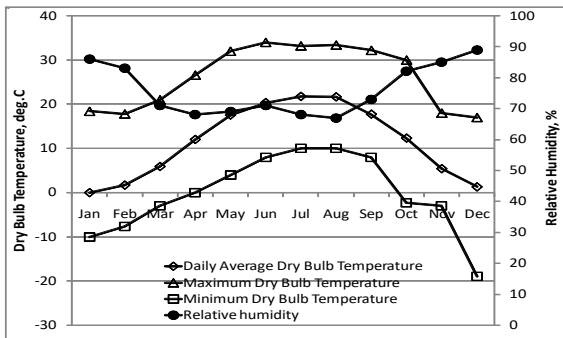
#### 4 Simulation and optimization

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

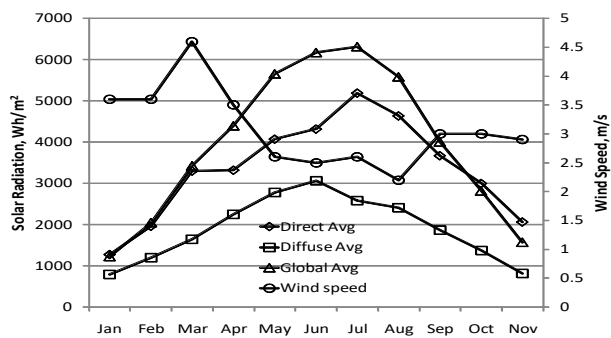
**Hot Water Consumption:** This installation generates four different types of hot water: that of tap, shower, dish-washer, and cloth-washer. Regarding its application, the water would be heated to two temperatures: 43.3 (tap and shower with the maximum flow rate of 0.0000945 m<sup>3</sup>/s) and 50<sup>0</sup>C (dish and clothes washer with the maximum flow rate of (0.000063 m<sup>3</sup>/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.

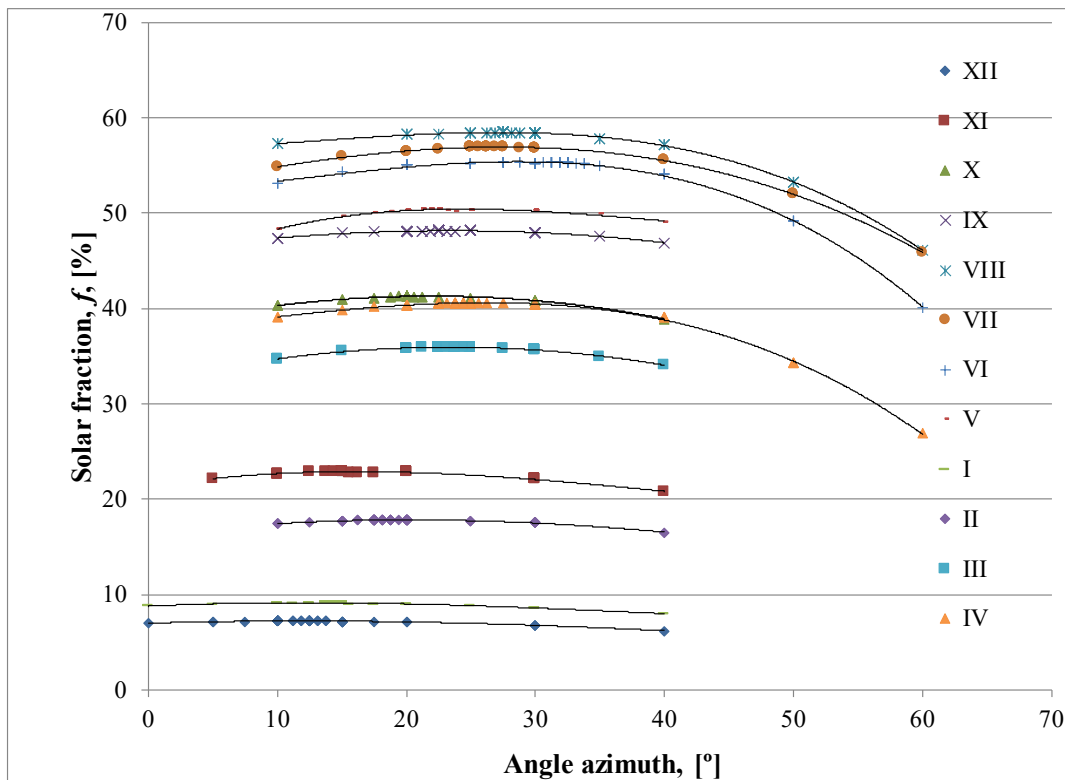
## 5 Results and discussion

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.

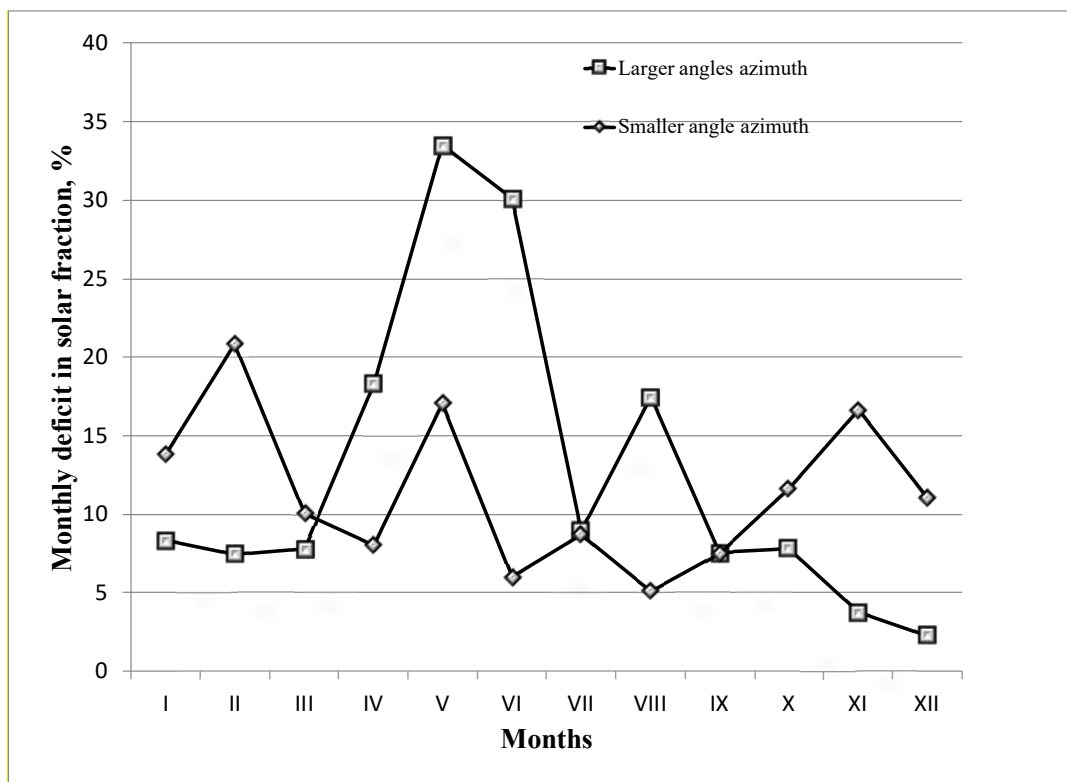
Figure 4 shows the twelve curves obtained by optimizing  $f_i$  ( $\beta_i = \beta_a, \text{opt}, \forall i$ ) i.e. when  $\beta_i = \beta_m, \text{opt} = \beta_a, \text{opt} = 37.5^\circ$  for SDHWS with SC # 12 operating in Belgrade. The curves represent the solar fraction which are obtained if SC # 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 ( $f_i$  ( $\beta_i = \beta_a, \text{opt}, \forall i$ ), ie when  $\beta_i = \beta_m, \text{opt} = \beta_a, \text{opt} = 37.5^\circ$  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  $\forall \text{opt}$  by  $22.5^\circ$ .





**Fig. 4** – Solar fraction in the function of the angle slope  $\beta_m$ ,  $opt = \beta_a$ ,  $opt = 37.5^\circ$  and azimuth angle for SDHWS with SC # 12 in Belgrade, Serbia



**Fig. 5** - Monthly deficit in solar fraction, deviation of the azimuth angle  $|\gamma - \gamma_{opt}| = 22.5^\circ$ , obtained by optimization ( $f_i$  ( $\beta_i = \beta_a$ ,  $opt$ ,  $\gamma_i$ ), ie when  $\beta_i = \beta_m$ ,  $opt = \beta_a$ ,  $opt = 37.5^\circ$ , 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  $f_i$  ( $\beta h = \beta a$ ,  $opt$ ,  $\forall h$ ), i.e. when  $\beta m$ ,  $opt = \beta a$ ,  $opt = 37.5$  for SDHWS with SC # 12. Equations are given for each month.

Month	Day	Solar fraction, [%]	Regression coefficient ( $R^2$ )
I	31	$f = 3 \cdot 10^{-5} \cdot Y^3 - 0.003 \cdot Y^2 + 0.064 \cdot Y + 8.797$	0.975
II	28	$f = 2 \cdot 10^{-5} \cdot Y^3 - 0.004 \cdot Y^2 + 0.173 \cdot Y + 16.18$	0.964
III	31	$f = -4 \cdot 10^{-6} \cdot Y^3 - 0.006 \cdot Y^2 + 0.312 \cdot Y + 32.25$	0.986
IV	30	$f = 10^{-5} \cdot Y^3 + 0.002 \cdot Y^2 + 0.144 \cdot Y + 37.59$	0.994
V	31	$f = 10^{-5} \cdot Y^3 - 0.02 \cdot Y^2 + 0.686 \cdot Y + 43.34$	0.967
VI	30	$f = 10^{-8} \cdot Y^3 + 0.006 \cdot Y^2 + 0.073 \cdot Y + 52.12$	0.988
VII	31	$f = -3 \cdot 10^{-5} \cdot Y^3 - 0.002 \cdot Y^2 + 0.282 \cdot Y + 52.33$	0.998
VIII	31	$f = 0.005 \cdot Y^2 + 0.026 \cdot Y + 56.62$	0.982
IX	30	$f = -2 \cdot 10^{-5} \cdot Y^3 - 0.003 \cdot Y^2 + 0.175 \cdot Y + 45.97$	0.991
X	31	$f = 10^{-5} \cdot Y^3 - 0.006 \cdot Y^2 + 0.293 \cdot Y + 38.01$	0.983
XI	30	$f = 7 \cdot 10^{-5} \cdot Y^3 - 0.008 \cdot Y^2 + 0.223 \cdot Y + 21.26$	0.983
XII	31	$f = 8 \cdot 10^{-6} \cdot Y^3 - 0.001 \cdot Y^2 + 0.039 \cdot Y + 7.015$	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  $\forall m$  is  $22.5^\circ$  greater than  $\forall m, opt$ , there is a greatest deficit in the value of  $f$  of about 15%.

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