

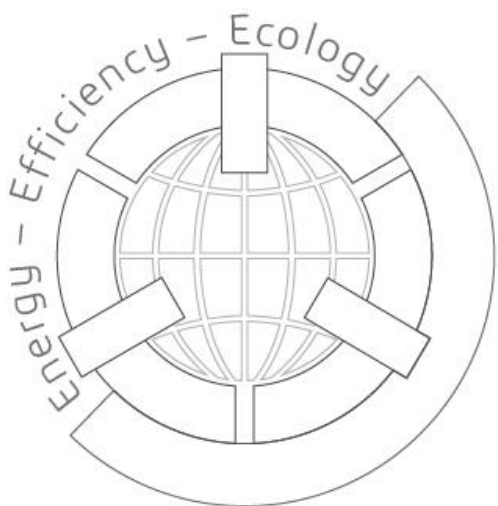
SimTerm 2019



PROCEEDINGS

**19th International Conference on
Thermal Science and Engineering of Serbia**

Sokobanja
October 22-25
2019



SimTerm 2019

PROCEEDINGS

19th International Conference on
Thermal Science and Engineering of Serbia

Sokobanja, Serbia, October 22 – 25, 2019

University of Niš, Faculty of Mechanical Engineering in Niš, Department of
Thermal Engineering and Society of Thermal Engineers of Serbia

ISBN 978-6055-124-7

Publisher: Faculty of Mechanical Engineering in Niš

2019

19th International Conference on Thermal Science and Engineering of Serbia

under the title

Energy – Ecology – Efficiency

is organized by

UNIVERSITY OF NIŠ, FACULTY OF MECHANICAL ENGINEERING IN NIŠ,
DEPARTMENT OF THERMAL ENGINEERING and

SOCIETY OF THERMAL ENGINEERS OF SERBIA

under the patronage of the

GOVERNMENT OF THE REPUBLIC OF SERBIA

MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT

CITY OF NIŠ

and supported by donors and sponsors

ELECTRIC POWER INDUSTRY OF SERBIA

OVEX

ICNT

NIGOS ELEKTRONIK

WILO

HERZ

SD CRVENI KRST NIŠ

GOVERNMENT OF THE REPUBLIC OF SERBIA



MINISTRY OF EDUCATION, SCIENCE AND
TECHNOLOGICAL DEVELOPMENT

MINISTRY OF MINING AND ENERGY



ЕЛЕКТРОПРИВРЕДА СРБИЈЕ



**19th International Conference on
Thermal Science and Engineering of Serbia**

International Scientific Committee

Dr Jordan Hristov, University of Chemical Technology and Metallurgy, Department of Chemical Engineering, Sofia, Bulgaria

Dr Gligor Kanevče, Macedonian Academy of Sciences and Arts, Skopje, North Macedonia

Dr Mikhail Shatrov, Moscow Automobile and Road Construction State Technical University, Moscow, Russia

Dr Zvonimir Guzović, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia

Dr Igor Vušanović, University of Montenegro, The Faculty of Mechanical Engineering, Podgorica, Montenegro

Dr Anna Stoppato, University of Padova, Department of Industrial Engineering, Padova, Italy

Dr Slavtcho G. Slavtchev, Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Dr Agis Papadopoulos, Aristotle University Thessaloniki, Department of Mechanical Engineering, Thessaloniki, Greece

Dr Joseph N. Moore, University of Utah, Energy & Geoscience Institute, Salt Lake City, USA

Dr Konstantinos Papakostas, Aristotle University Thessaloniki, Department of Mechanical Engineering, Thessaloniki, Greece

Dr Sophia Natalia Boemi, Aristotle University Thessaloniki, Department of Mechanical Engineering, Thessaloniki, Greece

Dr Petar Novak, University of Novo mesto, Faculty of mechanical engineering, Novo mesto, Slovenia

Dr Iliya Iliyev, University of Ruse, Department of Thermotechnics, Hydraulic and Ecology, Ruse, Bulgaria

Dr Dušan Golubović, University of East Sarajevo, Faculty of Mechanical Engineering, Sarajevo, Republic of Srpska, Bosnia and Herzegovina

Dr Ljubica Kanevče, St. Kliment Ohridski University, Faculty of Technical Sciences, Bitola, North Macedonia

Dr Petar Gvero, University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

Dr Maria Ichim, Institute for Bioengineering, Biotechnology and Environmental Protection, Bucharest, Romania

Dr Vesna Barišić, Sumitomo SHI FW, Espoo, Finland

Dr Dečan Ivanović, University of Montenegro, The Faculty of Mechanical Engineering, Podgorica, Montenegro

Dr Friedrich Dinkelacker, Leibniz University Hannover, Faculty of Electrical Engineering and Computer Science, Hannover, Germany

Dr Risto Filkoski, Ss. Cyril and Methodius University, Faculty of Mechanical Engineering, Skopje, North Macedonia

Dr Tetyana Morozyuk, Technical University Berlin, Institute for Energy Engineering, Berlin, Germany

Dr Zlatan Čar, University of Rijeka, Faculty of Engineering, Rijeka, Croatia

Dr Darko Knežević, University of Banja Luka, Faculty of Mechanical Engineering, Republic of Srpska, Banja Luka, Bosnia and Herzegovina

Dr Gyula Gróf, Department of Energy Engineering Hungary, Budapest, Hungary

Dr Zdravko Milovanović, University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

Dr Breda Kegl, University of Maribor, Faculty of mechanical engineering, Maribor, Slovenia

Dr Vladimir G. Tuponogov, Ural Federal University named after the first President of Russia B. N. Yeltsin, Ekaterinburg, Russia

Dr Vladimir Mijakovski, St. Kliment Ohridski University, Faculty of Technical Sciences, Bitola, North Macedonia

Dr Violeta Rasheva, University of Food Technology Plovdiv, Department of Industrial Thermal Engineering, Plovdiv, Bulgaria

Dr Oleh Onysko, Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine

Dr Lubomir Dimitrov, Technical University of Sofia, Sofia, Bulgaria

Dr Birol Kilis, Turkish Society of HVAC & Sanitary Engineers, Ankara, Türkiye



SimTerm 2019

Sokobanja
October 22-25
2019

**19th International Conference on
Thermal Science and Engineering of Serbia**



Program Committee

Dr Mladen Stojiljković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Milan Radovanović, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Dr Simeon Oka, University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia
Dr Miloš Banjac, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Dr Dragoslava Stojiljković, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Dr Predrag Stefanović, University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia
Dr Miodrag Mesarović, Serbian World Energy Council member committee, Belgrade, Serbia
Dr Dušan Gvozdenac, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
Dr Milun Babić, University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia
Dr Vladan Karamarković, University of Kragujevac, Faculty of Mechanical and Civil Engineering, Kragujevac, Serbia
Dr Maja Todorović, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Dr Dragoljub Živković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Dragan Pantić, University of Niš, Faculty of Electronic Engineering, Niš, Serbia
Dr Velimir Strefanović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Borislav Grubor, University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia
Dr Valentino Stojkovski, Ss. Cyril and Methodius University, Faculty of Mechanical Engineering, Skopje, North Macedonia
Dr Maja Đurović Petrović, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
Dr Mirjana Laković-Paunović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Mića Vukić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Vukman Bakić, University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia
Dr Dejan Ivezić, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia
Dr Uroš Karadžić, University of Montenegro, The Faculty of Mechanical Engineering, Podgorica, Montenegro
Dr Jelena Janevski, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Predrag Živković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia

Honorary Committee

Dr Mladen Stojiljković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Nenad T. Pavlović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Vlastimir Nikolić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Slobodan Laković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Nenad Radojković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Gradimir Ilić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Zoran Boričić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Žarko Stevanović, University of Belgrade, Vinča Institute of Nuclear Sciences, Belgrade, Serbia



SimTerm 2019 | Sokobanja
October 22-25
2019
**19th International Conference on
Thermal Science and Engineering of Serbia**



Organizing Committee

Dr Mirjana Laković-Paunović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Dejan Mitrović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Mirko Stojiljković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Marko Ignjatović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Branislav Stojanović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Mića Vukić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Jelena Janevski, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Goran Vučković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Predrag Živković, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Miloš Tasić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Milica Jovčevski, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Saša Pavlović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dr Marko Mančić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Dragana Dimitrijević Jovanović, Innovation Centre of Advanced Technologies, Niš, Serbia
Dr Ivan Pavlović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Jovan Škundrić, University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, Republic of Srpska, Bosnia and Herzegovina
Danijela Stanisavljević, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Jovan Milić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Marko Vučetić, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
Katarina Jovanović, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia



Contents

International Scientific Committee	4
Program Committee	5
Honorary Committee	5
Organizing Committee	6
1. PLENARY SESSION	18
District heating system in EU-28	19
Miloš Banjac and Mirjana Laković	19
A Forced Transition to 100% Renewable Energy	30
Miodrag Mesarović	
2. ENERGY EFFICIENCY AND RATIONAL ENERGY USAGE	44
Influence of Processing Oil Properties on Rubber Hardness and Power Consumption	
Dragan Govedarica, Novica Sovtić, Predrag Kojić, Olga Govedarica, Jelena Pavličević and Mirjana Jovičić	45
Energy Efficiency of Pneumatic Cylinder Control with Clamping Unit and Different Levels of Compressed Air Pressure	55
Vladislav Blagojević, Dragan Šešlija, Slobodan Dudić and Saša Ranđelović	55
Influence of Orientation and Architectural Design of Thermal Envelope on Energy Demand of Buildings in Climatic Conditions in Niš, Serbia	
Ivana Bogdanović Protić, Miomir Vasov, Dušan Ranđelović, Veliborka Bogdanović and Dragan Kostić	
A Comparison of the Embodied Carbon for Three Common Models of Building Family Housing – Case Study of Building Construction in Serbia	72
Marina Nikolić Topalović, Ana Momčilović, Zora Aleksić and Gordana Stefanović	72
Possibilities of Energy Efficiency Measure Implementation in Residential Sector	
Jelena Ogrizović and Erol Rožajac	
Analysis of the Outdoor Thermal Comfort: The Case Study of Multi-family Housing Area in Nis, Serbia	99
Ana Stanojević, Miomir Vasov, Veliborka Bogdanović and Branko Turnšek	99
Impact of Heat Exchanger and Heat Pumps on COP in Heat Recover System	113
Jozsef Nyers, Arpad Nyers, Daniel Stuparic and Laszlo Kajtar	113
Investigation of Green Roof Thermal Performance in The Summer Period	121
Biljana Vučičević, Danka Kostadinović, Nenad Stepanić, Marina Jovanović and Valentina Turanjanin	
3. TECHNOLOGIES AND PLANTS	126
Hypothetical Replacement of Slovenian Coal-Fired Thermal Power Plants with Photo-Voltaic Pumped-Storage Hydroelectric Power Plant	127
Igor Kuštrin and Andrej Senegačnik	127



<u>The Influence of Air Temperature on Aerodynamic and Acoustic Characteristics of Low-pressure Centrifugal Fans</u>	138
Jasmina Bogdanović-Jovanović, Živojin Stamenković, Miloš Kocić and Jelena Petrović	138
<u>Increasing Efficiency of The Coal Boilers with Improvement Sealing of The Regenerative Air Heater</u>	150
Lidija Joleska Bureska	
<u>Modeling of direct Co-Firing Lignite with Agricultural Residues in a 350 MWe Boiler Furnace</u>	157
Aleksandar Milićević, Srđan Belošević, Ivan Tomanović, Nenad Crnomarković and Dragan Tucaković	157
<u>Analysis of Influential Parameters on the Efficiency of the Solar Cooling Absorption System</u>	167
Lejla Ramić, Sandira Eljšan, Izet Alić and Indira Buljubašić	167
<u>Influence of The Selected Turbulence Model on The Lift and Drag Coefficients of Parametric Developed Geometry of 4 Digit NACA Hydrofoil</u>	
Filip Stojkovski and Aleksandar Noshpal	178
<u>Development of Pre-drying Procedures of Low-rank Coals to Increase Efficiency of Coal Fired Power Plant</u>	189
Milić Erić, Zoran Marković, Predrag Stefanović, Rastko Jovanović and Nikola Živković	
<u>Experimental Investigation of an 18-kW-Wood-Log-Fired Gasification Boiler</u>	201
Rade Karamarković, Đorđe Novčić, Anđela Lazarević, and Miloš Nikolić	201
<u>Quenching of Premixed Counter Flame at Different Nozzles Angle for Burner</u>	210
Hasanain Abdul Wahhab and Sadoon Ayed	210
<u>Problems of Accuracy of Tapered Thread for Small Diameter Drill Pipe Connections</u>	216
Iuliia Medvid, Oleh Onysko, Lolita Pitulei, Iryna Shuliarr and Yurii Havryliv	216
<u>Furnace Sorbent Injection and Effects on Furnace Operation Under Reduced Boiler Load</u>	222
Ivan Tomanović, Srđan Belošević, Nenad Crnomarković and Aleksandar Milićević	222
<u>An Initial Study on Adopting A Small-Scale Pellet Stove as A Generator in A Gas Absorption Heat Pump to Replace Gas (Propane Butane) Consumption with Biomass -Pellet</u>	230
Marko Ilić, Velimir Stefanović and Gradimir Ilić	230
<u>Possibilities of Absorption Cooling Usage – A Review</u>	238
Milan Grozdanović and Milica Jovčevski	238
<u>Material Selection of Wave Energy Extraction Turbine Blade</u>	245
Dušan Petković, Miloš Madić and Goran Radenković	245
<u>Performance Analysis of a Pellet Stove with Turbulator Installments</u>	253
Milica Jovčevski, Marjan Jovčevski, Filip Stojkovski and Mirjana Laković-Paunović	253
4. NEW AND RENEWABLE ENERGY SOURCES	260
<u>Geothermal Energy Potential of the North R. Macedonia Geospace</u>	
Tomislav Petrovski and Biserka Dimishkovska	261
<u>Energy and Exergy Design of a Solar Thermal System with Phase Change Materials</u>	269
Saša Pavlović, Evangelos Bellos, Mirjana Laković-Paunović, Bojan Drobnjaković and Christos Tzivanidis	
<u>The Economic Impact of Climate Change on the HPS Mavrovo</u>	279
Martin Panajotov and Vlatko Cingoski	279
<u>Energy Analysis of Solar Greenhouse with Photovoltaic System and Heat Pump</u>	292



Danijela Nikolić, Vanja Šušteršič, Mladen Josijević and Živan Spasić	292
Potentials and Possibilities of Using Renewable Energy Sources	303
Borislav Grubor, Branislav Repić and Aleksandar Erić	303
Status of Renewable Energy Sources Utilization in Republic of Serbia With an Overview of Biogas Potential	315
Milan Grozdanović, Saša Pavlović, Velimir Stefanović and Branka Nakomčić-Smaragdakis	315
Future of PV Systems Application in Serbia	329
Filip Kanacki	329
Influence of Stable Data Location on Wind Energy Prediction	335
Predrag Živković, Mladen Tomić, Filip Mojsovski, Cristian Barz, Dragana Dimitrijević Jovanović and Petar Cajić	335
A Systems Approach to Techno-Economic Analysis of The Justifiedness of Heat Pump Heating Using an Example of A Residential-Commercial Building	342
Velimir Stefanović, Saša Pavlović, Dejan Krstić and Jelena Malenović-Nikolić	342
5. FLOW, HEAT AND MASS TRANSFER, COMBUSTION	349
Heat Transfer in Greenhouse Whose Transparent Walls Protected with A Protective Film	350
Kire Popovski, Sevdie Stavreva, Ivo Kuzmanov and Igor Popovski	350
MHD Fluid Flow and Heat Transfer of Immiscible Viscous and Micropolar Fluid between Inclined Plates	354
Miloš Kocić, Živojin Stamenković and Jelena Petrović	
Drying Conditions for Tomato Processing in Solar Dryer	366
Filip Mojsovski, Vladimir Mijakovski and Igor Shesho	366
Temperature Variation for The Inclined Upper Wall Convectional Instability	371
Sadoon Ayed, Amir Alsammarraie and Hasanain Abdul Wahhab	
Labyrinth Seal Study for Explosive Atmosphere Leakage and Combustion Isolation	377
Răzvan Bimbaşa, Iulian Vlăduţă, Ion Malăel, Sorin Tomescu and Dan-Mihail Marin	377
Analysis of the Thermal Efficiency in CO₂ Laser Cutting of Stainless Steel and Some Optimization Aspects	383
Miloš Madić, Predrag Janković, Marin Gostimirović, Dušan Petković and Miroslav Radovanović	383
Heat Release Rate of Fire in Road Tunnels	393
Milica Jovčevski, Dragana Dimitrijević Jovanović, Emina Petrović, Dragoljub Živković, Predrag Živković and Ivan Pavlović	393
Investigation of Leakage impact on the Intensity of Heat Transfer in Shell and Tube Heat Exchanger	403
Mića Vukić, Predrag Živković, Mladen Tomić and Goran Vučković	403
6. EXAMINATION OF OPERATING PLANTS AND EXPERIMENTAL EXAMINATION OF PROCESSES	409
Drying of CuSO₄ Solutions in a Fluidized Bed of Inert Material	410
Mihal Đuriš, Tatjana Kaluđerović Radoičić, Darko Jaćimovski and Zorana Arsenijević	410
Determination of Polycyclic Aromatic Hydrocarbons in Biomass Ash from Cigar Burner Combustion Systems	420
Ana Marinković, Jovana Buha-Marković, Jasmina Savić, Milica Mladenović, Branislav Repić and Stevan Nemoda	420



Tests on The Feasibility of The Combustion of An Animal Fat-Light Hydrocarbons Mixture in A 55 Kw Residential Heating Appliance	431
Gheorghe Lăzăroiu, Lucian Mihăescu, Gabriel-Paul Negreanu, Ionel Pîșă, Andreya-Dana Bondrea and Viorel Berbece	431
Experimental and Numerical Analysis of Stresses in the Tube Plate of the Reversing Chamber on the Model of the Boiler	439
Milena Rajić, Dragoljub Živković, Milan Banić, Marko Mančić, Taško Maneski, Miloš Milošević and Nenad Mitrović	439
Numerical Analysis of Hydrogen Fueled IC Engine	450
Ivan Grujić, Jovan Dorić, Nadica Stojanović, and Oday Abdullah	450
Experimental and Numerical Investigation of Biomass Combustion in a Vertical Tubular Reactor	457
Aleksandar Erić, Stevan Nemoda and Branislav Repić	457
Problem of Gas Distribution in Electrostatic Precipitators of Unit A4 in TPP Nikola Tesla	
Zoran Marković, Milić Erić, Predrag Stefanović and Dejan Cvetinović	470
7. MATHEMATICAL MODELING AND NUMERICAL SIMULATION	486
The Influence of Vertical Forces According Two-Phase Turbulent Flow in Straight Horizontal Channels with a Square Cross-Section	487
Saša Milanović, Vladislav Blagojević, Miloš Jovanović and Boban Nikolić	487
The Numerical Simulation of the Friction Heat Generation on the Contact of Bodies with the Surface Roughness	496
Miroslav Mijajlović, Dušan Ćirić, Sonja Vidojković and Jelena Mihajlović	496
Zdravko Milovanović, Mirjana Laković-Paunović, Svetlana Dumonjić-Milovanović, Aleksandar Milasinović and Darko Knežević	508
MHD Mixed Convection Flow Through Porous Medium in an Inclined Channel	
Jelena Petrović, Živojin Stamenković, Miloš Kocić, Milica Nikodijević and Jasmina Bogdanović-Jovanović	526
CFD Modelling of the Two Phase Flow and Heat Transfer in Vertical Steam Generator Using Different Models for Interfacial Friction	535
Marija Gajević, Milada Pezo, Milan Petrović, Ivan Joksimović and Vladimir Stevanović	535
CFD Simulation of Indoor Air Temperature Inside Typical School Classroom in Serbia	547
Ivan Lazović, Valentina Turanjanin, Marina Jovanović, Rastko Jovanović and Biljana Vučićević	547
Application Extended Integral-differential Method for Research Mixed MHD Boundary Layer on a Body Embedded in a Porous Medium	558
Aleksandar Boričić and Slobodan Savić	
Integral Equations of the MHD Dynamic, Temperature and Diffusion Boundary Layer and their Application to Researched Concrete Flow	
Aleksandar Boričić and Miloš Jovanović	571
CFD Modelling for Predicting the Performance of An Axial Pump	582
Filip Stojkovski, Valentino Stojkovski and Tomi Ognjanovski	582
Numerical Investigation of the Convective Heat Transfer in Spirally Coiled Corrugated Pipes	592
Milan Đorđević, Marko Mančić and Velimir Stefanović	592



Numerical Study of Natural Convection Heat Transfer in Roof with Above-sheathing Ventilation Air Space	601
Goran Vučković and Milan Banić	601
Computational Performance Analysis of a Rotary Type Tri-Rotor Air Compressor Undergoing a Polytropic Process	609
Tutar Mustafa, Üstün Cihat Emre and Mutlu Hüseyin	609
Experience and Applications of Pinch Technology in Cases of Industrial Heat Integration of Solar Thermal Energy and Organic Rankine Cycle	622
Aleksandar Anastasovski, Almir Sedić, Predrag Rašković, Zvonimir Guzović and Tina Gegovska	622
Numerical Investigation of Structural Behavior of a Symmetrical Airfoil	634
Marija Lazarević, Valentino Stojkovski and Aleksandar Noshpal	634
Modeling and Simulation of a Hydraulic System under Conditions of the Stick-Slip Effect Occurrence and Its Removal	645
Darko Babunski, Emil Zaev, Atanasko Tuneski and Radmila Koleva	645
8. ENVIRONMENTAL PROTECTION, WATER, AIR AND SOIL QUALITY MANAGEMENT	652
Air Quality in R. North Macedonia	653
Biserka Dimishkovska and Tomislav Petrovski	653
In Situ Measurements of Pollutants Emissions from Individual Coal and Briquette Fired Furnaces in Pljevlja	660
Vladan Ivanović, Esad Tombarević and Milan Šekularac	660
Review of Major Greenhouse Gas Emissions in Skopje	
Monika Lutovska, Vladimir Mijakovski, Filip Mojsovski and Igor Shesho	668
Robotics in Waste Recycling	675
Emina Petrović, Nevena Tomić, Miloš Simonović and Sadoon Ayed	675
The Flow of Recycling Construction Plastics Waste	681
Zorica Eraković, Snežana Ilić-Stojanović and Stanko Žerajić	681
Reducing Pool Turnover Rates in Aquatic Centers	685
Z Paul Rhodes III	685
N-Methyl-2-Pyrrolidone (NMP), Organic Solvent for Sulfur-Dioxide Removal, Thermophysical Properties, and SO₂ Solubility	700
Nikola Živković, Milić Erić, Zoran Marković and Predrag Stefanović	700
Increase the Energy Efficiency at Run-Of River HPP With Inclusion of Small and Spilled Water	709
Ejup Bekiri, Valentino Stojkovski and Darko Mickoski	709
Reconstruction of Labyrinth Seals of The Turbine in HPP Vrben	718
Aleksandar Levkoski, Valentino Stojkovski and Stojce Ilievski	
Experimental and Numerical Study of The Selective Non-Catalytic Denitrification of Flue Gases Produced by Biomass Combustion	727
Milica Mladenović, Ana Marinković, Jasmina Savić and Stevan Nemoda	727
Point Source Pollution in the City of Niš	738
Predrag Živković, Mladen Tomić, Mića Vukić, Cristian Barz, Dragana Dimitrijević Jovanović and Petar Cajić	738
The Impact of School Building Green Roof on Outdoor Air Pollution	748
Danka Kostadinović, Marina Jovanović, Biljana Vučićević, Nikola Mirkov and Valentina Turanjanin	748



9. AUTOMATIZATION AND CONTROL OF PROCESSES **755**

<u>Extreme Learning Approach for Carbon Dioxide Emission Prediction</u>	756
Miloš Milovančević and Dalibor Petković	756
<u>Development of Methodology for Preventive Maintenance of Turbine and Hydromechanical Equipment at Hydro Power Plants</u>	763
Miodrag Arsić, Srđan Bošnjak, Vencislav Grabulov, Mladen Mladenović and Zoran Savić	763
<u>Modeling and Simulation of a Hydraulic System under Conditions of the Stick-Slip Effect Occurrence and Its Removal</u>	769
Darko Babunski, Emil Zaev, Atanasko Tuneski and Radmila Koleva	769
<u>Managing the Turbine Discharges of Hydro Cascade Power System in Electricity Market Environment</u>	776
Anton Chaushevski, Sofija Nikolova Poceva, Valentino Stojkovski, and Zoran Markov	776
<u>The Influence of the Temperature Change on the Force in the Hydraulic Brake of the Artillery System</u>	784
Dejan Jevtić, Dejan Micković, Slobodan Jaramaz, Predrag Elek and Miloš Marković	784
<u>Use of Vibration Technologies for Ensuring Quality Parameters of Products Surfaces</u>	794
Yaroslav Kusyi, Andrij Kuk and Olha Kostiuik	794
<u>Analysis of Longitudinal Oscillations of Piezoceramic Cantilever with Electrode Coatings</u>	801
Igor Jovanović, Ljubiša Perić, Uglješa Jovanović and Dragan Mančić	801
<u>Application of Rooftop Photovoltaics in Cooling and Freezing Facilities</u>	808
Marko Mančić, Dragoljub Živković, Mirjana Laković Paunović, Milan Đorđević, Bojana Vukadinović and Milena Rajić	808

10. ENERGY MANAGEMENT IN INDUSTRY AND BUILDINGS **820**

<u>Consumption Management of Natural Gas for Combustion in The Burner of The Tunnel Furnace for Baking of Brick Products in Igm Neimar Zrenjanin</u>	
Duško Salemović, Matilda Lazić, Aleksandar Dedić and Dragan Halas	821
<u>Implementation of Energy Efficiency Directive in the Republic of Croatia Legislation</u>	828
Ružica Budim, Danica Maljković	828
<u>Development of Intelligent System for Forecasting Natural Gas Consumption in the District Heating System</u>	836
Nedeljko Dučić, Milan Marjanović, Snežana Dragičević, Vojislav Vujučić, Ivan Milićević and Marko Popović	836
<u>Business Models for Small-scale Biomass Projects Development</u>	843
Dejan Ivezić, Miodrag Gluščević and Marija Živković	843
<u>At the Technology Level Settled Indicators for Energy Technologies Competitiveness Assessment</u>	848
Vojin Grković and Đorđije Doder	848
<u>Technical Criteria in Tendering Conditions Refer Efficiency of Construction at A Hydro Power Plant</u>	858
Duško Dimitrovski and Valentino Stojkovski	858
<u>Managing the Turbine Discharges of Hydro Cascade Power System in Electricity Market Environment</u>	866
Anton Chaushevski, Sofija Nikolova Poceva, Valentino Stojkovski and Zoran Markov	866
<u>A Model for Prediction of Electricity Consumption of Industrial Installations</u>	874



Mirjana Laković-Paunović, Miloš Banjac, Ivan Pavlović and Marko Mančić	874
<u>The Influence of The Change in The Base Temperature on The District Heating End User Heat Supply Price</u>	885
Mirjana Laković-Paunović, Miloš Banjac, Ivan Pavlović, Marko Mančić	885
<u>Applications of the Monte Carlo Simulation Method in energy management</u>	894
Ivan Pavlović, Mirjana Laković-Paunović, Marko Mančić and Milena Rajić	894
<u>Manual for disposal of waste wood biomass for small and medium enterprises of the Nish region</u>	900
Iva Nikolić, Katarina Jovanović, Jovan Milić, Marko Vučetić, Jelena Janevski and Marko Mančić	900
<u>Analysis of Biomass Potentials in The Territory of Niš</u>	910
Iva Nikolić, Katarina Jovanović, Jovan Milić, Marko Vučetić and Mirjana Laković-Paunović	910
11. ENERGY AND ENVIRONMENTAL ASPECTS OF TRANSPORT	918
<u>Determination of the Optimal Strategy for Preventive Maintenance the Vehicle Transmission's</u>	919
Vojislav Krstić and Božidar Krstić	919
<u>Research of the Influence of Alternative Fuels on Diesel Engine Noise Level</u>	928
Mikhail Shatrov, Andrey Iakovenko, Andrey Dunin and Vladimir Sinyavski	928
<u>Reduction of the Costs Influences in an Initial Solution of the Transportation Problem</u>	935
Predrag Rajković and Ana Kitić	935
<u>A One-Zone Model for Diesel, Gas Diesel and Gas Engine Simulation and Its Use for Development of a Gas Diesel Engine</u>	940
Mikhail Shatrov, Vladimir Sinyavski, Andrey Dunin, Ivan Shishlod, Andrey Vakulenko and Sergey Skorodelov	940
<u>The Influence of Air Distribution System Design and Setting in Agricultural Tractor Cab on The Operator's Thermal Sensation</u>	948
Dragan Ružić and Mirko Simikić	948
<u>Comparison of Two Models of Human Thermal Sensation in an Agricultural Tractor Cab</u>	960
Dragan Ružić, Jovanka Lukić, Jasna Glišović and Slavica Mačužić	960
<u>Simulation of Turbocharged Heavy-Duty Diesel Engine</u>	971
Jovan Dorić, Ivan Grujić and Nadica Stojanović	971
<u>Effect of Changes in Compression Ratio upon Experimental Diesel Engine Performance</u>	976
Saša Milojević, Radivoje Pešić, Aleksandar Davinić, Tomaš Skrucany and Dragan Taranović	976
<u>Investigation of Biofuel Combustion Process in Direct Injection Diesel Engine</u>	986
Dragan Knežević, Velimir Petrović, Željko Bulatović and Vlada Stajić	986
<u>Influence of biodiesel on the performance of diesel fuel injection system</u>	993
Boban Nikolić, Breda Kegl, Miloš Jovanović, Saša Milanović and Jovan Dorić	993
<u>Recommendations for organized and energy efficient use of biomass under the KeepWarm international project</u>	1000
Milica Mladenovića, Goran Živković, Biljana Vučićević	1000

Energy Analysis of Solar Greenhouse with Photovoltaic System and Heat Pump

Danijela Nikolić^a(CA), Vanja Šušteršič^b, Mladen Josijević^c and Živan Spasić^d

^aFaculty of engineering University of Kragujevac, Kragujevac, RS, danijelan@kg.ac.rs

^bFaculty of engineering University of Kragujevac, Kragujevac, RS, vanjas@kg.ac.rs

^cFaculty of engineering University of Kragujevac, Kragujevac, RS, mladenjosijevic@gmail.com

^dFaculty of mechanical engineering University of Niš, Niš, RS, zivans@masfak.ni.ac.rs

Abstract: Greenhouses have significant importance in the field of agriculture and horticulture. A special type of greenhouse is solar greenhouse, which is designed to collect solar energy during sunny days and to store heat for use at night or during periods without the Sun. In this paper it is investigated a solar greenhouse with photovoltaic panels. For greenhouse heating in the winter period and cooling in the summer period, a ground source heat pump was used. Solar greenhouse is simulated in EnergyPlus environment, while Open Studio plug-in in Google SketchUp was used for greenhouse design. Energy analysis was performed with the major aim to minimize greenhouse energy consumption, and to achieve solar greenhouse with net-zero energy consumption. Cases of different solar greenhouse orientations, different photovoltaic slope and different photovoltaic cell efficiency were considered. The simulation results showed that total energy consumption for heating and cooling of the greenhouse can be significantly reduced by using the optimal parameters (orientation and photovoltaic slope angle). Also, by changing the photovoltaics area and by using photovoltaics with higher cell efficiency, a concept of net-zero energy solar greenhouses can be achieved.

Keywords: Solar greenhouse, Photovoltaic, Heat pump, Energy consumption.

1. Introduction

The rapid population increase over the last two centuries has caused a major economic development, which influenced more energy consumption in the world. In recent years, question of energy security and stability has become the cardinal question of the entire world economy, economic and social system. The whole world today is faced with a problem of reducing the global warming due to the growing use of fossil fuels. In the energy sector, the most important mechanisms for the fight against climate change are generally known - increasing energy efficiency and the introduction of renewable energy sources.

Agriculture has relatively small share in total final energy consumption in both, industrialized and developing countries. Modern agriculture requires energy use at all stages of agricultural production: water management, irrigation, cultivation, harvesting and also farm machinery. In OECD countries around 3-5% of total final energy consumption is used directly in the agriculture sector, while in developing countries that range is 4-8% of total final commercial energy use [1]. According to the European energy statistics the total final energy consumption of the 27 EU countries of the sector "agriculture/forestry" was given as 1,071 PJ, which is corresponding to 2.2 % of the total final energy consumption in the European Union [2].

Greenhouses are widely used today all over the world, for indoor cultivation of vegetables, flowers, trees and other agricultural plants. They give better quality of plants and protect them from natural environmental effects such as wind or rain. At the other side, greenhouse is giving the ability for out of season growing. This type of agriculture is described as "protected agriculture" since it provides mechanical protections against outdoor climatic conditions [3]. Greenhouses are designed to provide control and maintain the amount of solar radiation, indoor air temperature, relative humidity and carbon dioxide levels in the aerial environment [4]. Significant amount of energy is necessary to greenhouse produce process and distribute the crops and plants and energy saving is an important issue for greenhouse farming. Application of solar energy in greenhouses could be of great importance, because it can reduce CO₂ emission and heating costs.

Solar greenhouse is a special type of greenhouse, which is designed not only to collect solar energy during sunny days but also to store heat for use at night or during cloudy periods. Overheating during the day can be prevented using natural or mechanical ventilation for cooling. Ventilation also regulates the relative air

humidity [5]. Solar greenhouse uses solar energy with passive or active systems. Passive solar greenhouses are a cost-efficient way for farmers to extend the growing season. Solar heating may be supplemented with some auxiliary heating system to protect plants against extreme cold. Active solar greenhouses use supplemental energy to move solar heated air or water from storage or collection areas to other regions of the greenhouse, or to produce electricity by photovoltaics [6]. Various systems, including steam, hot water radiation system or hot air heater system can be used for greenhouse heating, but it is considered that the ground source heat pump system is a favorable option for greenhouse since it can provide both heating and cooling energy [7]. In recent years, a large number of scientists have been studying various designs of greenhouses that have used solar energy and geothermal energy.

Solar energy usage in commercial greenhouses to electricity supply for the cooling and mechanical ventilation is an economic, sustainable solution. Solar photovoltaic array at greenhouses was the subject of many scientific papers and studies. Hassanien et al. [8] gave a review of the solar energy applications technologies in the environmental control systems of greenhouses (cooling, heating and lighting), generated energy of photovoltaic and the use of photovoltaics for water pumping for irrigation. They also showed economic analyses of this technology. Fatnassia et al. [9] analyzed two arrangements of photovoltaic panels array (straight-line and checkerboard) in two different prototypes of greenhouses with Computational Fluid Dynamic model. The study shows that compared to the straight-line arrangement, the checkerboard photovoltaic panel setup improved the balance of the spatial distribution of sunlight received in the greenhouse. Wang et al. [10] in their paper represent an integration of solar technology to modern greenhouse in China. They shown that China's modern solar greenhouses with photovoltaic (PV) has payback period of less than 9 years. Trypanagnostopoulos et al. [11] considered how PV installation influenced to the plant shading in the greenhouse. Photovoltaics were the fixed one, with panels placed on south facing greenhouse roof and two sun tracking modes. Allardyce et al. [12], Hassanien et al. [13] and Roslan et al. [14] describe the greenhouse with building integrated photovoltaics and their limitations. They have paid attention to the semi-transparent PV with Dye-Sensitized solar Cells, (DSSC) as alternative greenhouse glazing that offers advantages including enhanced thermal stabilization and improved yields. Influence of solar greenhouse shape to thermal performances analyzed Mobtaker et al. in their paper [15]. Yano and Cossu [16] investigate PV electricity generation in solar greenhouses, PV shading effects on plants and important aspects of greenhouse cultivation. Gao et al. in [17] considered energy performance of greenhouse with sun-tracking photovoltaics and concluded that quasi-perpendicular sun tracking improves the annual energy generation for 7.40 % compared to the closed position.

Using a different heat pumps system in greenhouse enables large energy savings for heating and cooling. Yang et al. [18] investigated heat pump system that used surplus air thermal energy and underground water thermal energy as heat sources for greenhouse. Significant energy saving was achieved by using two of this type of heat pump. Yang and Rhee evaluated a surplus air heat pump system for greenhouse cooling and heating in Korea [19], and determined maximum energy savings of 76.3 % daily and 25.7 % monthly. Benli in his paper [20] gave the comparison between a horizontal source and vertical source heat pump systems for a greenhouse heating in the mild climate in Elazığ, Turkey. The results showed that the utilization of the ground-source heat pump is suitable for greenhouse heating in this region. Noorollahi et al. carried out numerical modeling and economic analysis of greenhouse with a ground source heat pump in Iran [21]. Gas burning heating system and an evaporative cooling system are considered to supply the greenhouse energy, and they were compared with the GSHP system. The conclusion is that, due to the high price of electricity and heat pump units and low price of natural gas in Iran, using GSHPs for greenhouses in Iran is not cost-effective. Hassanien et al. [22] investigate the performance of using evacuated tube solar collector as a solar water heater assisted an electric heat pump for greenhouse heating in China. This integration provide more than 35% of the total required heat for greenhouse. Awani et al. [23] analyzed two cases of greenhouses: one with heat pump (water/air) which was coupled with flat plate collector and the other with a vertical heat exchanger in order to obtain a comfortable climate in the winter in the greenhouses. Good results are obtained comparing with others similar results in research area. Russo et al. [24] carried out environmental analysis of the efficiency of a Photovoltaic-Geothermal Heat Pump integrated system as a greenhouse heating system, compared to a conventional hot air generator using liquefied petroleum gas. The estimated payback-time for energy and for carbon emissions were 1 year and 2.25 years, respectively.

By installing more renewable energy technologies simultaneously in a solar greenhouse, the concept of nearly-zero greenhouses can be realized easily. Yildirim and Bilir [25] presented the evaluation of a hybrid system

for a nearly zero energy greenhouse in the Mediterranean climate. A hybrid system consisted of grid connected photovoltaics which generate sufficient electrical energy for lighting and assist a ground source heat pump. In this way, a nearly zero energy greenhouse concept is foreseen for three different agricultural products. Yearly coverage ratio values were between 86.8% and 104.5%. Sun et al. in [26] analyzed the possibilities for improving the traditional greenhouse to new low-cost near-zero-energy solar greenhouse in China. The main technical measures include internal and external insulation envelope using reflective aluminum knitting film; the ecological water circulation system for solar heat storage and collection, and geothermal energy utilization. It was concluded that the new solar greenhouse without artificial heating can achieve nearly zero net energy concept.

By reviewing the literature, it was found that there are no researches in the field of greenhouses with the use of renewable energy sources in the Serbia, which was a great challenge for investigation in this field. This particular fact is supported by the increasing energy consumption and energy saving opportunities with the use of renewable energy sources. The city of Kragujevac belongs to the Sumadija region, which has the great opportunities for agriculture production, especially due to good climate conditions. In order to improve agricultural production, the number of greenhouses has increased in the recent years. At the other side, a large amount of energy can be saved by using a photovoltaic system and a geothermal pump in a solar greenhouse, as shown by the results of this research. By setting a sufficiently large photovoltaic system it is possible to even realize the concept of zero energy solar greenhouse concept.

This paper represents energy analyses of solar greenhouse located in Kragujevac, Serbia. A ground source heat pump is implemented for heating in the winter period and cooling in the summer period, while grid connected photovoltaics generate the electricity. When photovoltaic array produce more electricity than greenhouse needs, the rest of PV generated electricity will be fed-in the electricity grid. When the PV system don't satisfy the greenhouse needs for electrical energy, then the electricity will be used from the electricity grid. Energy analysis was performed with the major aim to minimize greenhouse energy consumption, and to achieve solar greenhouse with zero net energy consumption. Solar greenhouse is simulated in EnergyPlus environment, while Open Studio plug-in in Google SketchUp was used for design of the greenhouse with implemented systems. Cases of different solar greenhouse orientations, different photovoltaic slope and different photovoltaic cell efficiency were considered. In a case of higher cell efficiency of PV array, nearly zero energy solar greenhouse concept can be achieved.

2. Model of analyzed solar greenhouse

Solar greenhouse, which is analyzed in this paper, is located in the city of Kragujevac, which lays in the Balkan Peninsula in the state of Serbia, around 120 km south of its capital city of Belgrade. Its average height above the sea is 209 m. The latitude of Kragujevac is 44.1°N, the longitude is 20.55 °E and the time zone is GMT+1.0 h. Kragujevac has a moderate continental climate, with warm and humid summers with temperatures as high as 37 °C. The winters are cool, with snow and with temperatures as low as -19 °C [27]. The EnergyPlus software uses weather data from its own data base with weather files.

2.1. Solar greenhouse architecture

The investigated solar greenhouse is shown in Figure 1 and it is south-oriented. Greenhouse has a rectangular shape (20x8 m), with a total area of 160 m².

The vertical side walls (east and west) are in the form of an irregular quadruple. The small quadruple south wall (20x0.5 m) is connected with the southern roof which has a slop angle of 40°. At a height of 4.86 m (ridge of greenhouse), the southern roof cuts the northern wall, which has a slope of 60° and it is all the way to the ground. South roof has dimensions 20x6.78 m with total area of 135.6 m², of which 126.88 m² are windows - there are 60 identical windows with dimensions 2.18x0.97 m. The northern roof has dimensions 20x5.61 m with total area of 112.2 m². Two doors (2x2.5 m) are located on the side walls – east and west.

The greenhouse is made from modular elements that enable quick assembly, and the used materials are stable and have lower heat conduction. Greenhouse frame is made of aluminum and it forms its shape. The northern wall, the south wall and the side walls together with the doors are made of non massive sandwich structures that are easily mounted on an aluminum frame. The sandwich structure consists of two layers of aluminum sheet (thickness of 2 mm), with polyurethane foam (100 mm thickness) among them. These structures are

available on the market and they have good thermal properties with heat transfer coefficient of the 0.269 W/m²K.

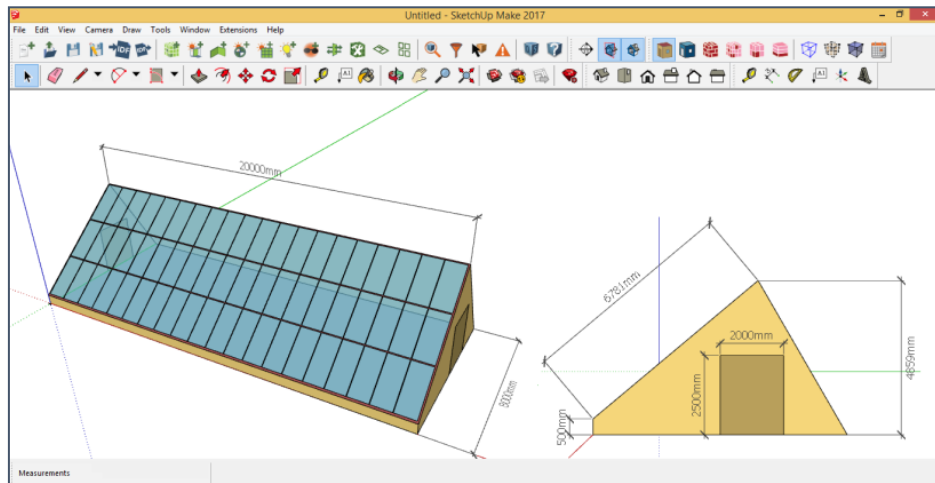


Figure 1. <Solar greenhouse model in Google Sketch-Up>

The windows on the southern roof are double glazed with high-transparent glass of 4 mm thickness and they are positioned at a distance of 13 mm (distances are fill with air space). The coefficient of solar transmission of glass at a normal incident angle is 0.9, solar heat gain coefficient (SHGC) is 0.859 and the U-value is 1.45 W/m²K. Double glazing prevents condensation and reduces heat losses.

Software EnergyPlus has no developed module for plant implementation, but it has the ability to simulate vegetation on the roofs. In this case, vegetative layer was used on the floor surface to calculate the share of energy absorbed and emitted by the plants.

The schedule provided that in the greenhouse various activities are performed by two people, 5 hours a day per day. The software takes into account people presence and the heat emission which is about 120 W per person.

The air in the greenhouse became aggressive, too humid, full of gases, and it is necessary to replace it with fresh air. By ventilation, these characteristics are altered to match the needs of cultivated crops. Natural ventilation by opening doors and windows is foreseen in the months when the greenhouse is overheated, from April 15th to October 15th. This can significantly save the cooling energy.

2.2. Photovoltaic array

Photovoltaic (PV) array is installed on the ridge of the greenhouse. The dimension of the surface on which the photovoltaic modules are sited is 20x4 m with total area of 80 m², while PV cell efficiency was 12 %. This area continues to the southern slope of the greenhouse roof, and this position does not make a shade to the greenhouse (Figure 2). The angle that this surface forms with the horizontal plane ranges from 0-90°.

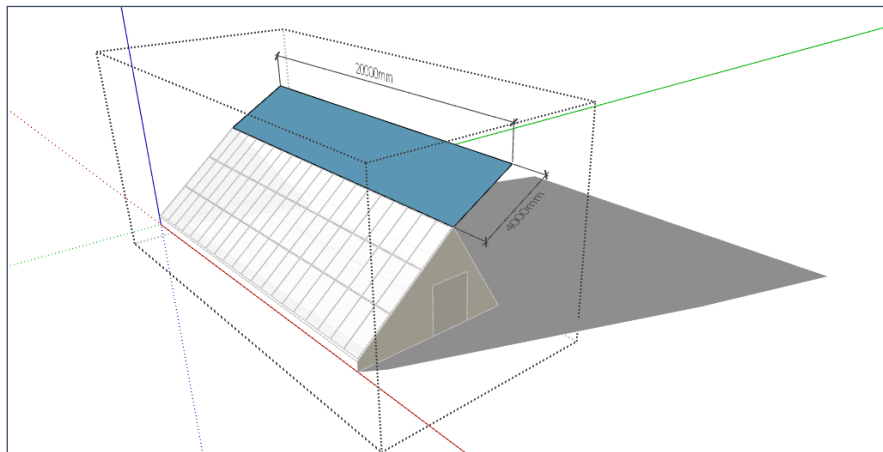


Figure 2. < External surface of the greenhouse model for the installation of photovoltaics>

The PV system consists of the PV array and an inverter. It is an on-grid system. The operation of the PV array is simulated by using EnergyPlus software. The main assumption is that when the PV system operates, generated electricity would be immediately consumed. The surplus electricity is sold to the electricity grid. PV panel is represented by the mathematical model of Generator:Photovoltaic:Simple from EnergyPlus [28], which describes a simple model of PV that may be useful for early phase design analysis. The Generator:Photovoltaic:Simple object represents the simplest model to predict photovoltaic energy production. In this model, the user specifies the efficiency with which the PV array converts the incident solar radiation to electricity. (In the other models, this efficiency is an output of the model.) The full geometric model for solar radiation is used, including sky models, shading, and reflections, to determine the incident solar resource.

2.3. Ground source heat pump

In this paper, a unique heating and cooling system was used, using a geothermal heat pump, which in the scientific research proved to be the most cost-effective. Ground source heat pump indirectly uses geothermal energy and has high efficiency.

Figure 3 schematically describes the heat pump loop. The working fluid on the Source side of the loop is water mixed with 15% glycol. Water circulates with circulation pump and thus transfers heat. In the winter period, heat is drawn from the earth, which has a constant temperature of about 14° C [19]. The working fluid in the earth evaporates and the vapor goes to the compressor station. The steam under pressure raises its temperature and with the tendency to surrender its heat, enters the heat exchanger where it cools and condenses. The condensate, which is still under pressure, encounters the expansion valve in order to reduce the pressure, which creates the conditions for the liquid to evaporate again. In this state, the liquid re-enters the exchanger in the ground and absorbs the heat required to evaporate, thereby closing this circuit and repeating it until the pump operating mode changes [29].

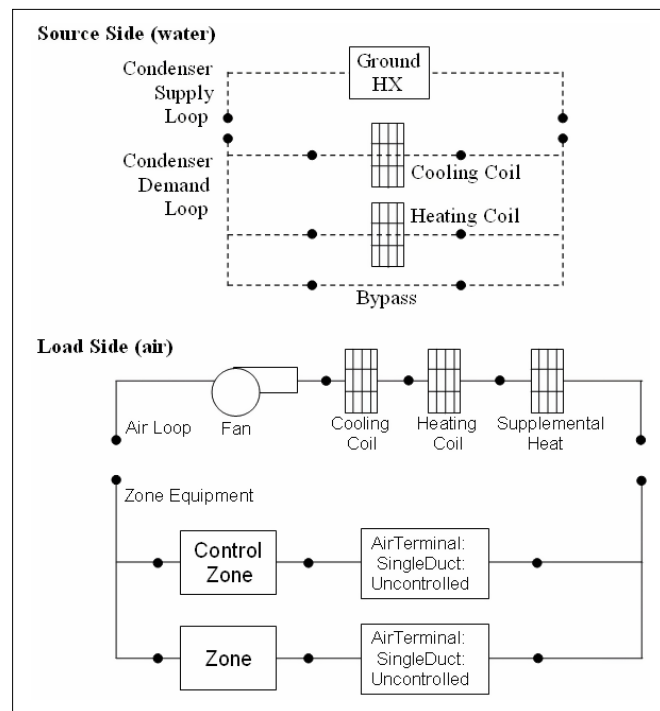


Figure 3. < Source Side and Load Side Configuration of Water To Air Heat Pump [29]>

The Load side of the system uses air as a working fluid, which receives heat from the water in the heat exchanger and, through the channel system with the fan, enters into thermal zone. In addition, this loop has an additional heater that uses electricity (in this case) and it is activated as needed when the temperature of the air supplied by the heat pump does not meet the needs of the thermal zone. In front of the heat exchanger there is a mixer in which the external air enters and refreshes the air transported in the thermal zone, while at the exit from the thermal zone, part of the air is released into the environment.

The heat pump changes the mode between cooling and heating depending on the zone's need using a thermostat and return valve. EnergyPlus defines two heat exchangers (heating and cooling) to approach the operation of

a single heat exchanger that can operate in the heating or cooling mode. The 25 W circulation pump conducts a constant fluid flow rate of $0.0033 \text{ m}^3/\text{s}$. Vertical ground heat exchanger consists of U tubes with length of 76.2 m, diameter 6.35 cm and heat conductivity coefficient 0.391 W/mK . The heat exchanger, which delivers heat to the consumers, has nominal capacity of 25 kW and an auxiliary heater of 32 kW [29].

Heating is needed during the cold season and can increase the growth of summer plants with keeping the temperature of the greenhouse above the ambient temperature. In the winter period, heat is drawn from the ground, which has a constant temperature of 14°C . During the summer temperatures in the greenhouse reach over 50°C , which plants can't stand, so it is necessary to cool the air. Natural ventilation in that case is not enough, and then other conventional cooling devices must be used.

Air temperatures in the greenhouse are defined in relation to the needs for cultivation of different cultures in different periods. The heating or cooling mode in EnergyPlus software is regulated by adjusting the thermostats. The following schedule was adopted:

- heating mode: in the period from November 1st to April 1st, air temperature 16°C (from 07-17 h) and 10°C (from 17-07 h);
- cooling mode: from April 1st to November 1st, air temperature 28°C (from 07-19 h) and 10°C (from 19-07 h);

3. Results and discussion

3.1. Different solar greenhouse orientation

Solar greenhouse with photovoltaic array (slope 40°) is simulated for four different orientations (Figure 4): northwest-southeast 20° from east-west orientation (NW-SE 20°), east-west (E-W), northeast-southwest 20° from west east orientation (NE-SW 20°) and northeast-southwest 40° from E-W orientation (NE-SW 40°).

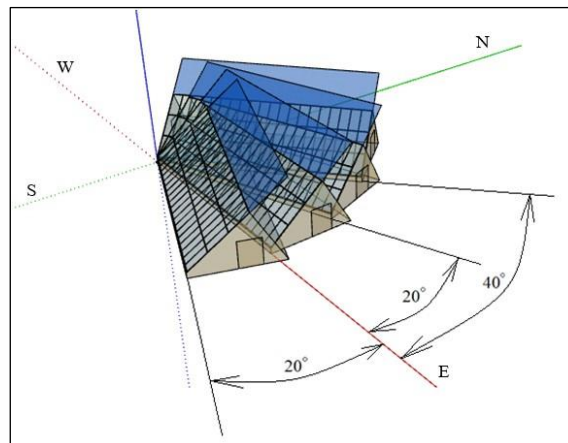


Figure 4. < Different orientation of solar greenhouse with photovoltaics (slope 40°) >

The simulation results show that total energy consumption of greenhouse is changing with greenhouse orientation. Differences in total energy consumption are not great, but any energy saving is significant. Total energy consumption of greenhouse with northwest-southeast 20° , east-west, northeast-southwest 20° and northeast-southwest 40° are 50.53 GJ, 50.2 GJ, 49.94 GJ and 49.69 GJ, respectively (Tab. 1). All simulations were done for a period of one year. According to these results, if the turning of greenhouses from south to north is observed, total energy consumption is reduced, so the most optimal orientation is the northeast-southwest 40° . The greenhouse oriented to the west consumes the most energy for cooling compared to the other orientations, while it does not have the least energy consumption for heating. In the summer, the east-west oriented greenhouse is the most open to receiving solar energy, and therefore it takes a lot of energy for cooling. On the other hand, in the winter, solar radiation reduces the heating energy consumption. The only reason why the northeast-southwest 40° oriented greenhouse (closest to the north) has the lowest energy consumption is due to the ratio of the required energy for heating and cooling, which is somewhat higher in favor of cooling (Fig. 5). This orientation is more opened to the east, where the Sun is coming out, and in the afternoon, the western wall creates a shadow that almost does not exist at the east-west orientation.

Table 1. <Total energy consumption, heating energy, cooling energy, generated and net-energy consumption in solar greenhouse with photovoltaics and different orientation>

Orientation	Total energy consumption (GJ)	Heating energy (GJ)	Cooling energy (GJ)	Generated energy (GJ)	Net-energy consumption (GJ)
NW-SE 20°	50.53	10.62	12.09	25.76	24.77
E-W	50.2	10.42	11.95	25.91	24.29
NE-SW 20°	49.94	10.48	11.64	25.5	24.40
NE-SW 40°	49.69	10.76	11.11	24.57	25.12

Total generated energy for greenhouse with northwest-southeast 20°, east-west, northeast-southwest 20° and northeast-southwest 40° are 25.76 GJ, 25.91 GJ, 25.5 GJ and 24.57 GJ, respectively. It is clear that most electricity is produced when photovoltaic array is turned to the east – west. Net-energy consumption is in all analyzed cases about 50 % from total energy consumption (Fig. 6). Generated electricity is used to supply the heat pump. By subtracting generated energy from the total energy consumption for four orientations it can be concluded that the lowest net-energy consumption is obtained for east-west oriented greenhouse.

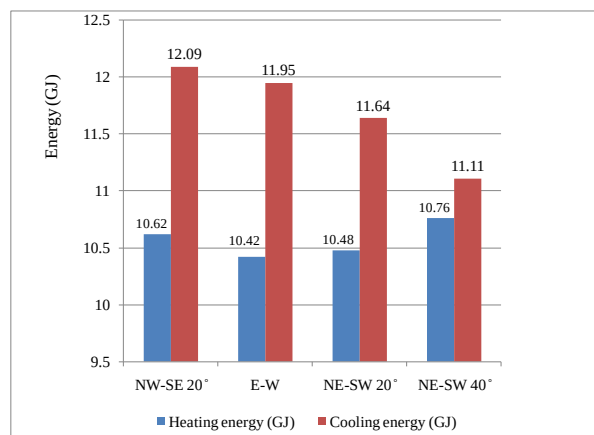


Figure 5. <Heating and cooling energy consumption in solar greenhouse with photovoltaics and different orientation>

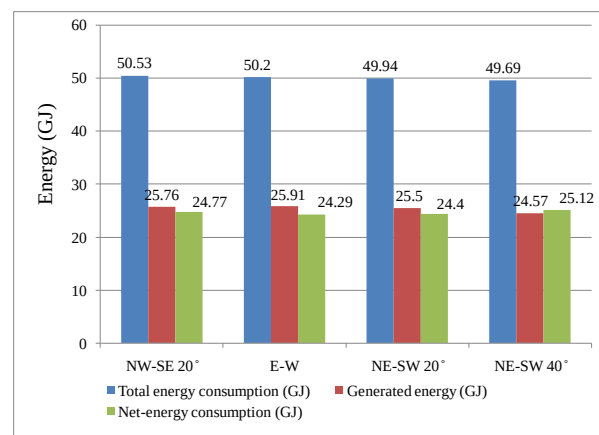


Figure 6. <Total energy consumption, generated electricity and net-energy consumption in solar greenhouse with PV array and different orientation>

3.2. Different slope angle of PV array

Electricity generation depends of photovoltaic slope. It is necessary to set PV panels in the optimum slope angle, where the photovoltaic cells will have the greatest involvement of the solar radiation. The model of photovoltaics with slope angle of 40° (previous simulations) is rotated, so photovoltaic modules with a slope of 0° (horizontal modules), 20°, 30° and 90° (vertical modules) are simulated (Fig 7).

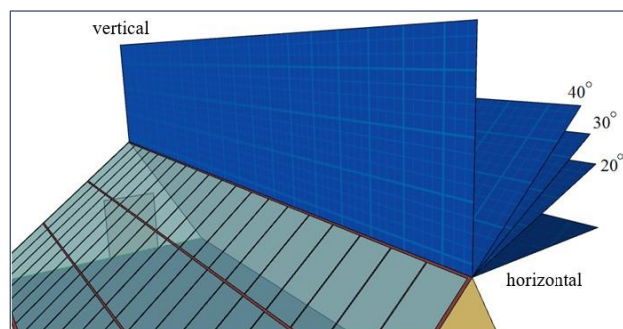


Figure 7. < Different slope angle of photovoltaics>

The greenhouse during the rotation of the module has the same orientation all the time - east-west. By simulating the photovoltaic modules from these four slopes, results were obtained for comparison of the produced electricity with the already known result of the module with a slope of 40°. When the FN modules have a horizontal position, 22.92 GJ of electricity is produced, 20.56 GJ of electricity is produced when the slope is 20°, 26 GJ is produced at slope of 30°, and at vertical position of PV array generates 17.33 GJ electricity

(Table 2, Fig. 8). According to these results, it can be concluded that the most optimal slope of photovoltaics is 30 °.

Table 2. <Total energy consumption, heating energy, cooling energy, generated and net-energy consumption in solar greenhouse with photovoltaics and different orientation>

Slope angle (°)	Generated electricity(GJ)	Generated electricity/total energy consumption (%)
0	22.92	45.68
20	25.56	50.92
30	26.03	51.85
40	25.91	51.62
90	17.33	34.61

Horizontal PV modules satisfy 45.68 % of the total energy consumption, photovoltaic modules with a slope of 20°, 30° and 40° meet 50.92 %, 51.85 % and 51.62 % of energy needs, while vertical modules satisfy 34.61% of total energy consumption.

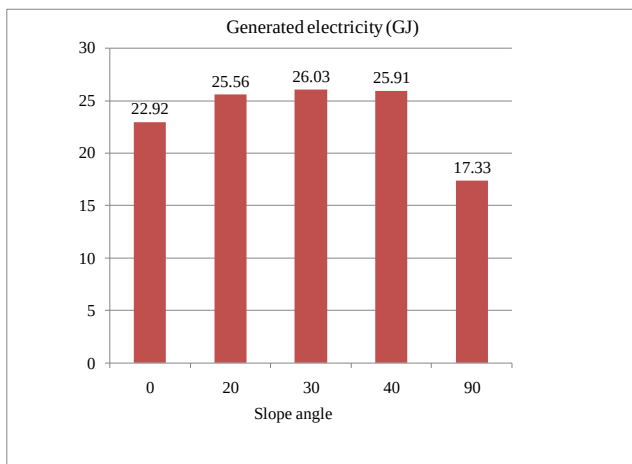


Figure 8. <Generated electricity in solar greenhouse with different photovoltaic slope>

3.3. Different photovoltaic cell efficiency

Photovoltaic cell efficiency directly influences to the electricity generation in PV array. Previous simulation was done with PV cell efficiency of 12 %, because these modules are cheapest and the most widespread on the market, but they are not always the best solution. In this investigation, cell efficiency of 14 % and 16 % are considered.

Simulation of greenhouse with optimal orientation (east-west) and optimal slope (30°) of photovoltaic array shows that the total electricity generation with PV cells efficiency of $\eta=14\%$ is 30.37 GJ and with PV cells efficiency of $\eta=16\%$ it is 34.71 GJ (Table 3 and Fig. 8), which is significantly higher than the generated energy of 26.03 GJ with PV cells efficiency of 12%. With the increase the PV cell efficiency, net-energy consumption is significantly reduced: 19.83 GJ for PV cells efficiency of 14 % and 15.49 GJ for PV cells efficiency of 16%, compared to total greenhouse energy consumption of 50.2 GJ.

Table 3. <Generated energy, net-energy consumption and satisfaction of greenhouse energy needs in solar greenhouse with optimal parameters and different PV cell efficiency>

PV cell efficiency (%)	Total energy consumption (GJ)	Generated energy (GJ)	Net-energy consumption (GJ)	Generated electricity/total energy consumption (%)
12	50.2	26.03	24.17	51.85
14	50.2	30.37	19.83	60.5
16	50.2	34.71	15.49	69.14

Electricity generated with PV cell efficiency of 14% meets 60.5% of greenhouse energy needs, while PV cell efficiency of 16 % satisfies 69.14% of total energy consumption in the greenhouse (Figure 9, Table 3).

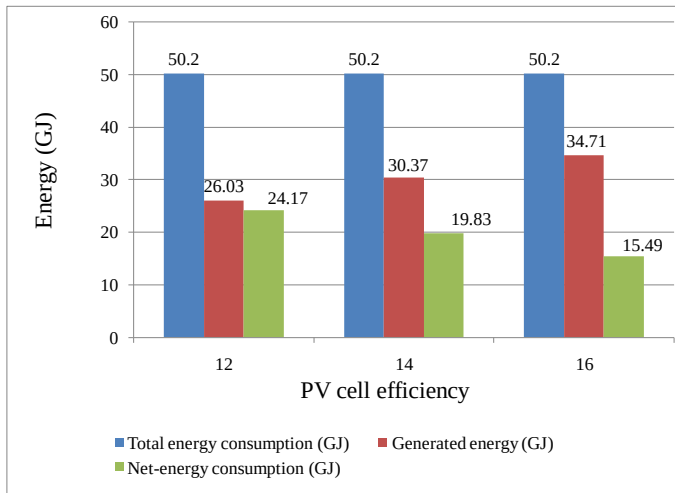


Figure 9. <Total energy consumption, generated electricity and net-energy consumption in solar greenhouse with PV array and different PV cell efficiency>

3.4. Net-zero energy solar greenhouse

Solar greenhouse of net-zero energy consumption is solar greenhouse whose systems use renewable energy sources to produce as much energy as the total energy consumption of solar greenhouse.

The obtained simulation results of the solar greenhouse with PV array total area of 80 m² show that this capacity is insufficient to produce enough energy to meet the energy needs of analyzed solar greenhouse. The maximum electricity generation is 69.42 % of the total energy consumption, and according to this relationship, the area of the PV array should be 116 m² for the production of electricity equal to the total energy consumption. According to the previous statement, the model of implemented photovoltaics was modified in the SkechUp program by increasing the external surface width by 1.8 m (Figure 10). This increasing in photovoltaics width resulted with electricity generation in amount which is just a little more than total energy consumption of solar greenhouse with defined optimal parameters.

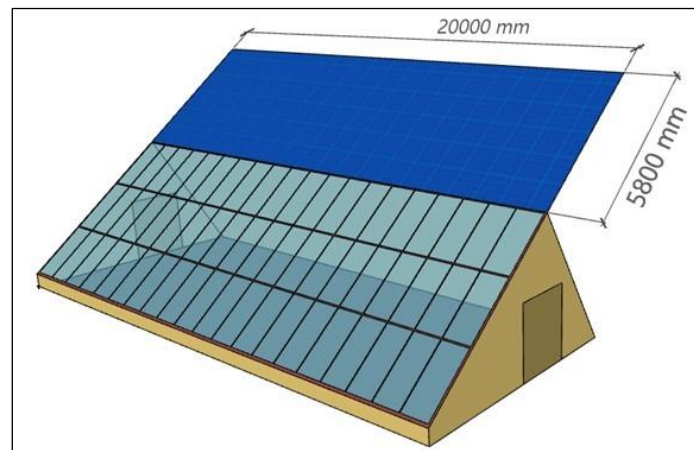


Figure 10. <Model of solar greenhouse with photovoltaic area of 116 m²>

By simulating east-west oriented solar greenhouse with PV modules of total area of 116 m², with slope angle of 30° and photovoltaic cell efficiency of 16 %, it can be concluded that the net-energy consumption is -0.13 GJ, i.e. generated electricity is more than total energy consumption (Table 4). Energy production reaches 100.26 % of total energy consumption.

Table 4. <Total energy consumption, generated energy, net-energy consumption and satisfaction of greenhouse energy needs in solar greenhouse with different PV area and optimal parameters>

	Total energy consumption (GJ)	Generated electricity (GJ)	Net-energy consumption (GJ)	Generated electricity/total energy consumption (%)
Greenhouse with PV area 80 m ²	50.2 GJ	34.71	15.49	69.14
Greenhouse with PV area 116 m ²	50.2 GJ	50.33	-0.13	100.26

Conclusion

The basic idea of this investigation was to determine the orientation and slope angle of PV array, at the simulated solar greenhouse model in EnergyPlus software, which enable the greatest possible electricity generation, and, achieving net-zero energy consumption in the greenhouse.

First, by comparing the results of energy consumption for heating and cooling in solar greenhouses with ground source heat pump and the electricity generation with PV (80 m²) for four different orientations, the east - west orientation was obtained as the best solution, according to the generated electricity. For the east - west orientation, the slope angle of the PV array of 30 ° was adopted as slope angle with maximal generated electricity. For these values of the orientation and slope angle of solar greenhouse, and the cell efficiency of the photovoltaics of 12 %, solar greenhouse had a total energy consumption of 50.2 GJ and net-energy consumption of 24.17 GJ.

The values of generated electricity for PV cell efficiency of 14 % and 16 % were analyzed too. The net greenhouse energy consumption for the adopted efficiency of 16% was reduced by 35.91 % compared to the efficiency of 12 % and it was 15.49 GJ.

The aim of this research also was to achieve the concept of net-zero energy consumption in the solar greenhouse. Therefore, it was necessary to increase the surface of the PV array to 116 m², while retaining the other parameters (orientation and slope) and cellular efficiency of the PV module of 16%, which resulted in a net energy consumption of - 0.13 GJ.

Economically, photovoltaic system besides the heat pump requires large investments [10, 11, 25] with a long payment period. With energy savings and increasing of agricultural yields, with the worldwide downward trend in the price of photovoltaic and other renewable technologies, it is expected an increasing application of RES in the field of agriculture.

Bearing in mind the high consumption of fossil energy and the increasing problem of global warming, in the future, humanity must nevertheless turn to the renewable energy sources. Solar energy is certainly a very attractive solution for the generation of energy because the sun is an inexhaustible source of energy and solar conversion extremely clean way of obtaining energy.

Acknowledgements

This investigation is part of the projects TR 33015 and III 42013. The authors would like to thank to the Ministry of Education and Science of Republic of Serbia for the financial support during this investigation.

References

- [1] Sims, R., Mercado P., Krewitt W., Bhuyan G., Flynn D., Holttinen H., Jannuzzi G., Khennas S., Liu Y., O'Malley M., Nilsson L. J., Ogden J., Ogimoto K., Outhred H., Ulleberg Ø., Hulle F. van, Integration of Renewable Energy into Present and Future Energy Systems, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011
- [2] Gołaszewski J., Visser C. at al., State of the Art of Energy Efficiency in Agriculture, Report of the FP7 project 289139, 2012, European Union
- [3] Ghani S., Bakochristou F., Ahmed ElBialy E. M. A., Gamaledin S. M. A., Rashwan M. M., Abdelhalim A. M., Ismail S. M., Design challenges of agricultural greenhouses in hot and arid environments – A review, Engineering in Agriculture, Environment and Food, 12 (2019), pp. 48–70
- [4] Panwar N.L., Kaushik S.C., Kothari., Solar greenhouse an option for renewable and sustainable farming, Renewable and Sustainable Energy Reviews, 15 (2011), pp. 3934– 3945
- [5] Stauffer V., Tokhmat T., Solar Greenhouses for the Trans-Himalayas: A Construction Manual, International Centre for Integrated Mountain Development, Indiana University, USA, 2004
- [6] Bellows B., Solar Greenhouses, NCAT Agriculture Specialist, USA, 2003
- [7] Yildirim N., Bilir L., Evaluation of a hybrid system for a nearly zero energy greenhouse, Energy Conversion and Management 148 (2017), pp. 1278-1290
- [8] Hassanien R. H. E., Li M., Lin W. D., Advanced applications of solar energy in agricultural greenhouses, Renewable and Sustainable Energy Reviews 54 (2016), pp. 989-1001

- [9] Fatnassia H., Ponceta C., Bazzano M. M., Bruna R., Bertin N., A numerical simulation of the photovoltaic greenhouse microclimate, *Solar Energy* 120 (2015), pp. 575-584
- [10] Wang T., Wu G., Chen J., Cui P., Chen Z., Yan Y., Zhang Y., Li M., Niu D., Li B., Chen H., Integration of solar technology to modern greenhouse in China: Current status, challenges and prospect, *Renewable and Sustainable Energy Reviews* 70 (2017), pp. 1178-1188
- [11] Trypanagnostopoulos G., Kavga A., Souliotis M., Tripanagnostopoulos Y., Greenhouse performance results for roof installed photovoltaics, *Renewable Energy* 111 (2017), pp. 724-731
- [12] Allardyce C. S., Fankhauser C., Zakeeruddin S. M., Grätzel M. Dyson P. J., The influence of greenhouse-integrated photovoltaics on crop production, *Solar Energy* 155 (2017), pp. 517-522
- [13] Hassanien R.H.E., Li M., Yin F., The integration of semi-transparent photovoltaics on greenhouse roof for energy and plant production, *Renewable Energy* 121 (2018), pp. 377-388
- [14] Roslan N., Ya'acob M. E., Radzi M. A. M., Hashimoto Y., Jamaludin D., Chen G., Dye Sensitized Solar Cell (DSSC) greenhouse shading: New insights for solar radiation manipulation, *Renewable and Sustainable Energy Reviews* 92 (2018), pp. 171-186
- [15] Mobtaker H. G., Ajabshirchi Y., Ranjbar S. F., Matloobi M., Simulation of thermal performance of solar greenhouse in north-west of Iran: An experimental validation, *Renewable Energy* 135 (2019), pp. 88-97
- [16] Yano A., Cossu M., Energy sustainable greenhouse crop cultivation using photovoltaic technologies, *Renewable and Sustainable Energy Reviews* 109 (2019), pp. 116-167
- [17] Gao Y., Dong J. Isabella O., Santbergen R., Tan H., Zeman M. Zhang G., Modeling and analyses of energy performances of photovoltaic greenhouses with sun-tracking functionality, *Applied energy* 233-234 (2019), pp. 424-442
- [18] Yang S. H., Lee S. D., Kim Y. J., Rhee J. Y., Greenhouse Heating and Cooling with a Heat Pump System using Surplus Air and Underground Water Thermal Energy, *Engineering in Agriculture, Environment and Food* 6 (2013) 3, pp. 86-91
- [19] Yang S. H., Rhee J. Y., Utilization and performance evaluation of a surplus air heat pump system for greenhouse cooling and heating, *Applied Energy* 105 (2013), pp. 244-251
- [20] Benli H., A performance comparison between a horizontal source and a vertical source heat pump systems for a greenhouse heating in the mild climate Elazığ, Turkey, *Applied Thermal Engineering* 50 (2013) 1, pp. 197-206
- [21] Noorollahi Y., Bigdelou P., Pourfayaz F., Yousefi H., Numerical modeling and economic analysis of a ground source heat pump for supplying energy for a greenhouse in Alborz province, Iran, *Journal of Cleaner Production* 131 (2016), pp. 145-154
- [22] Hassanien R.H.E., Ming L., Tang Y., The evacuated tube solar collector assisted heat pump for heating greenhouses, *Energy and Buildings* 169 (2018), pp. 305-315
- [23] Awani S., Chargui R., Kooli S., Farhat A., Guizani A., Performance of the coupling of the flat plate collector and a heat pump system associated with a vertical heat exchanger for heating of the two types of greenhouses system, *Energy Conversion and Management* 103 (2015), pp. 266-275
- [24] Russo G., Verdiani A. S. A. G., Mugnozza G. S., Environmental analysis of geothermal heat pump and LPG greenhouse heating systems, *Biosystems Engineering* 127 (2014), pp. 11-23
- [25] Yildirim N., Bilir L., Evaluation of a hybrid system for a nearly zero energy greenhouse, *Energy Conversion and Management* 148 (2017), pp. 1278-1290
- [26] Sun S., Yhan C., Yang G., Yu Y., Research on A New Technology Integrated Low-cost, Near-zero-energy Solar Greenhouse, *Procedia Engineering* 145 (2016), pp. 188-195
- [27] Bojić M., Skerlić J., Nikolić D., Cvetković D., Miletić M., Toward future: positive net-energy buildings, *Proceedings, 4th IEEE International Symposium on Exploitation of Renewable Energy Sources, EXPRES 2012*, Subotica, Serbia, March 9-10, 2012., pp. 49-54
- [28] Anonymous, ENERGYPLUS - Input Output Reference - The Encyclopedic Reference to EnergyPlus Input and Output, University of Illinois & Ernest Orlando Lawrence Berkeley National Laboratory, Chichago, USA, 2016
- [29] Anonymous, ENERGYPLUS - Engineering Reference, U.S. Department of Energy, University of Illinois & Ernest Orlando Lawrence Berkeley National Laboratory, Chichago, USA, 2016



Ovex inženjering d.o.o. postoji i uspešno posluje na tržištu Srbije od 1991. godine. Preduzeće se bavi inženjeringom, konsaltingom i trgovinom u oblasti tretmana i kondicioniranja vode. Primarni cilj je preduzeća je zadovoljenje potreba za kvalitetom vode u raznim oblastima industrije kako sa stanovišta tehnologije tako i sa stanovišta isporuke opreme i kompleksnih hemijskih sredstava, poštanja u rad, održavanja i praćenja postignutog kvaliteta kod svih svojih potrošača.

Zahvaljujući visoko obrazovanom i obučenom kadru, Ovex inženjering uspeva da zadovolji i najzahtevnije vodorashladne, parne i vrelovodne kotlovske sisteme. Svoju kompetentnost i opredeljenost kvalitetu smo dokazali u dugogodišnjem poslovanju i našim referencama.



Inovacioni centar naprednih tehnologija, ICNT, formiran je na inicijativu grupe redovnih profesora sa Elektronskog fakulteta i Mašinskog fakulteta Univerziteta u Nišu. Shodno tome, nastao je kao rezultat dugogodišnje akumulacije znanja iz različitih oblasti od kojih se izdvajaju Informaciono-komunikacione tehnologije, telekomunikacije, elektronika, energetika, mehatronika, energetska efikasnost i obnovljivi izvori energije.

Osnivanje ICNT podržala je i kompetentna grupa naučnih istraživača i eksperata iz Niškog regiona. Osnovni zadatak ICNT jeste da prati uticaj nauke i tehnologije na ukupni razvoj savremenog društva, da razvija inovativne proizvode i usluge i da pomaže transfer znanja i difuziju novih tehnologija u industriju. Mi sebe vidimo kao sastavni deo Evropskog istraživačkog prostora, ERA (European Research Area) i spremni smo da aktivno učestvujemo u realizaciji međunarodnih, regionalnih, nacionalnih i lokalnih inovacionih i naučnoistraživačkih projekata.

Naslov publikacije	PROCEEDINGS, 19 th Conference on Thermal Science and Engineering of Serbia, Sokobanja, Serbia, October 22 - 25, 2019
Urednici	Mirjana Laković-Paunović, Mladen Stojiljković
Tehnička obrada	Marko Manić
Grafik dizajn	Dragana Dimitrijević Jovanović
Izdava :	MAŠINSKI FAKULTET UNIVERZITETA U NIŠU
Štampanje	MAŠINSKI FAKULTET UNIVERZITETA U NIŠU, 2019
Tiraž:	200

CIP - Каталогизacija u publikaciji - Narodna biblioteka Srbije, Beograd

620.9(082)(0.034.2)
502/504(082)(0.034.2)

INTERNATIONAL Conference on Thermal Science and Engineering of Serbia (19 ; 2019 ; Sokobanja)

Proceedings [Elektronski izvor] / SimTerm 2019 - 19th International Conference on Thermal Science and Engineering of Serbia, Sokobanja, Serbia, October 22-25, 2019 ; [organised by] University of Niš, Faculty of Mechanical Engineering in Niš, Department of Thermal Engineering and Society of Thermal Engineers of Serbia ; [urednici Mirjana Laković-Paunović, Mladen Stojiljković]. - Niš : Mašinski fakultet Univerziteta, 2019 (Niš : Mašinski fakultet Univerziteta). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 200. - Bibliografija uz svaki rad.

ISBN 978-86-6055-124-7

1. Mašinski fakultet (Niš). Katedra za termotehniku, termoenergetiku i procesnu tehniku 2. Društvo termičara Srbije

a) Енергетика - Зборници b) Животна средина - Заштита - Зборници

COBISS.SR-ID 281110028

