



UNIVERSITY OF EAST SARAJEVO
FACULTY OF MECHANICAL
ENGINEERING



6th INTERNATIONAL SCIENTIFIC CONFERENCE



COMETa 2022

***„Conference on Mechanical Engineering
Technologies and Applications“***

PROCEEDINGS

17th-19th November
East Sarajevo, RS, B&H

COMET_a 2022

6th INTERNATIONAL SCIENTIFIC CONFERENCE

17th - 19th December 2022

Jahorina, B&H, Republic of Srpska



University of East Sarajevo

Faculty of Mechanical Engineering

Conference on Mechanical Engineering Technologies and Applications

Z B O R N I K R A D O V A

P R O C E E D I N G S

*Istočno Sarajevo, BiH, RS
17 - 19. novembar 2022.*

*East Sarajevo, B&H, RS
17th – 19th November, 2022*

ZBORNİK RADOVA SA 6. MEĐUNARODNE
NAUČNE KONFERENCIJE
"Primijenjene tehnologije u mašinskom inženjerstvu"
COMETA2022, Istočno Sarajevo, 2022.

PROCEEDINGS OF THE 6th INTERNATIONAL
SCIENTIFIC CONFERENCE
"Conference on Mechanical Engineering
Technologies and Applications"
COMETA2022, East Sarajevo, 2022

<i>Organizator:</i>	Univerzitet u Istočnom Sarajevu Mašinski fakultet Istočno Sarajevo
<i>Organization:</i>	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
<i>Izdavač:</i>	Univerzitet u Istočnom Sarajevu Mašinski fakultet Istočno Sarajevo
<i>Publisher:</i>	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
<i>Za izdavača: For publisher:</i>	PhD Milija Kraišnik, associate professor
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<i>Izdanje: Printing:</i>	Prvo 1 st
<i>Register: Register:</i>	ISBN 978-99976-947-6-8 COBISS.RS-ID 137162497

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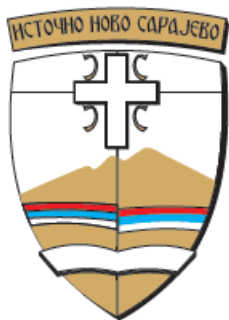
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The conference has been supported by:



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the Promotion of Mechanism
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for Design, Elements
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Technicians of Republic of Srpska*

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PREFACE

The economic power of a society can be expressed by different indicators. However, it is certain that the competitiveness of the economy is one of the most important. In this sense, it is necessary for industrial production to follow modern development trends, which are based on current scientific achievements. Only a holistic approach in the application of knowledge in various engineering fields, and especially in the field of mechanical engineering, is a guarantee of economic progress, which enables long-term stability and prosperity of each country. Precisely for these reasons, the Faculty of Mechanical Engineering of the University of East Sarajevo organized the 1st International Scientific Conference COMETA in 2012, and this year is its 6th edition.

The main goal of the conference is to strengthen cooperation with the academic community, scientific-research institutions and, above all, with business entities. Conference COMETA 2022 is an opportunity for all participants to offer guidelines and create a better environment for more intensive industrial development through the exchange of knowledge and experience. That is going to have impact to increasing the competitiveness of national economic entities on the foreign market. The participation of a significant number of domestic and foreign scientists and researchers strengthens our conviction that in the near future we will be able to overcome challenges that are present in the technical-technological development of an advanced society in the 21st century, mainly through the generation of new ideas and the introducing of modern approaches to solving complex tasks in the field of mechanical engineering. In this sense, all your proposals and suggestions are more than welcome and will be carefully considered by the Scientific and Organizing Committee in order to improve the organization of the next conferences. Acknowledging the importance of the wide field of mechanical engineering for the overall industrial development of society, the work of the conference will take place through 7 sections, including the Student section. The program is focused on the following thematic areas:

- Manufacturing technologies and advanced materials,
- Applied mechanics and mechatronics,
- Machine design, simulation and modeling,
- Product development and mechanical systems,
- Energy and thermotechnic,
- Renewable energy and environmental protection,
- Maintenance and technical diagnostics,
- Quality, management and organization.

At this year's conference COMETA 2022, 105 papers including 4 plenary lectures will be published in the Proceedings.

We are specially looking forward that conference registered a record number of participants from abroad. Namely, 300 authors come from 25 countries. This is certainly the result of strenuous activities that were aimed at raising the international reputation and visibility of the conference in the regional, but also in the wider academic and scientific research space, which will be one of the primary goals in the future.

On behalf of the Organizing Committee of the conference COMETA 2022, we express our great gratitude to all the authors of the papers, reviewers, universities, faculties, business entities, national and international institutions and organizations that supported the conference. Without their help the organization and work of the conference would certainly not be at the level that its status deserves.

East Sarajevo, November 14th, 2022.

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A handwritten signature in blue ink, appearing to read 'Dušan Golubović'.

President of the Organizing
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A handwritten signature in blue ink, appearing to read 'Milija Krašnik'.

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NUMERIČKA ANALIZA UKUPNOG DOLAZNOG SOLARNOG ZRAČENJA NA POVRŠINU RAVNOG SOLARNOG PRIJEMNIKA SA JEDNOOSNIM PRIVIDNIM PRAĆENJEM SUNCA – SLUČAJ SA NAGNUTOM S-J OSOM I PRAĆENJEM U PRAVCU I-Z

Aleksandar Nešović¹

Rezime: U ovom radu koristi se softver Energy Plus da bi se numerički analizirala moguća implementacija mehanizma jednoosnog (oko nagnute S-J ose u pravcu I-Z) prividnog praćenja kretanja Sunca na konstrukciju ravnog (pločastog, zastakljenog) solarnog prijemnika, sve sa ciljem da se maksimizira prikupljanje ukupnog dolaznog solarnog zračenja. Na osnovu velikog broja simulacija, napravljen je petomesečni (od juna do oktobra) uzorak, a potom su definisana tri osnovna obrasca ponašanja navedene solarne konstrukcije: pri izrazito vedrom (prvi slučaj), vedrom (drugi slučaj) i oblačnom vremenu (treći slučaj). Rezultati pokazuju opravdanost primene ovakvog solarnog dizajna, jer u prvom (16. avgust) slučaju na pokretni solarni prijemnik dospeva i do 50% više solarnog zračenja nego na fiksni solarni prijemnik iste aktivne površine. U drugom (26. jul) slučaju, ta razlika je nešto manja, tj. 35% u korist pokretnog solarnog prijemnika, da bi u trećem (6. septembar) slučaju ona bila najmanja (ispod 10%), ali i dalje u korist pokretnog solarnog prijemnika.

Ključne riječi: Jednoosno prividno praćenje Sunca, Numerička simulacija, Pokretni solarni prijemnik, Ukupno dolazno solarno zračenje, Fiksni solarni prijemnik.

NUMERICAL ANALYSIS OF THE TOTAL INCIDENT SOLAR RADIATION ON THE FLAT-PLATE SOLAR COLLECTOR WITH SINGLE-AXIS TRACKING – CASE WITH INCLINED N-S AXIS AND E-W TRACKING

Abstract: In this paper, the Energy Plus software was used to numerically analyze the possible implementation of the single-axis (around the inclined N-S axis in the E-W direction) tracking mechanism on the flat-plate solar collector, all with the aim of maximizing the collection of the total incident solar radiation. Based on a large number of simulations, a five-month (from June to October) sample was created, and then three basic behavior patterns of the mentioned solar structure were defined: extremely

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clear (first case), clear (second case) and cloudy weather (third case). The results were showed the application justification of this solar design, because in the first case (August 16), up to 50% more solar radiation reaches the single-axis tracking flat-plate solar collector than the fixed flat-plate solar collector of the same active surface. In the second (July 26) case, that difference is somewhat smaller, i.e. 35% in favor of the single-axis tracking flat-plate solar collector, so that in the third (September 6) case it would be the smallest (below 10%), but still in favor of the single-axis tracking flat-plate solar collector.

Keywords: Fixed flat-plate solar collector, Numerical simulation, Single-axis tracking, Total incident solar radiation, Tracking flat-plate solar collector.

1 UVOD

U stambenom sektoru najveću primenu imaju ravni (pločasti, zastakljeni) solarni prijemnici, koji su, prema tradicionalnoj klasifikaciji, nekoncentrišući i nepokretni. Konstrukcija ravnih solarnih prijemnika prilično je jednostavna: određeni broj lamela sa integrisanim protočnim kanalima spaja se u aktivnu površinu za prikupljane solarne energije, tj. apsorbersku ploču (ravnu površinu), koja se sa gornje strane prekriva zastakljenjem (jednoslojnim ili višeslojnim), a sa donje strane štiti slojem izolacije. Time se toplotni gubici ravnog solarnog prijemnika smanjuju, a termički stepen korisnosti povećava.

Praksa je ipak pokazala da navedena konstrukcija ne mora uvek da bude nekoncentrišuća i nepokretna. Iako su sistemi za prividno praćenje kretanja Sunca više karakteristični za PV panele i neke druge tipove solarnih prijemnika, do danas je objavljen određen broj radova u kojima se ravni solarni prijemnik rotira oko jedne ili obe ose (Tab. 1). U tabeli 2, hronološki su prikazani radovi u kojima se kod ravnih solarnih prijemnika primenjuju razne koncentrišuće, odnosno reflektujuće površine.

Tabela 1. Istorijski razvoj primene nekonvencionalnih ravnih solarnih prijemnika
Prvi deo (od 1970. do 2000.)

Godina	70	77	78	79	80	81	86	90	91	92	95
Reflektor	[1]	[2]	-	[3]	[4] [5]	-	[6]	-	-	[7]	[8]
Koncentrator	-	-	-	-	-	[17]	-	[18]	-	-	-
Prividno praćenje Sunca	-	-	[21] [22]	-	-	-	-	-	[23]	[24]	-

Tabela 2. Istorijski razvoj primene nekonvencionalnih ravnih solarnih prijemnika
Drugi deo (od 2000. do 2021.)

Godina	12	13	14	15	17	18	20	21
Reflektor	[9]	[10]	[11]	[12] [13]	[14]	[15]	[16]	-
Koncentrator	-	-	[19]	-	-	-	[20]	-
Prividno praćenje Sunca	-	[25]	[26] [27] [28]	[29]	-	[30] [31]	[32]	[33]

U ovom radu napravljen je još jedan mali iskorak, koji se ogleda u primeni savremenih softverskih alata (u ovom slučaju programa Energy Plus) u termičkim analizama pokretnih (mobilnih) solarnih sistema. Autor se nada da će ovo istraživanje biti od značaja budućim istraživačima, još više, ako se u obzir uzme da pomenuti softver u sebi poseduje alate za istraživanje samo fiksnih ravnih solarnih prijemnika, sto znači da su uslovi istaživanja pokretnih ravnih solarnih prijemnika veštački kreirani od strane korisnika.

2 ENERGY PLUS MODEL UKUPNOG DOLAZNOG SOLARNOG ZRAČENJA

U softveru Energy Plus postoji model za proračun ukupnog dolaznog solarnog zračenja na proizvoljno orijentisanu fiksnu ravnu površinu, u ovom slučaju solarnog prijemnika I_{TOT} [W]. Proračun ovog zračenja je veoma složen, ali se u opštem slučaju može predstaviti kao zbir direktnog I_{DIR} [W], difuznog I_{DIFF} [W] i reflektovanog I_{REFL} [W] solarnog zračenja Jed. (1):

$$I_{TOT} = I_{BEAM} + I_{DIFF} + I_{REFL} \quad (1)$$

Difuzno solarno zračenje na površinu solarnog prijemnika dospeva iz tri pravca: nebeske kupole (engl. *Sky Dome*) $I_{DIFF-SD}$ [W] i horizonta (engl. *Horizon*) I_{DIFF-H} [W], kao i uske oblasti koja se formira oko direktnog solarnog zraka (engl. *Circumsolar*) I_{DIFF-C} [W] Jed. (2):

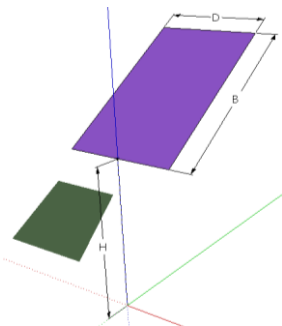
$$I_{DIFF} = I_{DIFF-SD} + I_{DIFF-H} + I_{DIFF-C} \quad (2)$$

Reflektovano solarno zračenje nastaje odbijanjem solarnog zračenja (direktnog i difuznog) od zemlje I_{REFL-G} [W] i okolnih površina I_{REFL-S} [W] Jed. (3):

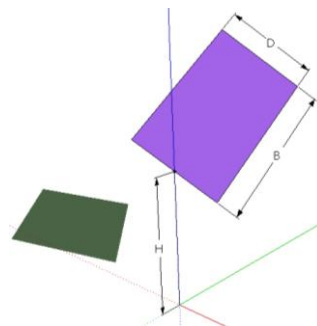
$$I_{REFL} = I_{REFL-G} + I_{REFL-S} \quad (3)$$

3 SCENARIO SIMULACIJA

Na narednoj slici prikazani su Energy Plus modeli fiksnog (Sl. 1a) i pokretnog ravnog solarnog prijemnika sa jedoosnim praćenjem kretanja Sunca u pravcu I-Z (Sl. 1b), oba sa istim S-J nagibom prema horizontali pod uglom od 34° (optimalni ugao za grad Kragujevac). Njihove geometrijske karakteristike prikazane su u Tab. 3.



Slika. 1a. Fiksni ravni solarni prijemnik



Slika. 1b. Pokretni ravni solarni (jednoosno praćenje Sunca u pravcu I-Z)

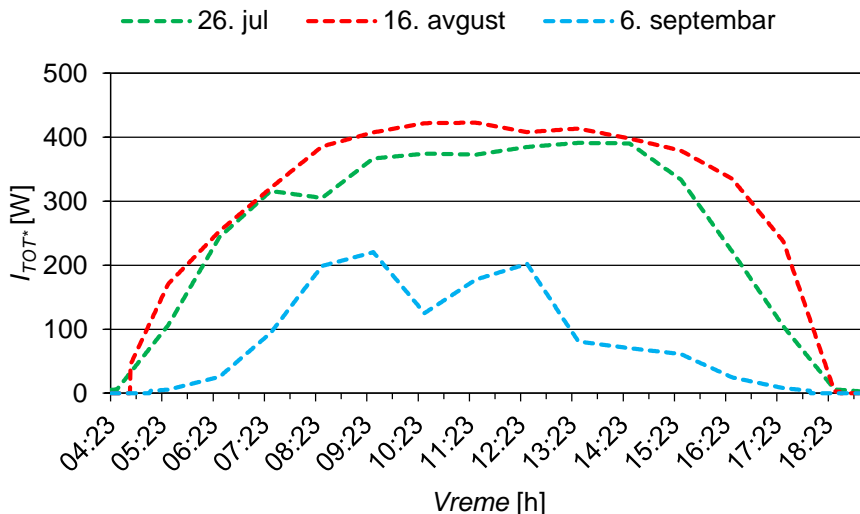
Tabela 3. Geometrijske karakteristike analiziranih solarnih prijemnika

Solarni prijemnik	Fiksni	Pokretni
B [mm]	800	
D [mm]	500	
H [mm]	700	
Broj simulacija	1	181
Lokacija	Kragujevac, Srbija	
Vremenske prilike	26. jul (vedar dan)	
	16. avgust (izrazito vedar dan)	
	6. septembar (oblačan dan)	

Kako u softveru Energy Plus ne postoje modeli za analizu pokretnih solarnih prijemnika, za potrebe ove studije, modeli su veštacki napravljeni. Naime, nizom simulacija, vršen je proračun ukupnog dolaznog solarnog zračenja tokom čitavog dana, za svaki ugao zakretanja ravne površine: od -90° (trenutak izlaska Sunca) do $+90^\circ$ (trenutak zalaska Sunca), pri čemu je korak zakretanja bio 1° . Da bi rezultati bili što precizniji, korišćen je vremenski fajl sa jednom minutnim korakom. Nakon toga, maksimalna brojna vrednost ukupnog dolaznog solarnog zračenja (za dati ugao zakretanja u datom vremenskom trenutku) korišćena je za formiranje dnevne krive ukupnog dolaznog solarnog zračenja.

4 REZULTATI I DISKUSIJA

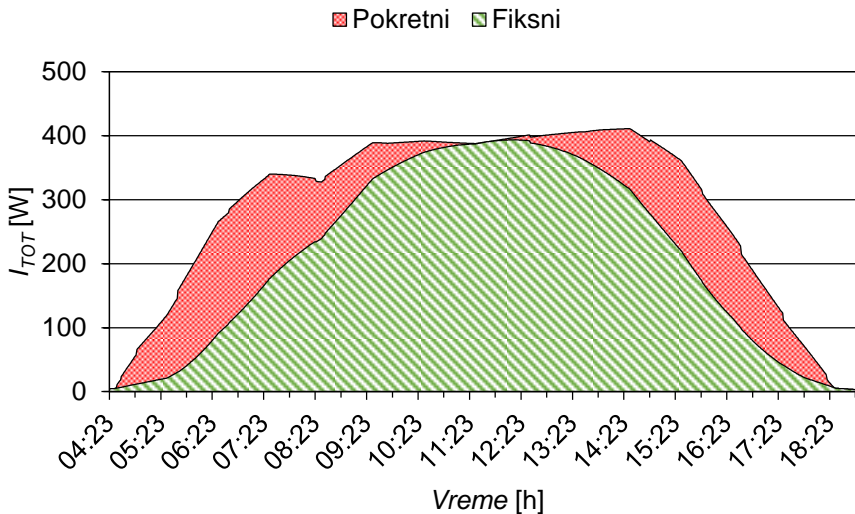
Intenzitet ukupnog dolaznog I_{TOT} [W] solarnog zračenja na horizontalnu ravnu površinu za tri karakteristična slučaja (26. jul – vedar dan, 16. avgust – izrazito vedar dan i 6. septembar – oblačan dan) prikazan je na Sl. 2.



Slika. 2. Ukupno dolazno solarno zračenje na horizontalnu ravnu površinu

Za 26. jul (vedar dan, izlazak Sunca u 04:23 h, zalazak Sunca u 17:03 h) prosečan dnevni intenzitet $I_{TOT} = 267.05$ W. Dijagram (Sl. 2) pokazuje blagi diskontinuitet (od 07:00h do 15:00 h), što se objašnjava prisustvom delimične oblačnosti. Vrednost I_{TOT} najveća je u 13:30 h (391.2 W). Za 16. avgust (izrazito vedar dan, izlazak Sunca u 04:46 h, zalazak Sunca u 18:36 h) prosečna dnevna vrednost $I_{TOT} = 328.52$ W, dok je maksimalna dnevna vrednost 385,2 W (10:30 h). Solarna kriva za 6. septembar (izlazak Sunca u 05:09 h, zalazak Sunca u 18:01 h) govori da se radi o oblačnom danu (prisustvo velikih solarnih fluktuacija). Tokom ovog dana (Sl. 2) prosečna dnevna vrednost ukupnog dolaznog solarnog zračenja na horizontalnu ravnu površinu je 100.34 W. Maksimalna vrednost solarnog zračenja zabeležena je u 09:30 h (220,4 W).

Na sledećim slikama (Sl. 3-5) prikazano je poređenje fiksnog i pokretnog ravnog solarnog prijelnika za pomenute (prema Sl. 2) dane.

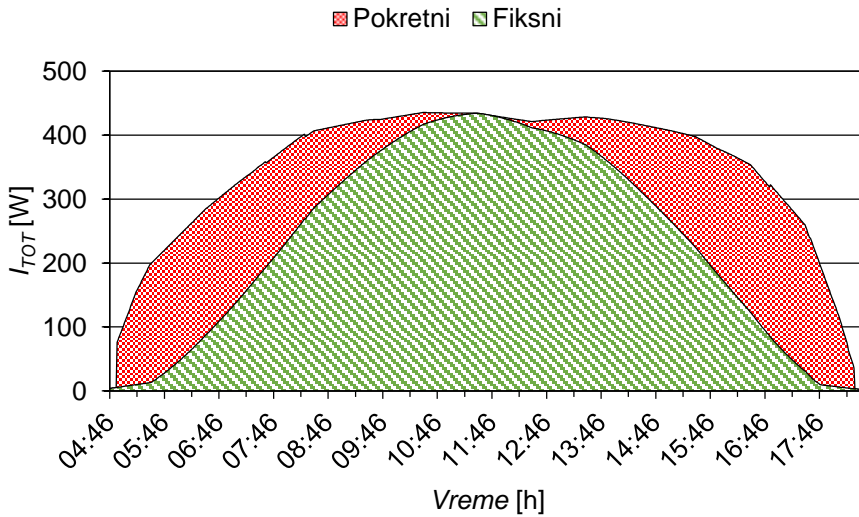


Slika. 3. Ukupno dolazno solarno zračenje na površinu ravnog solarnog prijelnika (26. jul)

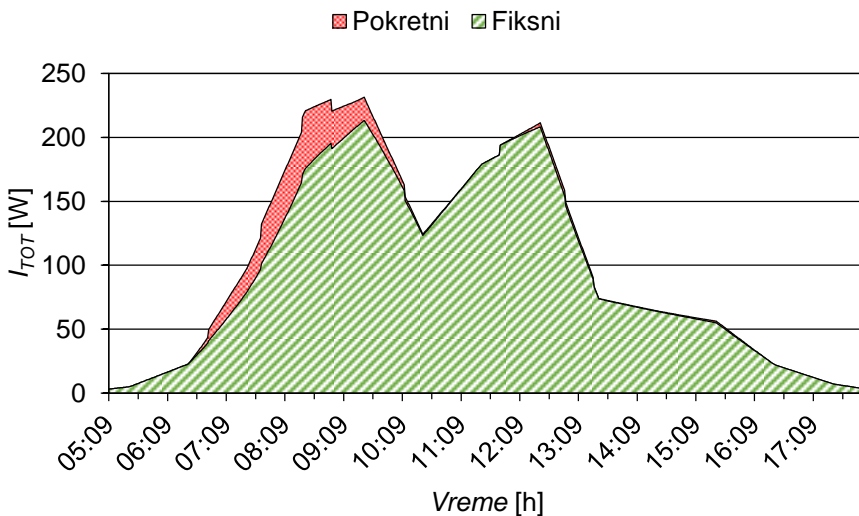
Pokretni solarni prijelnik tokom vedrog dana (26. jul, Sl. 3) može postići do 35.92% bolje rezultate od fiksnog solarnog prijelnika, jer na njegovu površinu tada u proseku dospeva 284.41 W solarnog zračenja, dok na površinu fiksnog solarnog prijelnika dospeva 209.24 W. Kada su vremenske prilike još povoljnije (karakteristike izrazito vedrog vremena), pokretni solarni prijelnik u stanju je da prikupi i do 347.1 W, što je za 47.55% više od fiksnog solarnog prijelnika (Sl. 4). Tokom oblačnih dana, kada je udeo difuznog solarnog zračenja u ukupnom solarnom iznosu veći od udela direktnog solarnog zračenja, razlike između pokretnih i nepokretnih solarnih prijelnika se smanjuju, pa mogu pasti ispod 8% (slučaj prikazan na Sl. 5). U ovoj situaciji, ukupno prosečno dnevno dolazno solarno zračenje na površine fiksnog i pokretnog ravnog solarnog prijelnika redom su (6. septembar): 95.11 W i 101.88 W.

Bolji rezultati, koje ostvaruje pokretni ravni solarni prijelnik u odnosu na fiksni, leže u primeni jedoosnog sistema za prividno praćenje kretanja Sunca. Ovakvim mehanizmom obezbeđuje se minimalna vrednost solarnog upadnog ugla (ugao između vektora položaja Sunca, tj. direktnog solarnog zračenja i vektora normale na površinu ravnog solarnog prijelnika) u svakom trenutku, što je od posebne važnosti za

transferzalnu (poprečnu) ravan, koja ima prednost korišćenja u ovakvim termičkim analizama (karakteristične za pokretne solarne sisteme) u odnosu na još jednu – uzdužnu ravan.



Slika. 4. Ukupno dolazno solarno zračenje na površinu ravnog solarnog prijelnika (16. avgust)



Slika. 5. Ukupno dolazno solarno zračenje na površinu ravnog solarnog prijelnika (16. avgust)

Primena ovakvog mehanizma tokom dana dolazi do punog izražaja pre i posle solarnog podneva, tj. pre i posle tzv. zenitnog položaja, kada se obezbeđuje "upravnost" direktnog solarnog zračenja (po intenzitetu slabijeg) na površinu solarnog

prijemnika. U trenutku solarnog podneva, ravni u kojima leže pokretni i fiksni solarni prijemnik međusobno su paralelne, a njihove aktivne površine za prikupljanje solarnog zračenja jednake, pa su im i termičke karakteristike identične. Drugim rečima, u trenutku solarnog podneva, solarna kriva pokretnog solarnog prijemnika preklapa se sa solarnom krivom fiksnog solarnog prijemnika (Sl. 3-5).

5 ZAKLJUČAK

U ovom radu izvršeno je poređenje termičkih karakteristika pokretnog (oko nagnute S-J ose u pravcu I-Z) i fiksnog ravnog solarnog prijemnika (istih aktivnih površina i sa istim nagibom prema horizontali) korišćenjem savremenog softverskog paketa Energy Plus. Rezultati su pokazali opravdanost primene ovakvih solarnih sistema, jer se time može prikupiti 7-50% više solarne energije, zavisno od vremenskih prilika. Uloga numeričkih alata u ovakvim situacijama (kada eksperimentalna i svaka druga istraživanja mogu biti dosta skupa) može biti od presudnog značaja, jer se time štede i vreme i novac, pa bi softveri (poput Energy Plus programa), trebalo da zauzmu posebno mesto svim početnim fazama istraživanja svih mogućih tipova HVAC sistema. Da bi to bilo moguće, potrebno je da se neprestano radi na usavršavanju softvera kako bi se ispratilo sve potrebe njihovih korisnika.

ZAHVALNOST

Ovo je rezultat rada u okviru dva projekta: projekat TR 33015 Tehnološkog razvoja Republike Srbije, projekat III 42006 Integralna i interdisciplinarna istraživanja Republike Srbije. Prvi projekat je pod nazivom "Istraživanje i razvoj Srpske kuće nulte neto postrošnje energije". Drugi projekat je pod nazivom "Istraživanje i razvoj energijski i ekološki visoko efikasnih sistema poligeneracije zasnovanoj na obnovljivim energijskim izvorima". Želim da se zahvalim Ministarstvu prosvete, nauke i tehnološkog razvoja Republike Srbije na njihovj finansijskoj podršci tokom ovog istraživanja.

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