47. kgh

47. MEĐUNARODNI KONGRES I IZLOŽBA O GREJANJU HLAĐENJU I KLIMATIZACIJI

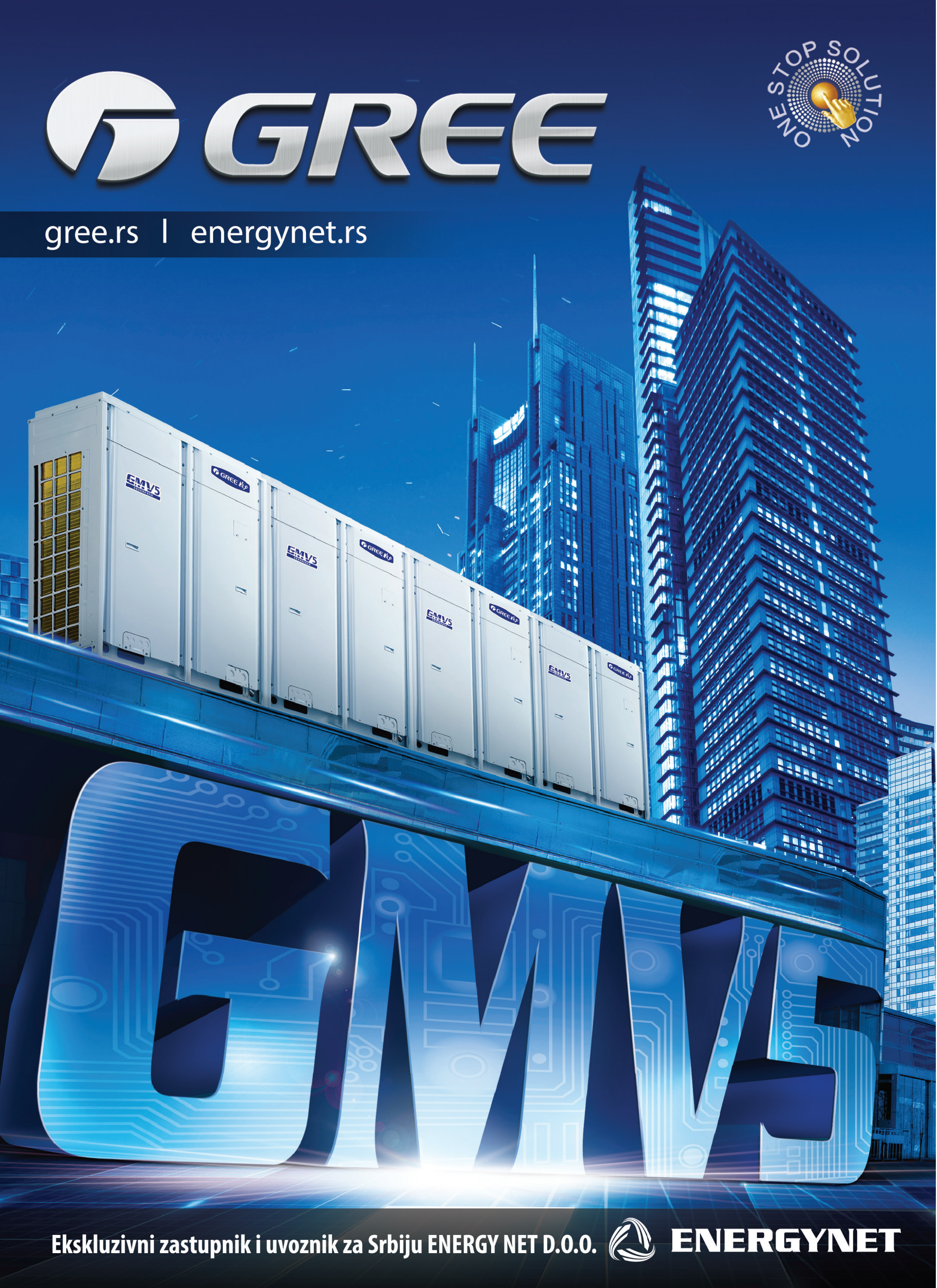
47th INTERNATIONAL CONGRESS & EXHIBITION ON HEATING, REFRIGERATION AND AIR CONDITIONING

Beograd, Sava centar,
30. novembar – 2. decembar 2016.

Belgrade, Sava Center,
30 November – 2 December 2016

ZBORNIK RADOVA PROCEEDINGS

Generalni pokrovitelj	General patron
Pokrovitelj izložbe	Exhibition patron
Organizator	Organiser
Organizacioni odbor	Organizing committee
Međunarodni organizacioni odbor	International organizing committee
Nacionalni naučni savet	National organizing committee
Programski sponzori	Program supporters
Glavni sponzori	Main sponsors
Sponzori	Sponsors
Počasni odbor	Honorary commitee
Program ukratko	Program at a glance
Sadržaj	Contents
Ko je ko u KGH 2016	Who is Who in HVAC&R 2016


GREE
ONE STOP SOLUTION
gree.rs | energynet.rs
GMV5
Ekskluzivni zastupnik i uvoznik za Srbiju ENERGY NET D.O.O.
ENERGYNET

GENERALNI POKROVITELJ
GENERAL PATRON

Kać

POKROVITELJ IZLOŽBE
PATRON OF THE EXHIBITION

Beograd

DOMAĆIN KOKTELA DOBRODOŠLICE
WELCOME COCTAIL HOST

ORGANIZATOR
ORGANIZER

Društvo za grejanje, hlađenje i klimatizaciju (KGH) Srbije pri
Savezu mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS),
Kneza Miloša 7a/II, 11000 Beograd
Tel. 011/3230-041, 3031-696, tel./faks 3231-372
Tekući račun broj 255-0007430101000-55
E-mail: office@smeits.rs
www.smeits.rs • www.kgh-drustvo.rs

ORGANIZACIONI ODBOR
ORGANIZING COMMITTEE

Aleksandar Anđelković
Bratislav Blagojević
Bojan Bogdanović
Vladan Galebović
Marko Ignjatović
Dušan Ličina
Dimitrije Lilić
Jovan Milić
Nenad Miloradović
Slobodan Pejković
Živojin Perišić
Dragomir Šamšalović
Biserka Švarc
Marija S. Todorović
Branislav Todorović, (*President*)
Petar Vasiljević
Milovan Živković

MEĐUNARODNI PROGRAMSKI ODBOR
INTERNATIONAL PROGRAMME COMMITTEE

Hashem Akbari	*Professor, Concordia University, Montreal Canada*
Costas Balaras	*Professor, National Observatory Athens, Greece*
Marianna Brodatch	*AVOK Journal Editor, Professor, Moscow Institute of Architecture, Russia*
Stefano Corgnati	*REHVA President, Politecnico di Torino, Italy*
Didier Coulomb	*Director, International Institute for Refrigeration, France*
Ioan Silviu Doboşi	*Member of Board of Directors, REHVA, Romania*
Andrea Gasparella	*IBPSA Board, University of Bozen/Bolzano, Italy*
Karel Kabele	*REHVA, Professor, Czech Technical University, Prague, Czech Republic*
Branko Kovačević	*President of the Academy of Engineering Sciences of Serbia, Belgrade*
Halvart Koeppen	*Regional Network Coordinator (ECA), UNEP*
Junjie Liu	*School of Environmental Sciences & Technology, Tianjin University, Tianjin, China*
Zoltan Magyar	*ASHRAE Danube Chapter President, Hungary*
Farooq Mahboob	*President of the ASHRAE Region At Large, Pakistan*
Ljiljana Marjanović-Halburd	*Professor, University College London, UK*
Jian-lei Niu	*Professor, The Hong Kong Polytechnic University, Kowloon, Hong Kong*
Peter Novak	*Professor, Faculty for Technology and Systems, Novo mesto, Slovenia*
Baris Ozerdem	*Professor, Bahçeşehir Üniversitesi Istanbul, Turkey*
Branimir Pavković	*Professor, University of Rijeka, Faculty of Engineering, Croatia*
Adrian Retezan	*Professor, Universitatea Politehnica Timisoara, Romania*
Matheos Santamouris	*Professor, University of Athens, „Energy & Buildings“ Journal Editor, Greece*
Chandra Sekhar	*Professor, National University Singapore, Singapore*
Jelena Srebrić	*Professor, University of Maryland, USA*
Yuri A. Tabunschikov	*Professor, Moscow Institute of Architecture (State Academy), President ABOK, Russia*
Karim Ghazi Wakili	*IABP, Institute of Applied Building Physics, Winterthur, Switzerland*

NACIONALNI NAUČNI SAVET
NATIONAL SCIENTIFIC COMMITTEE

Miloš Banjac	*Faculty of Mechanical Engineering, Belgrade*
Velimir Čongradac	*Faculty of Technical Sciences, Novi Sad*
Olvera Ećim-Đurić	*Faculty of Agriculture, Belgrade*
Radomir Folić	*Union of Civil Engineers of Serbia, Belgrade*
Zoran Keković	*Faculty of Security Studies, Belgrade*
Milan Kilibarda	*Faculty of Civil Engineering, Belgrade*
Franc Kosi	*Faculty of Mechanical Engineering, Belgrade*
Miomir Kostić	*School of Electrical Engineering, Belgrade*
Radivoje Mitrović	*Faculty of Mechanical Engineering, Belgrade*
Milovan Vidaković	*National Organization of Engineers and Technicians for Directing Fire Risks, Belgrade*
Božidar Radenković	*Faculty of Organizational Sciences, Belgrade*
Budimir Sudimac	*Faculty of Architecture, Belgrade*
Eva Vaništa-Lazarević	*UrbanLab, Belgrade*
Dušan Vukotić	*IEC TC 57-WG14 Member, President KS N057–ISS, Belgrade*

PROGRAMSKI SPONZORI
PROGRAMME SUPPORTERS

Republika Srbija, Ministarstvo poljoprivrede i zaštite životne sredine
Republic of Srbia, Ministry of Energy, Development and Environmental Protection

Federacija evropskih društava za grejanje i klimatizaciju – REHVA
Federation of European Heating and Air-Conditioning Associations – REHVA

Međunarodni institut za hlađenje (IIR)
International Institute of Refrigeration (IIR)

Program Ujednjenih nacija za životnu sredinu – UNEP
UNEP – The United Nations Environment Programme

Američko društvo inženjera za grejanje, hlađenje i klimatizaciju (ASHRAE)
American Society of Heating, Refrigerating and Air-Conditioning Engineers – ASHRAE

Inženjerska komora Srbije
Serbian Chamber of Engineers

Međunarodna asocijacija za simulaciju osobina – dinamike ponašanja zgrada
The International Building Performance Simulation Association

GLVNI SPONZORI
GENERAL SPONSORS

Airtrend Limited KOVENT
Beograd

BOSCH
Beograd

Danfoss
Beograd

EMERSON Climate Technologies
Istočna Evropa

Etaž
Beograd, Vrčin

FENIKS BB
Niš

FilterFRIGO d.o.o.
Beograd

GILLES BIOMASS HEATING
Beograd

gge
Beograd

GroupProtem GREJANJE • KLIMATIZACIJA • VODOVOD
Beograd

GRUNDFOS
Beograd

IMI Hydronic Engineering
Beograd

ITN GROUP
Beograd, Zemun

KLIMA M
Beograd

Klima-Tehnika
Beograd

LG
Beograd

Lindab IMP Klima
Beograd

mpg kgh
Beograd

5 PET-PROM
Beograd

PORTAL GREJANJE DOMOVA
Zaječar

Life Is On Schneider Electric
Beograd

SENZ COOLING SYSTEMS
Kragujevac

SIDEK INŽENJERING
Beograd

SBT
Beograd

SIPATEC
Beograd

SOKO INŽINJERING
Beograd

steelsoft
Beograd

systemair
Beograd

TAM
Beograd

Technical SOLUTION
Beograd

TECHNOLOGY international services
Beograd

TERMO PLUS
Beograd

termoinženjering
Između prirode i tehnologije
Beograd

TERMOSISTEM Panasonic
Crna Gora

TRACO
Beograd

TROX TECHNIK
The art of handling air
Beograd

UNEP
Francuska

Vaillant
Beograd

VIESSMANN
Beograd

wilo
Beograd

zehnder
Beograd

SPONZORI KONGRESA
CONGRESS SPONSORS

AEROPRODUKT ZRT	*Mađarska*
AKTING	*Beograd*
ALFA CLIMA	*Knjaževac*
ANTIĆ KLIMATIZACIJA	*Beograd*
BELIMO AUTOMATION	*Beograd*
CALEFFI HIDROTERMIKA	*Beograd*
CIM GAS	*Subotica*
CWG Balkan	*Beograd*
DRAVIDIS	*Beograd*
ELMARK	*Beograd*
ESOT-INVEST doo Celje, Ogranak ESOT-INVEST Beograd	*Beograd*
EURO HEAT	*Kragujevac*
EUROFRIGO	*Beograd*
GAS LIDER	*Beograd*
HALTON FOODSERVICE GmbH	*Nemačka*
HERZ ARMATUREN	*Nova Pazova*
INSTALACIJA INŽENJERING	*Beograd*
INTERFRIGO	*Beograd*
IPROS	*Novi Sad*

ISOPLUS	*Beograd*
IZOLIR	*Zrenjanin*
KAN-THERM	*Poljska*
KIM TEC	*Beograd*
KLIMA DOP	*Beograd*
KOMO-YU	*Beograd*
KORAJA	*Loznica*
OVENTROP	*Beograd*
OVEX	*Beograd*
PEZOS EXPORT IMPORT	*Novi Sad*
RACIONALIZACIJA ENERGIJE	*Beograd*
RADIUS-KELIT	*Austrija*
REHAU	*Beograd*
TEHNOSAM	*Subotica*
TERMO TEC FLEX	*Zabrežje, Obrenovac*
TERMOMEHANIKA	*Beograd*
TERMOPLUS (CIAT)	*Beograd*
TOPTHERM	*Bečej*
TRACO INVEST	*Beograd*
UNICOM	*Beograd*
VIS COMPANY	*Beograd*
WEISHAUPT	*Beograd*

POČASNI ODBOR
HONORARY COMMITTEE

Bora Antić	*ANTIĆ KLIMATIZACIJA, Beograd*
Dragan Arsenović	*ELCOMTRADE, Beograd*
Arpad Balog	*TOPTHERM, Bečej*
Dejan Baltić	*ISOPLUS, Beograd*
Pavle Banić	*SMART BUILDING TECHNOLOGIES, Beograd*
Aleksandar Batinić	*DANFOSS, Beograd*
Zoran Biserčić	*VAILLANT d.o.o. Beograd, Beograd*
Bratislav Blagojević	*FENIKS BB, Niš*
Dragan Božović	*TERMOSISTEM, Crna Gora*
Vojislav Brajković	*INSTALACIJA INŽENJERING, Beograd*
Dragan Brenesel	*IPROS, Novi Sad*
Srđan Budišin	*TERMO PLUS – CIAT, Beograd*
Zoran Damjanović	*STEELSOFT, Beograd*
Dušan Durković	*GRUNDFOS SRBIJA d.o.o., Beograd*
Branislav Džinić	*MPG KGH, Beograd*
Milomir Đačić	*DRAVIDIS, Beograd*
Nebojša Filipović	*UNICOM, Beograd*
Bojan Grujički	*VIESSMANN, Beograd*
Saša Ilić	*WEISHAUPT, Beograd*
Saša Jakimov	*TRACO, Beograd*
Siniša Janjušević	*GGE ESCO, Beograd*
Andrej Jergović	*SOKO INŽINJERING, Beograd*
Branislav Jordanov	*LG ELECTRONICS, Beograd*
Saša Jović	*ALFA CLIMA, Knjaževac*
Bojan Jovović	*EUROFRIGO, Beograd*
Ivet Keler	*AEROPRODUKT ZRT., Mađarska*
Čaba Kern	*CIM GAS, Subotica*
Nataša Klen	*AKTING, Beograd*

Stanko Knežević	*PET-PROM, Beograd*
Vasilije Kodžopeljić	*SCHNEIDER ELECTRIC, Beograd*
Goran Kolić	*AIRTREND – KOVENT, Beograd*
Zoran Kovljen	*GILLES, Austrija*
Zoran Krstić	*TECHNICAL SOLUTION, Bograd*
Mladen Kuparić	*ROBERT BOSCH, Beograd*
Božo Lazić	*ENERGYNET, Kać*
Darko Marinković	*TDM, Beograd*
Miljan Marković	*KAN, Poljska*
Slobodan Marković	*KOMO-YU, Beograd*
Aleksandar Marković	*ITN GROUP, Beograd, Zemun*
Pavle Markovski	*KLIMA M, Beograd*
Miomir Matić	*IZOLIR, Zrenjanin*
Dragana Mijatović	*KIM TEC, Beograd*
Vladimir Milidragović	*CALEFFI HIDROTERMIKA, Beograd*
Alen Milović	*ETAŽ, Beograd-Vrčin*
Aleksandar Minić	*IMI INTERNATIONAL, Beograd*
Dušan Mišić	*PORTAL, Zaječar*
Biljana Nedeljkov	*PEZOS EXPORT-IMPORT, Novi Sad*
Srđan Nikodijević	*OVENTROP, Beograd*
Dragan Obradović	*KLIMA DOP, Beograd*
Vlada Obradović	*TECHNOLOGY INTERNATIONAL SERVICES, Beograd*
Aleksandar Obradović	*ZEHNDER, Nemačka*
Milovan Paunović	*TERMO PLUS, Beograd*
Predrag Pažin	*TERMOINŽENJERING, Beograd*
Slobodan Pejković	*FILTER FRIGO, Beograd*
Darko Perušinović	*GAS LIDER, Beograd*
Stevan Petković	*EURO HEAT, Kragujevac*
Brana Petrović	*BELIMO AUTOMATION, Beograd*
Čedomir Petrović	*RACIONALIZACIJA ENERGIJE, Zemun*
Irena Popović	*TROX TECHNIK, Austrija*
Željko Protić	*KLIMA TEHNIKA, Beograd*
Jelena Prstojević	*ESOT-INVEST doo Celje Ogranak Beograd, Beograd*
Slavko Radovanović	*TEHNOSAM, Subotica*
Dragana Santovac	*CWG BALKAN, Beograd*
Dušan Savić	*INTERFRIGO, Beograd*
Dragan Senić	*SENA, Kragujevac*
Dragan Simonović	*WILO, Beograd*
Dejan Slepčević	*SIDEK INŽENJERING, Beograd*
Mirjana Sofrenović	*SYSTEMAIR, Beograd*
Bojan Sretenović	*OVEX INŽENJERING, Beograd*
Nebojša Stanić	*REHAU, Beograd*
Andrej Škorc	*SIPATEC d.o.o., Beograd*
Saša Šumić	*GROUP PROTEM, Beograd*
Dimitrije Trifunović	*THERMO TEC FLEX , Beograd*
Nemanja Tubić	*HERZ ARMATUREN, Nova Pazova*
Mihailo Vasić	*KORAJA, Loznica*
Narcis Vodopivec	*HALTON FOODSERVICES GmbH, Nemačka*
Zorica Vojinović	*LINDAB d.o.o. Beograd, Beograd*
Mirko Vojnović	*TRACO INVEST, Beograd*
Bojan Vukotić	*VIS COMPANY, Beograd*
Damir Žilić	*EMERSON, Istočna Evropa*

SREDA • Wednesday			
SALA 1/0 • Hall 1/0		**ANEKS B • Annex B**	
09:00 ~ 09:45	Registracija Participants Registration		
10:00 ~ 10:30	Otvaranje kongresa i izložbe Opening of Congress and Exhibition		
10:30 ~ 13:30	Sesija 1 Plenarna predavanja Keynote Lectures		
13:30 ~ 14:30	**Koktel dobrodošlice • Welcome Cocktail**		
14:30 ~ 17:10	Sesija 2 Standardizacija Standardization	14:30~17:45	Sesija 3 Daljinsko grejanje District Heating

ČETVRTAK • Thursday					
SALA 1/0 • Hall 1/0		**ANEKS A • Annex A**		**ANEKS B • Annex B**	
09:00 ~ 13:00	Sesija 4 Forum: Poboljšanje energetske efikasnosti u novim tehnologijama hlađenja pogodnim za očuvanje klimatskih uslova i ozonskog omotača Forum: Improving Energy Efficiency in Climate and Ozone Friendly Latest Refrigeration Technologies	09:00 ~ 12:00	Sesija 7 Obnovljivi izvori energije Solar and other Renewables	09:00 ~ 10:40	Sesija 10 Približavanje zgradama i gradovima nulte emisije CO_2 – tehnologije i rizici Approaching Zero CO_2 Emission Buildings and Cities – Technologies and Risks
14:00 ~ 15:50	Sesija 5 Srpska regulativa i evropska „F“ gas regulativa HFC Policy & Legislative Options in Serbia and European “F” gas legislation	12:15 ~ 15:15	Sesija 8 Projektovanje energetski efikasnih i zdravih sistema za KGH HVAC Systems Design for Energy Efficiency and Health	11:00 ~ 15:30	Sesija 11 Program za studente, mlade inženjere i profesionalni razvoj – kombinovano sa prezentacijama glavnih sponzora Students, Young Engineers & Professional Development Program – Combined with Main Sponsors Presentations
16:00 ~ 18:00	Sesija 6 Mašine i sistemi za hlađenje Refrigeration Machines and Systems	15:30 ~ 17:50	Sesija 9 Predviđanje i validacija sistema za KGH HVAC Systems Peformace Prediction and Validation	16:30 ~ 18:10	Sesija 12 Optimizacija i predviđanje energetskog ponašanja zgrada Buildings Energy Performance Optimization And Predictions
20.00 h Banket • Banquet					

PETAK • Friday	
ANEKS B • Annex B	
09:00 ~ 10:40	Session 13 Analytical and Experimental Methods Advances
10:55 ~ 14:00	Session 14 FORUM: Europe, Asia, Australia, Africa and America Harmonised Rurban Development Needs – HVAC & Cold Chain, Healthy EnergyPlus Buildings, Smart Zero CO_2 Settlements, Sustainability, Security and ResilienceTowards 5 Continents Cooperation – Science, Research & Development, Standardization, Certification, Education Engineering & Manufacturing (KGH-SMEITS & ECS, UNEP, UNDP, IIR, ASHRAE-Danube, REHVA, IBPSHA-Danube, ABOK, Chinese and Australian Engineers)
14.00 h Završetak rada skupa • Congress Closing Ceremony **14.10 h Oproštajni ručak • Farewell Lunch**	

SADRŽAJ • CONTENTS

I. PLENARNA PREDAVANJA • Plenary Keynote Lectures

1. VODA KAO RASHLADNI FLUID
   USE OF WATER AS REFRIGERANT
   Alexander COHR PACHAI, Technology Manager Sabroe Factory by Johnson Controls, Denmark
2. ISTRAŽIVANJE PERFORMANSI SISTEMA I OPTIMIZACIJA RETROFITA POSTOJEĆEG SISTEMA GSTP U OŠTRO HLADNOJ KLIMATSKOJ ZONI KINE
   SYSTEM PERFORMANCE INVESTIGATION AND OPTIMIZATION RETROFIT OF AN EXISTING GSHP SYSTEM IN THE SEVERE COLD ZONE IN CHINA
   Ping CUI, Shandong, Haipeng AN, Haiyang JIANG, Shandong Jianzhu University, Jinan, China

II. STANDARDIZACIJA • Standardization

3. EKSERGIJA KAO FIZIČKA MERA ODRŽIVOSTI ENERGETSKOG SISTEMA
   EXERGY AS PHYSICAL MEASURE OF SUSTAINABILITY OF ENERGY SYSTEM,
   Peter NOVAK, Slovenija
4. DOSTIZANJE CILJA PROTIV SIROMAŠTVA U SVETLU STRATEGIJA ZA POVEĆANJE ENERGETSKE EFIKASNOSTI
   MEETING THE ANTI-POVERTY TARGET IN THE LIGHT OF INCREASING ENERGY EFFICIENCY STRATEGIES
   Livio de SANTOLI, Sapienza Universita di Roma, AICARR President
5. STANDARDIZACIJA U PODRUČJU TERMALNE SREDINE
   STANDARDIZATION IN THE FIELD OF THE THERMAL ENVIRONMENT
   Francesca Romana d'Ambrozio ALFANO, Dipartimento di Ingeneria Industriale, Universita degli Studi di Salerno, Salerno, Italy

III. DALJINSKO GREJANJE • District Heating

6. ULOGA DALJINSKOG GREJANJA U BUDUĆIM PAMETNIM ENERGETSKIM SISTEMIMA
   THE ROLE OF DISTRICT COOLING IN THE FUTURE SMART ENERGY SYSTEMS
   Oddgeir GUDMUNDSSON, Jan Eric THORSEN, Marek BRAND, Danfoss A/S, Heating Segment, Application and Technology, Nordborg, Danmark
7. GRAĐEVINSKA REŠENJA ZA NISKOTEMPERATURNO SNABDEVANJE TOPLOTNOM ENERGIJOM
   BUILDING SOLUTIONS FOR LOW TEMPERATURE HEAT SUPPLY
   Oddgeir GUDMUNDSSON, Jan Eric THORSEN, Marek BRAND, Danfoss A/S, Heating Segment, Application and Technology, Nordborg, Danmark

8. POVEĆANJE STEPENA KORISNOSTI KOTLA I TEHNO-EKONOMSKA ANALIZA UGRADNJE UTILIZATORA NA VRELOVODNOM KOTLU SNAGE 116 MW NA TOPLANI „KONJARNIK“ U BEOGRADU
   INCREASING THE BOILER COP AND TECHNO-ECONOMIC ANALYSIS OF UTILIZATOR IMPLEMENTATION ON 116 MW HOT BOILER IN „KONJARNIK” HEATING PLANT IN BELGRADE
   Vladimir TANASIĆ, Marko MLADENOVIĆ, JKP „Beogradske elektrane“,Beograd

9. POREĐENJE GUBITAKA VODE IZ TOPLOVODNE MREŽE U TOPLANAMA RAZLIČITIH RADNIH PARAMETARA
   COMPARISON OF WATER LOSES FROM PIPELINE NETWORK IN HEATING PLANTS WITH DIFERENT OPERATION MODE
   Nenad MILORADOVIĆ, JKP „Beogradske elektrane“, Beograd

10. PREMOŠĆAVANJE RAZLIKE IZMEĐU STVARNE I PROJEKTOVANE POTROŠNJE ENERGIJE ZA GREJANJE PRILIKOM BOTTOM-UP MODELIRANJA STAMBENIH ZGRADA
   BRIDGING THE GAP OF ACTUAL AND CALCULATED HEATING ENERGY CONSUMPTION IN BOTTOM-UP RESIDENTIAL BUILDING STOCK MODELING
   Constantinos A. BALARAS, Elena G. DASCALAKI, Kalliopi G. DROUTSA, Simon KONTOYANNIDIS, Group Energy Conservation, Institute for Environmental Research & Sustainable Development, National Observatory of Athens, Athens, Greece

11. PREDNOSTI GREJANJA JAVNIH I STAMBENIH OBJEKATA SISTEMOM TOPLOTNIH PUMPI (SMMS-E)
   ADVANTAGES OF HEATING AND HOUSING FACILITIES HEAT PUMPS SYSTEM (SMMS-E)
   Dragan ŠOŠKIĆ JP „Toplifikacija“, Lazarevac

12. MOGUĆNOSTI INDIVIDUALNOG ISKLJUČENJA SISTEMA DALJINSKOG GREJANJA
   POSSIBILITIES OF INDIVIDUAL DISCONNECTION FROM THE DISTRICT HEATING SYSTEM
   Milan MITRIĆ, Biro „Solar”, Pančevo, Srbija

13. CFD MODELIRANJE HIDRODINAMIČKIH POJAVA I PRENOSA TOPLOTE U KANALIMA PLOČASTIH RAZMENJIVAČA TOPLOTE
   CFD MODELING OF HYDRODYNAMIC PHENOMENA AND HEAT TRANSFER IN CHANNELS OF PLATE HEAT EXCHANGERS
   Dragan MANDIĆ, JKP „Beogradske elekrane“, Beograd

IV. Poboljšanje energetske efikasnosti u novim tehnologijama hlađenja pogodnim za očuvanje klimatskih uslova i ozonskog omotača • Improving Energy Efficiency In Climate And Ozone Friendly Latest Refrigeration Technologies

14. BUŠOTINE ILI TOPLOTNE PUMPE VAZDUH–VODA. ŠTA I GDE KORISTITI?
   BOREHOLE INSTALLATIONS OR AIR-TO-WATER HEAT PUMPS. WHAT TO USE AND WHERE?
   Gert NIELSEN, Multiconsult A/S, Nesttun, Norway

VI. RASHLADNE MAŠINE I SISTEMI • Refrigeration Machines and Systems

15. AMONIJAČNE UNUTRAŠNJE REVERZIBILNE TOPLOTNE PUMPE/ČILERI VAZDUH–VODA
INTERNAL REVERSIBLE AMMONIA AIR-TO-WATER HEAT PUMP / CHILLER
Gert Nielsen – Multiconsult A/S, Nesttun, Norway, Carl RASMUSSEN, NH3 Solutions, Roskilde, Denmark

VII. OBNOVLJIVI IZVORI ENERGIJE • Solar and other Renewables

16. OSNOVNE POSTAVKE STANDARDA ZA OSTVARENJE KVALITETA ČVRSTIH BIOGORIVA IZ SEKUNDARNIH SIROVINA
BASIC QUALITY STANDARDS OF SOLID BIOFUELS FROM WOOD SECONDARY RAW MATERIALS
Predrag PETROVIĆ, Institut za opštu fizičku hemiju, Beograd, Marija PETROVIĆ, Poljoprivredni fakultet Univerziteta u Beogradu, Beograd

17. KONCENTRISANI SUNČEVI TOPLOTNI PRIJEMNICI ZA HLAĐENJE ZGRADA: PROCENE ZA GRČKU
CONCENTRATING SOLAR THERMAL COLLECTORS FOR COOLING OF BUILDINGS: AN ASSESSMENT FOR GREECE
Vassiliki DROSOU1,2, Elli KYRIAKI3, Agis M. PAPADOPOULOS3, Argiro DIMOUDI2; 1 Laboratory of Environmental and Energy Design of Buildings and Settlements, Democritus University of Thrace, Dept of Environmetal Engineering, Xanthi, Greece; 2 Centre for Renewable Energy Sources and Saving, Solar Thermal Systems Dept, Pikermi, Greece; 3 Process Equipment Design Laboratory, Dept of Mechanical Engineering Aristotle University of Thessaloniki, Thessaloniki, Greece

18. EKSERGETSKA OPTIMIZACIJA ZGRADA RAZLIČITIM SOLARNIM SISTEMIMA
EXERGY OPTIMIZATION OF BUILDINGS WITH DIFFERENT SOLAR SYSTEMS
Danijela NIKOLIĆ, Faculty of Engineering, University at Kragujevac, Kragujevac, Serbia

19. OPTIMIZACIJA GEOMETRIJSKIH PARAMETARA SUNČEVIH PRIJEMNIKA POMOĆU HEURISTIČKIH METODA OPTIMIZACIJE
OPTIMIZATION OF SOLAR COLLECTOR GEOMETRIC PARAMETERS USING A HEURISTIC OPTIMIZATION METHODS
Nenad KOSTIĆ, Miloš MATEJIĆ, Nenad PETROVIĆ, Mirko BLAGOJEVIĆ, Nenad MARJANOVIĆ, Faculty of Engineering, University at Kragujevac, Kragujevac, Serbia

20. MOGUĆNOSTI I NAČINI KORIŠĆENJA SUBGEOTERMALNE ENERGIJE U BEOGRADU
POSSIBILITIES AND MANNERS OF USAGE OF THE SUBGEOTHERMAL ENERGY IN BELGRADE
Ivan MATIĆ1, Stevan ŠAMŠALOVIĆ, S. ĆURČIĆ2, Z. GOLUBOVIĆ3, G. KOVAČEVIĆ4, Z. MARKOVIĆ4, I. TANASKOVIĆ5, 1 Faculty of Mining and Geology, University of Belgrade, 2 Unioninvest-Engineering and Projecting, Belgrade, 3 Faculty of Mechanical Engineering, University of Belgrade, 4 Swiss Term, Belgrade, 5 GeaWater Work, Smederevo, Serbia

21. ANALIZA I OCENA SOLARNIH SISTEMA BUDUĆNOSTI
ANALYSIS AND ASSESSMENT OF SOLAR ENERGY SYSTEMS FOR A SUSTAINABLE FUTURE
Jasmina SKERLIĆ, Danijela NIKOLIĆ, Jasna RADULOVIĆ, Faculty of Engineering, University at Kragujevac, Kragujevac, Serbia

VIII. PROJEKTOVANJE ENERGETSKI EFIKASNIH I ZDRAVIH SISTEMA ZA KGH • HVAC Systems Design for Energy Efficiency and Health

22. ODRŽIVO PROJEKTOVANA KLIMATIZOVANA DŽAMIJA RADI TOPLOTNE UGODNOSTI
SUSTAINABLE DESIGNED AIR-CONDITIONED MOSQUE FOR THERMAL COMFORT
Redhwan N. AL-GABRI1, and Essam E. KHALIL2; 1 Cairo University, Cairo, Egypt; 2 Department of Mechanical Engineering, Cairo University, Cairo, Egypt

23. HLAĐENJE OTVORENOG PROSTORA RADI POSTIZANJA TERMIČKE UGODNOSTI GLEDALACA U KLIMATIZOVANIM SPORTSKIM OBJEKTIMA
OUTDOOR COOLING FOR THERMAL COMFORT AROUND SPECTATORS IN AIR CONDITIONED SPORT FACILITIES
Essam E. KHALIL; Department of Mechanical Engineering, Cairo University, Cairo, Egypt

24. EFIKASNI SISTEMI KGH U BOLNICAMA
EFFICIENT HVAC SYSTEMS IN HOSPITALS
Egon VENKO, Damjan MAKUC, Program apsolutne filtracije vazduha, Slovenija

25. PROMJENA TERMIČKE UGODNOSTI U FAZI POTHLAĐIVANJA UNUTRAŠNJOSTI VOZILA
CHANGE OF THE THERMAL COMFORT IN THE COOLING PHASE OF A VEHICLE INTERIOR
Svetozar GRAHOVAC, Manhajm, Nemačka

IX. PREDVIĐANJE I VALIDACIJA SISTEMA ZA KGH • HVAC Systems Performance Prediction and Validation

26. POREĐENJE ENERGETSKIH PREGLEDA KOMERCIJALNIH OBJEKATA PO EU DIREKTIVI I ASHRAE METODOLOGIJI
COMPARISON AND EXPERIENCE FROM ENERGY AUDITS ACCORDING TO EU DIRECTIVE AND ASHRAE METHODOLOGY WITH RECOMMENDATIONS FOR DEVELOPMENT OF SERBIAN METHODLOGYOF ENERGY AUDITS
Rade ĐUKANOVIĆ, „Rade Đukanović Agencija za projektovanje i konsalting", Beograd

27. DINAMIČKA EKSERGETSKA ANALIZA VIŠENAMENSKE ZGRADE NA OSNOVU PRIKUPLJENIH PODATAKA
DYNAMIC EXERGY ANALYSIS OF A MULTIFUNCTIONAL BUILDING USING MONITORED DATA
Saeed SAYADI, Amir NAGHSHEJAHAN, Tatiana MOROSUK, George TSATSARONIS; Technische Universität Berlin, Institute for Energy Engineering, Berlin, Germany

28. KVANTITATIVNE I KVALITATIVNE PROCENE TEMPERATURE I KVALITETA UNUTRAŠNJEG VAZDUHA U DVEMA KANCELARIJSKIM ZGRADAMA
QUANTITATIVE AND QUALITATIVE EVALUATION OF INDOOR THERMAL AND AIR QUALITY IN TWO OFFICE BUILDINGS
Panagiota ANTONIADOU, George MANTIKAS, Agis M. PAPADOPOULOS; Process Engineering Design Laboratory, School of Mechanical Engineering, Aristotle University Thessaloniki, Thessaloniki, Greece

29. POBOLJŠANJE PONAŠANJA ZGRADE OPTIMIZACIJOM KONTROLNE STRATEGIJE SISTEMA ZA KGH
IMPROVEMENT OF BUILDING PERFORMANCE BY OPTIMIZATION OF HVAC CONTROL STRATEGY
Alojz TOVAROVIĆ, Ministry of Defense of Bosnia and Herzegovina

X. PRIBLIŽAVANJE ZGRADAMA I GRADOVIMA NULTE EMISIJE CO_2 – TEHNOLOGIJE I RIZICI • Approaching Zero CO_2 Emission Buildings and Cities – Technologies and Risks

30. METODOLOŠKI PRISTUP OPTIMIZACIJI OMOTAČA ZGRADE POMOĆU PCM
METHODOLOGICAL APPROACH ON THE BUILDING ENVELOPE OPTIMIZATION USING PCM
Christina V. KONSTANTINIDOU, Agis M. PAPADOPOULOS, Process Equipment Design Laboratory, School of Mechanical Engineering Aristotle University of Thessaloniki, Thessaloniki, Greece

31. STUDIJA SLUČAJA PRIMENE PRIRODNIH RASHLADNIH FLUIDA
NATURAL REFRIGERANTS STUDY CASE APPLICATION
Gratiela-Maria TARLEA2, Ana TARLEA1, Mioara VINCERIUC1, Ion ZABET1; 1 Romanian General Association of Refrigeration, 2 Tecnical University of Civil Engineering, Bucharest, Romania

32. ANALIZA MERA ZA UŠTEDU ENERGIJE POTREBNE ZA ZAGREVANJE POSTOJEĆE STAMBENE ZGRADE ANALYSIS OF ENERGY SAVING MEASURES FOR AN EXISTING RESIDENTIAL BUILDING
Novak NIKOLIĆ, Nebojša LUKIĆ, Zoran KONČALOVIĆ, Faculty of Engineering, University of Kragujevac, Serbia

33. UTICAJ TROMBOVOG ZIDA NA POTROŠNJU ENERGIJE ZA GREJANJE I HLAĐENJE KUĆE NETO-NULTE POTROŠNJE ENERGIJE
THE INFLUENCE OF THE TROMBE WALL ON ENERGY CONSUMPTION FOR HEATING AND COOLING OF NET-ZERO ENERGY HOUSE
Jovan MALEŠEVIĆ, Dragan CVETKOVIĆ
Fakultet inženjerskih nauka Univerziteta u Kragujevcu, Kragujevac, Srbija

XI. PROGRAM ZA STUDENTE, MLADE INŽENJERE I PROFESIONALNI RAZVOJ – KOMBINOVANO SA PREZENTACIJAMA GLAVNIH SPONZORA • Program for Students, Young Engineers & Professional Development – Combined with Main Sponsors Companies Presentations – Internship and Employment Prospects

34. INTEGRALNI I ODRŽIVI PRISTUP PROJEKTOVANJU U ZGRADARSTVU – IDEJNO REŠENJE OBJEKTA JAVNE UPRAVE U PEKINGU
INTEGRAL AND SUSTAINABLE BUILDING DESIGN – CONCEPTUAL SOLUTION OF A MUNICIPAL BUILDING IN BEIJING
Živanović VLADISLAV, Franceško LUKA, Berec GABOR, Dragan BOTIĆ, Vladimir MUNĆAN, Igor MUJAN, Aleksandar ANĐELKOVIĆ, Fakultet tehničkih nauka, Novi Sad, Srbija

35. BIOGORIVO LIGNOCELULOZNE SIROVINE
BIOFUELS FROM LIGNOCELLULOSIS FEEDSTOCKS
Vladan MIĆIĆ1, Sabina BEGIĆ2, Zoran PETROVIĆ1, Darko MANJENČIĆ3; 1 Tehnološki fakultet, Zvornik, 2 Tehnološki fakultet, Tuzla, Republika Srpska, BiH, 3 Tehnološki fakultet, Novi Sad, Srbija

36. PROBLEMI KONDENZACIJE VLAGE NA ZASTAKLJENJU BAZENSKIH OBJEKATA I LCCA RAZLIČITIH TIPOVA KLIMA KOMORA
PROBLEMS OF MOISTURE CONDENSATION ON POOL FACILITIESGLAZING AND LCCA OF DIFFERENT TYPES OF HVAC CHAMBERS
Aleksandar PJEVIĆ, Lindab, Moscow, Russia

37. ENERGETSKI ASPEKTI SUŠENJA DRVETA
ENERGY ASPECTS OF WOOD DRYING
Vuk MAROVIĆ, Student (mentor Assistant professor Damir ĐAKOVIĆ), University of Novi Sad, Faculty of technical sciences, Department of energy and process engineering

XII. OPTIMIZACIJA I PREDVIĐANJE ENERGETSKOG PONAŠANJA ZGRADA • Buildings Energy Performance Optimization and Predictions

38. AKTIVNI PCM SISTEMI SKLADIŠTENJA TOPLOTNE ENERGIJE ZA „SLOBODNO" GREJANJE I HLAĐENJE ZGRADA
ACTIVE PCM THERMAL STORAGE SYSTEMS FOR „FREE" HEATING AND „FREE" COOLING OF BUILDINGS
Uroš STRITIH, University of Ljubljana, Ljubljana, Slovenija

39. OMOTAČ ZGRADE – KLJUČNI PARAMETAR ZA ODRŽIVE ZGRADE
BUILDING ENVELOPE – A KEY ROLE PARAMETER FOR SUSTAINABLE BUILDINGS
Elli KYRIAKI, Effrosyni GIAMA, Agis M. PAPADOPOULOS, Process Equipment Design Laboratory, School of Mechanical Engineering Aristotle University of Thessaloniki, Thessaloniki, Greece

40. IZMEĐU TEORIJE I PRAKSE NA KONKRETNOM PRIMERU ENERGETSKE SANACIJE OBJEKTA
BETWEEN THEORY AND PRACTICE – CASE STUDY ON ENERGY SANATION ON AN OBJECT
Marija ILIĆ, Ustanova gerontološki centar, Beograd, Aleksandar SAVIĆ, Elektrotehnička škola „Rade Končar", Beograd

41. OBRAZUJTE SE – VIDETI ILI NE
GET LEDUCATED – TO SEE OR NOT TO SEE
Aleksandar SAVIĆ, Elektrotehnička škola „Rade Končar", Beograd, Marija ILIĆ, Ustanova gerontološki centar, Beograd

42. UTICAJ KOEFICIJENTA TRANSFORMACIJE PRIMARNE ENERGIJE NA NISKOTEMPERATURNE PANELNE SISTEME GREJANJA
THE IMPACT OF PRIMARY ENERGY COEFFICIENT ON LOW TEMPERATURE PANEL HEATING SYSTEMS
Dragan CVETKOVIĆ, Aleksandar NEŠOVIĆ
Fakultet inženjerskih nauka Univerziteta u Kragujevcu, Kragujevac, Srbija

XIII. ANALYTICAL AND EXPERIMENTAL METHODS ADVANCES

43. INSTALACIJA ZA EKSPERIMENTALNA ISTRAŽIVANJA PRIRODNE I PRIRODNO-PRINUDNE (MEŠOVITE) KONVEKCIJE DUŽ VERTIKALNE TERMOAKTIVNE SOBNE POVRŠINE
    EXPERIMENTAL APPARATUS FOR EXPERIMENTAL STUDIES OF NATURAL AND MIXED CONVECTION ALONG VERTICAL THERMO ACTIVE ROOM SURFACE
    Samo VENKO, Erik PAVLOVIČ, Lindab IMP Klima d.o.o., Godovič, Slovenia, Ciril ARKAR, Sašo MEDVED, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenija
44. ZAPTIVENOSTI KANALSKIH MREŽA KGH
    TIGHTNESS CANAL NETWORK HVAC
    Milovan ŽIVKOVIĆ, Capotto Build, Beograd, Miloš GOLUBOVIĆ, Termopart, Beograd
45. PRIMENA LINEARNE REGRESIONE ANALIZE U PRAKSI – POSTROJENJE ZA GREJANJE OBJEKATA TOPLOTNIM PUMPAMA, EFIKASNOST TOPLOTNIH PUMPI
    USAGE OF LINEAR REGRESSION ANALYSIS IN PRACTICE – PLANT FOR HEATING OBJECTS WITH HEAT PUMPS, EFFICIENCY OF HEAT PUMPS
    Miroslav VULIĆ, Kristijan VUJIČIN, Mašinski fakultet Univerziteta u Beogradu, Beograd
46. ODREĐIVANJE SADRŽAJA VLAGE U OTPADNOM GASU – EKSPERIMENTALNA I TEORIJSKA METODA
    DETERMINATION OF THE WATER VAPOR CONTENT IN FLUE GAS – STANDARD REFERENCE METHOD AND MATERIAL BALANCE METHOD
    Marko PAVLOVIĆ1, Veselin ANĐELKOVIĆ1, Milan GOJAK2, Mihajlo GIGOV1, Sandra PETKOVIĆ1, Lazar ANĐELIĆ1; 1 Rudarski institut d.o.o., Beograd, 2 Mašinski fakultet, Univerzitet u Beogradu, Beograd

10.55–14.00 h **XIV.** FORUM: EUROPE, ASIA, AUSTRALIA, AFRICA AND AMERICA HARMONISED RURBAN DEVELOPMENT NEEDS – HVAC & COLD CHAIN, HEALTHY ENERGYPLUS BUILDINGS, ZERO CO2 SETTLEMENTS, SUSTAINABILITY, SECURITY AND RESILIENCE

TOWARDS 5 CONTINENTS COOPERATION – SCIENCE, RESEARCH & DEVELOPMENT, STANDARDIZATION, CERTIFICATION, EDUCATION ENGINEERING & MANUFACTURING (KGH-SMEITS & ECS, UNEP, UNDP, IIR, ASHRAE-DANUBE, REHVA, ABOK, CHINESE AND AUSTRALIAN ENGINEERING ASSOCIATIONS)

(All participants are invited to be active panelists)

47. ADAPT TODAY TO SHAPE TOMORROW
    Tim WENTZ, ASHRAE President
48. ADVANCES IN ENVIRONMENTAL PRESERVATION: THE ROLE OF SOLID WASTE MANAGEMENT
    Doaa M. El-SHERIF, Urban Training & Studies Institute (Uti); Housing & Building National Research Center (Hbrc); Ministry Of Housing, Egypt
49. THE ROLE OF FACADE ON FIRE SPREAD
    Milovan VIDAKOVIĆ, Serbia
50. DISASTER MANAGEMENT IN SMART SETTLEMENT - RESILIENCE APPROACH AND LAYERED APPROACH TO (DISASTER) RESILIENCE ANALYSIS OF URBAN SETTLEMENTS
    Zoran KEKOVIĆ, Ozren DZIGURS, Vladimir NINKOVIĆ, Faculty of Security, Serbia

EKSERGETSKA OPTIMIZACIJA ZGRADA SA RAZLIČITIM SOLARNIM SISTEMIMA

EXERGY OPTIMIZATION OF BUILDINGS WITH DIFFERENT SOLAR SYSTEMS

Danijela NIKOLIĆ, Jasna RADULOVIĆ, Jasmina SKERLIĆ,
Faculty of engineering, University at Kragujevac, Serbia,
danijelan@kg.ac.rs

Eksergija, kao mera korisnog rada koji se dobija interakcijom sistema i okoline, koristi se za optimizaciju i definisanje raspodele gubitaka u energetskom sistemu. Takodje je i u širokoj upotrebi za dizajn, simulaciju i evaluaciju performansi energetskog sistema. U ovom radu je istraživana srpska porodična kuća sa instaliranim fotonaponskim sistemom i solarnim kolektorima na krovu. Zgrada ima sistem električnog grejanja. Eksergetska optimizacija (uključujući i sopstvenu eksergiju) je rađena sa glavnim ciljem određivanja maksimalne vrednosti generisane električne energije. Na taj način se minimizira potrošnja primarne energije. Analizirane su zgrade sa fotonaponskim modulima različite ćelijske efikasnosti. Zgrade su simulirane u okruženju softvera EnergyPlus, Open Studio plug-in u Google SketchUp-u je korišćen za dizajniranje zgrade, Hooke-Jeeves algoritam za optimizaciju, a GENOPT softver za izvršnu kontrolu softvera pri optimizaciji.

Ključne reči: *eksegija; fotonaponski paneli; solarni kolektori; simulacija; optimizacija.*

Exergy, as a measure of useful work that can be obtained by the interaction of the system and the environment, is used for the optimization and allocation of losses in the energy system. It is also widely used in the design, simulation and performance evaluation of energy systems. In this paper it is investigated the Serbian residential building with photovoltaics and solar collectors on the roof. The building has electrical space heating. Exergy optimization (including embodied exergy) was performed with the aim to determine the maximum value of the generated electricity. On that way, primary energy consumption can be minimized. The residential buildings with variable PV cell efficiency are investigated. The buildings were simulated in EnergyPlus, Open Studio plug-in in Google SketchUp was used for buildings design and Hooke-Jeeves algorithm for optimization. GENOPT was used for software execution control during optimization.

Key words: *Exergy; Photovoltaic; Solar collector; Simulation; Optimization.*

1. Introduction

The exergy analysis, founded by Carnot in 1824 and Clausius in 1865, is a method based on the Second law of thermodynamics and the concept of irreversible production of entropy. The performances of energy-related engineering systems are evaluated primarily by using the energy balance. In recent years, the exergy concept has gained considerable interest in the thermodynamic analysis of thermal processes since it has been seen that the First law analysis is insufficient for evaluation of energy performance [1]. Exergy analysis quantifies the loss of efficiency in a process that is due to the loss in energy quality.

Solar energy is the most capable of the alternative energy sources. Due to increasing demand for energy and rising cost of fossil fuels, solar energy is considered an attractive source of renewable energy that can be used for electricity generation and domestic water heating in residential buildings. Photovoltaic (PV) technology is an attractive option for clean and renewable electricity generation because it represents the direct conversion of solar radiation into electricity. Electrical energy can be treated as totally convertible to work, so the electricity is pure exergy. At the other side, heating water consumes nearly 20% of total energy consumption for an average family [2]. So, solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide most of hot water required by a family. Using photovoltaics and solar collectors together, represent a great opportunity for reducing the consumption of primary energy in residential buildings.

This paper reports investigations of the exergy optimization, with the major aim to determine the optimal size of PV panels and solar collectors on the roof, in order to achieve the maximum amount of exergy. On that way, it can be obtain the maximum value of exergy efficiency for installed solar systems, and primary energy consumption will be minimized. The residential building with variable PV cell efficiency is analyzed.

The investigated building was located in Kragujevac, Serbia. The building is designed with PV panels and solar collectors installed on the roof. Generated heat energy is used for domestic hot water (DHW) heating. Electricity generated by the PV may be used for space heating, cooling, lighting, and electric equipment. Analyzed building has an electrical space heating system. Heating devices operated from 15 October to 14 April next year.

In this paper, the EnergyPlus, Open Studio plug-in in Google SketchUp, Hooke-Jeeves algorithm and Genopt were used for simulation and optimization.

2. Simulation softwares

EnergyPlus software simulates the energy use in a building and energy behavior of the building for defined period. In this study, the version 8.1.0 was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [3] and it has been tested using the IEA HVAC BESTEST E100-E200 series of tests [4]. For PV electricity generation, EnergyPlus uses the different component, like PV array and inverter [5].

Open Studio plug-in in Google SketchUp software is a free 3D software tool that combines a tool-set with an intelligent drawing system [6]. The software enables to place models using real world coordinates. The OpenStudio is free plug-in that adds the building energy simulation capabilities of EnergyPlus to the 3D SketchUp environment. The software allows to the user to create, edit and view EnergyPlus input files within SketchUp.

GenOpt is an optimization program for the minimization of cost function evaluated by an external simulation program. GenOpt serves for optimization problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. It can be coupled to any simulation program that reads its input from text files and writes its output to text files. GenOpt is written in Java so that it is platform independent. It has a library with adaptive Hooke-Jeeves algorithm [7].

Hooke–Jeeves optimization algorithm is used for the optimization, and it is direct search and derivative free optimization algorithm [8]. In this algorithm, only the objective functions and the constraint values are used to guide the search strategy. The main advantage of this algorithm is reducing the compute time.

3. Weather conditions

The investigated residential building was located in the city of Kragujevac, Republic of Serbia. Its average height above sea level is 209 m. Its latitude is $44^0 10$ N and longitude $20^0 55$ E. The time zone for Kragujevac is GMT + 1.0 h. In the city of Kragujevac summers are very warm and humid, with temperatures as high as 37^0C. The winters are cool, and snowy, with temperatures as low as -12 ^{0}C. The EnergyPlus uses weather data from its own database file.

4. Building model in energyplus software

The modeled residential building is shown in Figure 1. The building has the south-oriented roof with a slope of 37.5^0, and PV array and solar collectors installed on the roof. The building has two floors and 6 conditioned zones. The total floor area of the building is 160 m^2 and total roof area 80.6 m^2. The windows are double glazed. The concrete building envelope, roof, and the floor were thermally insulated by polystyrene. In this investigation, the polystyrene thickness was 0.15 m. Air temperatures in the heated rooms are set to 20^0C from 07:00-09:00 and from 16:00-21:00, and to 15^0C from 09:00-16:00. The simulation time step is 15 min.

The PV system consists is an on-grid system. The life cycle of PV array is set to 20 years, the embodied energy of PV panels is set to 3.75 GJ/m^2 [9, 10], and the embodied exergy of PV panels is set to 5 GJ/m^2 [11]. The PV panel is represented by the mathematical model of Photovoltaic:Simple from EnergyPlus [4]. The life cycle of solar collectors is also set to 20 years, the embodied energy of solar collectors is set to 2.75 GJ/m^2 [11], and the embodied exergy of solar collectors is set to 3.8 GJ/m^2 [11].

The main part of exergy (i.e. electricity) obtained from PV array ($E_{x,\ PV}$), is consumed for electrical space heating in the building. Additionally, electricity was consumed for lighting, domestic hot water (DHW) and appliances. Exergy obtained from solar collectors is marked by $E_{x,\ KOL}$ and it is equal to the sum of exergy of the end consumers: shower ($E_{X,\ SHOW}$), sink ($E_{X,\ SINK}$), cloth washing machine ($E_{X,\ CW}$) and dish washing machine ($E_{X,\ DW}$):

$$E_{x,\ KOL} = E_{X,\ SHOW} + E_{X,\ SINK} + E_{X,\ CW} + E_{X,\ DW}$$

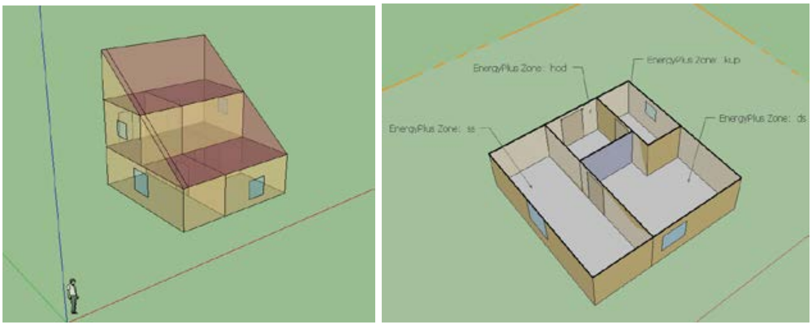


Figure 1 – Modeled residential building

Shower and sink required lower water temperature, so it is necessary to mix water from DHW system with cold water. In the exergetic optimization considered exergy of cold water is added to the exergy calculation.

Sun exergy ($E_{x,\ SUN}$) is calculated based on the value of the mean annual insulation at the city of Kragujevac, Serbia (I=1447.85 kWh/m^2) [11].

5. Optimization procedure

Through exergy optimization, the maximum value of the exergy efficiency of the system of photovoltaic panels and solar collectors is determined. The maximum exergy efficiency is achieved at the optimal size of PV array and solar collectors, which is given by the roof area covered with PV array in the optimization code (value y). The value y exists in the calculated total exergy of PV system and solar collectors. Objective function in optimization procedure is exergy efficiency without embodied exergy:

$$\eta_X = \frac{E_{X,PV-KOL}}{E_{X,SUN}}$$

where: $E_{x,\ SUN}$ – Sun exergy (J), $E_{x,\ PV\text{-}KOL}$ (J) – exergy obtained by PV array and solar collectors, and it is equal to the sum of exergy obtained by the PV array ($E_{x,\ PV}$) and exergy obtained by the solar collectors ($E_{x,\ KOL}$), i. e.

$$E_{X,PV-KOL} = E_{X,PV} + E_{X,KOL}$$

It is also calculated the exergy efficiency with embodied exergy:

$$\eta_{X,EE} = \frac{E_{X,PV-KOL,EE}}{E_{X,SUN}}$$

where: $E_{x,\ PV\text{-}KOL,\ EE}$ (J) – exergy obtained from PV array and solar collectors, with their embodied exergy. This value is equal to the subtraction of exergy obtained by the PV array and solar collectors ($E_{x,\ PV\text{-}KOL}$) and embodied exergy of PV array (EE_{PV}) and solar collector (EE_{KOL}), i. e.

$$E_{X,PV-KOL,EE} = E_{X,PV-KOL} - EE_{PV} - EE_{KOL}$$

Through the exergy optimization, it is also calculated some other parameters, which can be very useful as a valid indicators of the exergy flows in the analyzed solar systems. They are ratios between required and obtained exergy e_x and $e_{x,\ EE}$ (without and with embodied exergy of solar systems):

$$e_X = \frac{E_{X,POT}}{E_{X,PV-KOL}} \quad e_{X,EE} = \frac{E_{X,POT}}{E_{X,PV-KOL,EE}}$$

where: $E_{x,\ POT}$ – total consumer exergy (J) (sum of needed exergy of all consumers, yearly). Ratios of required and obtained exegy should be as small as possible.

In the proces of exergy optimization, it is calculated total electricity consumption E_{EL} (GJ), primary energy consumption (GJ), generated finaly and primary energy (GJ), and avoided operative primary energy E_{PRIM}. Avoided operative primary energy consumption due to operation of the solar systems (J) is [12]:

$$E_{PRIM}=R_{EL}(E_{PV}+E_{COLL})-C_m((E_{em,\ PV} + E_{em,\ COLL})C_{inst})-C_{m1}E_{em,\ ISO}$$

where: R_{EL} = 3.04 – primary conversion multiplier; E_{PV} – yearly electrical energy generated by PV array (J); E_{COLL} – yearly heat energy generated by solar collectors (J); $_{Eem,\ PV}$ – PV array embodied energy (J); $E_{em,\ COLL}$ – solar collectors embodied energy (J); Cm=1/LC; where LC is life cycle of PV and solar collectors, in years, $C_{m1}=1/LC_{ISO}$; where LC_{ISO} is life cycle of thermal isolations, in years, $_{Eem,\ ISO}$ – insulation embodied energy (J) [12] and C_{inst} – coefficient of instalation and maitenance of solar systems during their life cycle [13].

6. Results and discusion

Exergy optimization (including embodied exergy) was performed with the aim to determine the maximum value of the exergy efficiency. The residential building with electrical space heating and with variable cell efficiency of PV array was analyzed. The first case is the PV array with 12 % of cell efficiency, the second case is the PV array with 14 % and the third case is PV array with 16 % of cell efficiency, respectively. Total annual energy consumption of the building was 68.36 GJ (final energy), i.e. 207.81 GJ (primary energy). The results obtained by exergy optimization are shown in Table 1.

Table 1 – The results obtained by exergetic optimization, for residential building with varieble cell efficiency of PV array

	PV cell efficiency		
	12 %	14 %	16 %
η_x – exergy efficiency without embodied exergy (%)	12,64	14,71	16,78
$\eta_{x, EE}$ – exergy efficiency with embodied exergy (%)	7,63	9,71	11,78
e_x – ratio between required and obtained exergy (without embodied exergy)	1,075	0,9236	0,8095
$e_{x, EE}$ – ratio between required and obtained exergy (with embodied exergy)	1,78	1,4	1,153
$E_{x, POT}$ – total consumer exergy (GJ)	54,45	54,45	54,45
$E_{x, PV\text{-}KOL}$ – exeegy obtained by solar systems (without embidied exergy) (GJ)	50,65	58,96	67,26
$E_{x, PV\text{-}KOL, EE}$ – exeegy obtained by solar systems (with embidied exergy) (GJ)	30,6	38,91	47,21
E_{EL} – Total electricity consumption (GJ)	68,36	68,36	68,36
$E_{EL,PRIM}$ – Primary energy consumption (GJ)	207,81	207,81	207,81
Fraction of PV panels on the roof (%)	98,75	98,75	98,75
Generated energy (GJ)	55,68	64,42	73,17
Generated primary energy (GJ)	169,27	195,85	222,43
E_{PRIM}– avoided operative primary energy (GJ)	149,02	175,6	202,18
Building type (without embodied energy)	**NNEB**	**NNEB**	**PNEB**
Building type (with embodied energy)	**NNEB**	**NNEB**	**NNEB**

Acording the Table 1, it can be concluded that with the increasing of PV cell efficiency, there is a significant increase in both the exergy efficiency (with and without embedded exergy). Exergy efficiency η_x for PV cell efficiency of 12%, 14% and 16% are 12.64%, 14.71% and 16.78%, respectively, while the exergy efficiency $\eta_{x,EE}$ for the same values of PV cell efficiency are 7.63%, 9.71% and 11.78%, respectively. Preview of these two exergy efficiency is given in Figure 2.

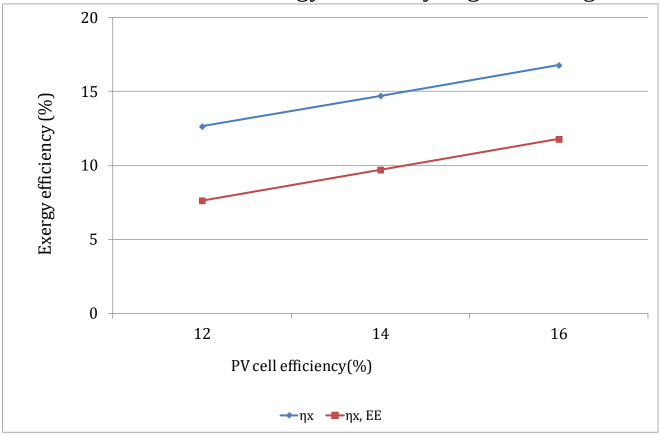


Figure 2 – Exergy efficiency for building with defferent cell efficiency

Ratio between required and obtained exergy e_x and $e_{x, EE}$ (with and without embodied exergy), decreases with increasing PV cell efficiency. For PV cell efficiency of 12%, 14% and 16%, the ratio of required and obtained exergy (without embodied exergy) is 1.075, 0.9236 and 0.8095, respectively, while the ratio between required and obtained exergy calculated with embodied exergy is 1.78, 1.4 and 1.153, respectively. It can be concluded that with the implementation of PV module with cell efficiency of 14% and 16%, can be achieved the values of ratio between required and obtained exergy which is less then 1 (e_x <1). This means that installed solar system generates more exergy than required exergy of all consumers in the building (without embodied exergy). The graphical representation of the required and obtained exergy for different PV cell efficiency is shown in Figure 3.

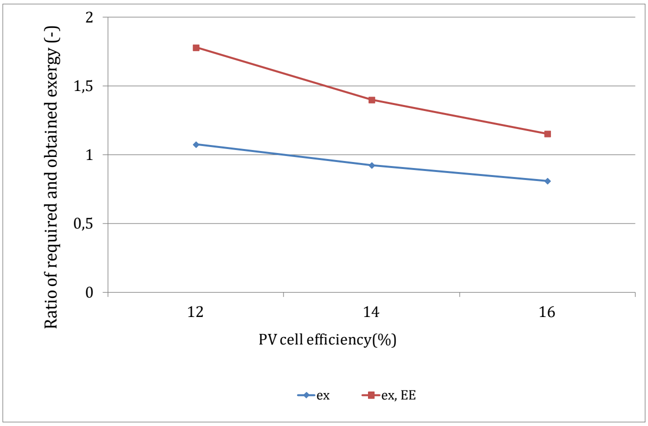


Figure 3 – Ratio between required and obtained exergy for building with defferent cell efficiency

Required exergy of all building consumers and exergy obtaned from solar systems (with or without embodied exergy) for different PV cell efficiency and electric heating system, are graphically shown in Figure 4. With PV cell efficiency increasing, exergy obtained from the solar system increases too. Required exergy in all the cases was the same – 54.45 GJ. Fraction of PV panels on the roof is the same for all the values of PV cell efficiency – 98.75 % (79.6 m^2 of PV array and 1 m^2 of solar collector). On this way, it can be generated 169.27 GJ of primary energy, while the avoided operative primary energy is 149.02 GJ annually.

Figure 5 represent total electricity consumption, primary energy consum–ption, generated primary energy and avoided operative primary energy consumption in building with different cell efficiency of PV array.

By using the PV array with 12 % and 14 % of cell efficiency, building will be NNEB (building type approach with and without embodied energy). By using the PV array with 16 % of cell efficiency, it is possible to achieve the concept of positi-ve-net energy building (PNEB) without embodied energy of installed solar systems and insulation. If it is taken into account, the building is negative-net energy building (NNEB). With 16 % PV cell efficiency, it is generated 222.43 GJ of primary energy, which is more than the energy demands of the building (207.81 GJ).

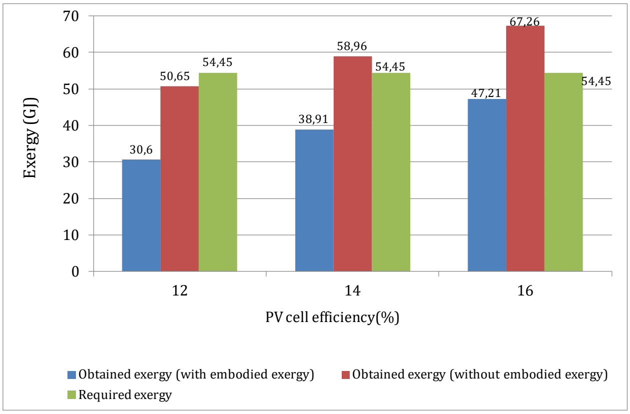


Figure 4 – Required and obtained exergy for building with defferent cell efficiency

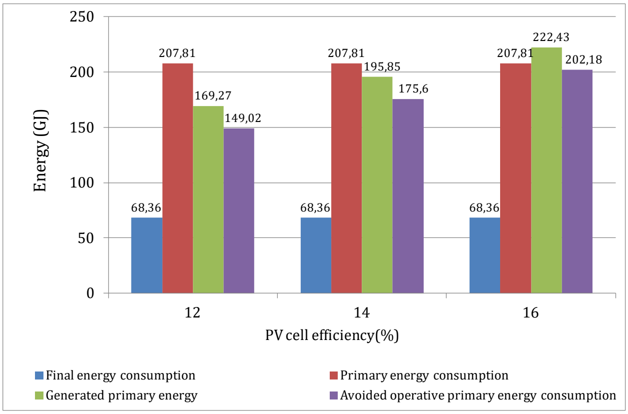


Figure 5 – Total electricity consumption, primary energy consumption, generated primary energy and avoided operative primary energy for buildings with different cell efficiency of PV panels (Yearly values)

7. Conclusion

In this paper exergy optimization was performed with the major aim to determine the maximum value of the exergy efficiency (without and with embodied exergy). On that way, the maximum value of the generated electricity can be achieved, and also primary energy consumption can be minimized. All considered buildings had electric heating system.

By using PV modules with greater cell efficiency (14% and 16%) it is possible to generate significantly greater amount of electrical energy compared with PV modules of cell efficiency 12%. With the increasing of PV cell efficiency, there is a significant increase in both the exergy efficiency (with and without embedded exergy).

Ratio between required and obtained exergy e_x and $e_{x, EE}$ (with and without embodied exergy), decreases with increasing PV cell efficiency. If the values of ratio between required and obtained exergy is less then 1 (e_x <1, case without embodied exergy), then installed solar system generates more exergy than required exergy of all consumers in the building.

By using the PV array with 14 % and 16 % of cell efficiency, building can produce more electricity, so the concept of PNEB can be achieved with PV cell efficiency of 16 % (approach without embodied energy).

Acknowledgement

This paper is a result of three projects: TR33015, III 42006, and COST action TU1205-BISTS. The projects TR33015 and III 42006 are financed by the Ministry of Education, Science, and Technological Development of Republic of Serbia. The COST action TU1205-BISTS is supported by EU. The authors thank to the all institutions for their financial support.

References

[1] **Koroneos C., Tsarouhis M**., Exergy analysis and life cycle assessment of solar heating and coling systems in the building enviromnent, *Journal of Cleaner Production, Volume 32*, 2012, p. 52-60

[2] **Johari D., Yadav A., Verma R.,** Study of solar water heaters based on exergy analysis, *Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, Faridabad, Haryana, 2012*

[3] **Anonymous,** ENERGYPLUS, Input Output Reference – The Encyclopedic Reference to EnergyPlus Input and Output, University of Illinois & Ernest Orlando Lawrence Berkeley National Laboratory, 2009

[4] **Henninger R.H., Witte M.J., Crawley D.B**., Analytical and comparative testing of EnergyPlus using IEA HVAC BESTEST E100-E200 test suite, Energy and Buildings 36 (8), (2004), p. 855–863.

[5] Lawrence Berkeley National Laboratory. EnergyPlus – Engineering documentation: the reference to EnergyPlus calculations. University of Illinois & Ernest Orlando Lawrence Berkeley National Laboratory; 2001.

[6] **Bojić M., Skerlić J., Nikolić D., Cvetković D., Miletić M**, Toward future: positive net-energy buildings, *Proceedings 4thRenewable Energy Sources, EXPRES 2012*, March 9-10, 2012., Subotica, Serbia, p. 49-54 IEEE International Symposium on Exploitation of

[7] **Wetter, M**., 2004. GenOpt, Generic Optimization Program. User Manual, Lawrence Berkeley National Laboratory, Technical Report LBNL– 54199, p. 109.

[8] **Hooke R., Jeeves T.A**., Direct search solution of numerical and statistical problems, *Journal of the Association for Computing Machinery, Volume 8* (1961), pp. 212–229

[9] **Alsema, E.A., Nieuwlaar, E.,** Energy viability of photovoltaic systems, *Energy Policy, Volume 28(14),* 2000, pp. 999–1010

[10] **Alsema E.A**., Energy pay-back time and CO2 emissions of PV systems, *Progress in Photovoltaics: Research and Applications 8(1),* (2000), pp. 17–25

[11] **Nikolić D.,** Energetsko-eksegetska optimizacija veličina fotonaponskih panela i solarnih kolektora kod kuća neto-nulte potrošnje energije, Doktorska disertacija, Fakultet inženjerskih nauka Univerziteta u Kragujevcu, Kragujevac, 2015.

[12] **Nikolić D.,** Bojić M., Skerlić J., Radulović J., Energy optimization of serbian buildings with solar collectors and different pv systems, CD Conference proceedings и Зборник радова, ISBN 978-86-81505-79-3, 4*6th International HVAC&R congress*, Beograd, decembar 2015.

[13] **Cabeza L.F., Rincón L., Vilariño V., Pérez G., Castell A**., Life cycleassessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review, *Renewable and Sustainable Energy Reviews, Volume 29*, 2014, 394–416

GREE

Go Green With GREE

Prvi svetski fotonaponski VRF sistem

NO WASTE
Five operation modes can be switched at real time to supply residual power to the national grid.

NO ELECTRIC CHARGE
Adopt photovoltaic power generation for perfect combination of photovoltaic power and home appliances. The photovoltaic VRF system is not just an engine that runs on power but also a machine that provides it.

NO WORRY
Reliable operation with inverter technology for wider application range.

Ekskluzivni distributer ENERGYNET

www.energynet.rs