WORKSHOP ON SMART HYBRID COOLING TECHNIQUES FOR PHOTOVOLTAIC TECHNOLOGIES

6/7 JULY 2022

HRZZ Croatian Science Foundation

THIS WORKSHOP HAS BEEN SUPPORTED IN PART BY CROATIAN SCIENCE FOUNDATION UNDER THE PROJECT „SMART HYBRID COOLING TECHNIQUES FOR SILICEOUS PHOTOVOLTAIC PANELS" (IP-01-2018)

ORGANIZED BY

SHORT PROGRAM

July 6, 2022

WORKING MEETING (closed)

OPENING SPEECH AND INTRODUCTION TO THE WORKSHOP TOPIC
„Smart Hybrid Cooling Techniques for Siliceous Photovoltaic Panels: Project Outcomes (2018-2022)", **Sandro Nižetić**

INVITED TALK 1
„Integration of PV-PCM Systems in Zero Energy Buildings: An Updated Review", **Agis M. Papadopoulos**

INVITED TALK 2
„Cooling Performance Enhancers By Passive Techniques in PV-PCM Systems: An Updated Review and a Case Study on Geometric Modification on PCM Container", **Müslüm Arici**

INVITED TALK 3
„Experimental Investigation of the Smart and Hybrid Cooling Design for Free-Standing Photovoltaic Panel", **Mišo Jurčević**

CLOSING REMARKS

July 7, 2022

WORKING MEETING (closed)

OPENING SPEECH
Sandro Nižetić

INVITED TALK 4
„Indicators in Terms of Circular Economy and Life Cycle Impact Assessment of PV Energy Systems", **Effrosyni A. Giama**

INVITED TALK 5
„Data Collection and Processing of Long-Term Measurment Results", **Duje Čoko**

INVITED TALK 6
„Progress in Photovoltaic systems: integration, operation, life cycle assessment", **Theocharis Tsoutsos**

CLOSING REMARKS

Workshop on Smart hybrid cooling techniques for siliceous photovoltaic panels - CONTENTS

1. CHAIR MESSAGE

Sandro Nižetić
University of Split
Croatia

Dear participants of the 4th International workshop related to the Smart hybrid cooling techniques for siliceous photovoltaic panels. It is my pleasure to welcome you to the workshop devoted to the one of the fast growing renewable energy technologies. The main goal of the ongoing research project that is funded by Croatian Science Foundation is to investigate smart and effective cooling techniques for silicon based photovoltaic (PV) panels, in order to improve energy conversion efficiency as well as to extend lifetime of the commercial silicon PV panels. Interesting invited talks are scheduled within the workshop and that are closely linked with the main project scope and topic in general.
Thank you for your participation on the workshop and hope that workshop would be a quality platform for exchange of ideas between academia members as well as professionals.
Special thanks to the invited speakers and all workshop participants. Finally, sincere appreciations to Croatian Science Foundation for support of the research work!

Sandro Nižetić,
Head of the research project

2. FINAL PROGRAM OUTLINE

Wednesday, July 6, 2022

WORKING MEETING (CLOSED)

OPENING SPEECH AND INTRODUCTION TO THE WORKSHOP TOPIC
„Smart Hybrid Cooling Techniques for Siliceous Photovoltaic Panels: Project Outcomes (2018-2022)", **Sandro Nižetić**

INVITED TALK 1
„Integration of PV-PCM Systems in Zero Energy Buildings: An Updated Review", **Agis M. Papadopoulos**

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„Cooling Performance Enhancers By Passive Techniques in PV-PCM Systems: An Updated Review and a Case Study on Geometric Modification on PCM Container", **Müslüm Arici**

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„Experimental Investigation of the Smart and Hybrid Cooling Design for Free-Standing Photovoltaic Panel", **Mišo Jurčević**

CLOSING REMARKS

Thursday, July 7, 2022

WORKING MEETING (CLOSED)

OPENING SPEECH
Sandro Nižetić

INVITED TALK 4
„Indicators in Terms of Circular Economy and Life Cycle Impact Assessment of PV Energy Systems", **Effroysni A. Giama**

INVITED TALK 5
„Data Collection and Processing of Long-Term Measurment Results", **Duje Čoko**

INVITED TALK 6
„Progress in Photovoltaic systems: integration, operation, life cycle assessment", **Theocharis Tsoutsos**

CLOSING REMARKS

3. WORKSHOP GENERAL

International workshop is focused on the recent advancements in the field of the smart and efficient cooling techniques for photovoltaics as part of the ongoing research project funded by Croatian Science Foundation. Different important topics would be discussed and that are related to the smart cooling systems of the silicon-based photovoltaics with main emphasis on techno-economic, environmental and modelling aspects. Several internationally recognized researchers and project collaborators will present and discuss specific topics linked with ongoing research on the project (Smart and hybrid cooling techniques for siliceous photovoltaic panels-IP-01-2018-2814).

SCHEDULED PRESENTERS:

Sandro Nižetić, *University of Split*
Agis M. Papadopoulos, *Aristotle University Thessaloniki, Greece*
Müslüm Arici, *Kocaeli University, Turkey*
Mišo Jurčević, *University of Split*
Effrosyni A. Giama, *Aristotle University of Thessaloniki, Greece*
Duje Čoko, *University of Split*
Theocharis Tsoutsos, *Technical University of Crete*

4. SPEAKERS

July 6

SPEAKER

Sandro Nižetić, University of Split, Croatia

SMART HYBRID COOLING TECHNIQUES FOR SILICEOUS PHOTOVOLTAIC PANELS: PROJECT OUTCOMES (2018-2022)

The research project " Smart hybrid cooling techniques for siliceous photovoltaic panel" funded by Croatian science foundation had main goal to develop, and experimentally investigate the specific cooling approaches for siliceous photovoltaic panels. Based on the conducted analysis the final experimental setup was determined and focused on development and design of photovoltaic thermal (PVT-PCM) collector with incorporated organic phase change material (PCM). Beside the targeted improvement in electrical efficiency due to cooling approach, the idea was also to utilize produced hot water. The development approach was integral since beside the performance analysis the economic as well as environmental evaluation was also obtained. Finally, an overview of main project activities would be presented, together with discussion of the main project outcomes.

Sandro Nižetić, PhD is Professor at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB) at University of Split (Croatia). He got Dean Award for overall success during the study period, state prize for the research for 2016 as well as rector research award for 2018 from University of Split. He has experience in theoretical and applied thermodynamics, HVAC systems, energy efficiency in buildings, rational usage of energy, utilization of renewable energy sources, and more than fifteen years of the teaching experience. From 2005 he is an ASHRAE member and also ASHRAE student branch advisor at University of Split. From 2009 to 2013 he was UNDP (United Nations Development Programme) project coordinator in Croatia on projects related to the implementation of Energy Efficiency measures in public buildings. He was also the head of the research project from 2008 to 2013 related to the development of a novel energy concept (solar power plant with short diffuser). He served as a deputy minister in the ministry of construction and spatial planning in the Croatian government and he was also a vice dean for the research at faculty of FESB. He has visited several research and educational institutions worldwide as visiting researcher or as visiting lecturer and he is author of more than eighty research and conference papers as well as also several techno-economic professional case studies. He has organized and chaired several international conferences and co-founder of the SpliTech conference (International conference on Smart and Sustainable Technologies). He is head of the laboratory for thermodynamics and energy efficiency at Faculty of FESB, University of Split (LTEF-Laboratory). He is Associate Editor in Journal of Cleaner Production (Elsevier) and International Journal of Energy Research (Willey).

July 6

INVITED SPEAKER

AGIS M. PAPADOPOULOS, Aristotle University Thessaloniki, Greece

INTERGATION OF PV-PCM SYSTEMS IN ZERO ENERGY BUILDINGS: AN UPDATED REVIEW

PVs are steadily gaining momentum in building applications for two reasons: (a) contemporary and future building energy performance regulations call for an increased utilization of RES on the buildings, PVs being the most obvious choice in the urban environment, (b) the declining cost of PV modules, and the emerging new PV technologies, qualifies them as competitive technologies for providing electricity to buildings to cover their respective loads. The levelised cost of PV generated electricity installed in commercial and industrial buildings is now in par if not cheaper with most fossil fuel powered generation stations, especially as the looming energy crisis has led electricity prices to unprecedented levels.
Regarding the renovation of buildings Building Integrated Photovoltaics (BIPV) are the most promising option, as they are directly integrated into building elements such as roofs or façades. Thus, they do not compromise at all the aesthetics of a building while they replace other materials in building construction.
However, one of the main issues for BIPVs is overheating, which not only reduces their efficiency may lead to increasing the building's cooling loads. In that sense, it is of particular interest to utilize any cooling techniques of the PVs, including the use of PCMs, that may contribute to addressing this issue.
As part of the workshop, an updated review will be provided on the state of the art and trends of BIPV technologies, including solutions for flat and pitched roofs, facades and glazing systems.

Agis M. Papadopoulos obtained his Diploma in Mechanical Engineering from the Aristotle University Thessaloniki in 1989, his Master of Science in Energy Conservation and the Environment from Cranfield University (UK), in 1991, and his Doctorate in Mechanical Engineering, specializing on solar thermal systems, from the Aristotle University Thessaloniki in 1994. Since 1998 he is Professor at the Department of Mechanical Engineering of the Aristotle University Thessaloniki. His main research interests lie in the fields of (a) Energy efficiency and integration of energy systems in buildings, (b) Energy resources economics and (c) Elaboration, monitoring and evaluation of legislative and regulatory measures to promote Energy Efficiency and Renewable Energy actions. Since 2013 he is Director of the Process Equipment Design Laboratory. He has coordinated more than 60 national and international research projects with a budget of more than 6 M€ and authored or co-authored more than 115 papers published in peer reviewed journals and 260 papers in conference proceedings. He is Editor-in-Chief of the International Journal of Sustainable Energy. He has worked as an expert for a series of international consulting projects, in the fields of analyzing and implementing energy efficiency and RES policies in Cyprus, Eastern Europe, Egypt and Central Asia. He has been a Visiting Professor at the University of Cyprus and is currently a Visiting Professor at the International Hellenic University, Greece, and at the Technical University of Hamburg, Germany. Between 2014 and 2018 he was Vice-Chairman of the Governing Board of the Open University of Cyprus. Since 2018 he is Board Member of the Open University of Cyprus.

July 6

INVITED SPEAKER

MIŠO JURČEVIĆ, University of Split, Croatia

EXPERIMENTAL INVESTIGATION OF THE SMART AND HYBRID COOLING DESIGN FOR FREE-STANDING PHOTOVOLTAIC PANEL

The newly proposed concept of hybrid cooling of a photovoltaic panel is a micro-cogeneration system since it can produce electricity and heat (PVT collector). An experimental study in Mediterranean climate conditions was conducted to determine the cooling efficiency and the amount of waste heat produced that could be utilized in low-temperature heating systems. Hybrid panel cooling operates in primary, passive mode and secondary, active mode. The passive mode is based on the phase change material (PCM) while the water cooling is activated after the latent heat of the PCM has been consumed. For the first time, an organic phase change material based on pork fat was used in the thermal management system of a photovoltaic panel. Temperatures on the surfaces of the reference and hybrid panel as well as the produced electricity were continuously monitored. Measurements revealed a significant increase in the efficiency of the hybrid PV panel in both modes compared to the reference panel. In addition, active cooling extended the operating time of PCM in the thermal regulation system of the free-standing photovoltaic panel.

Mišo Jurčević is a PhD student at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split. He received Master's Degree in Industrial Engineering (2015) and Master's Degree in Mechanical Engineering (2018) from the University of Split. He is currently working as a research and teaching assistant at the Department of Mechanical Engineering and Naval Architecture. He participates in teaching courses on Fluid Mechanics, Hydraulic Machines, Fluids Flow and Computational Fluid Dynamics. His fields of interest are Renewable Energy, Thermodynamics, Heat and Mass Transfer, Fluid Mechanics and Computational Fluid Dynamics.

Mišo Jurčević is a PhD student at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split. He received Master's Degree in Industrial Engineering (2015) and Master's Degree in Mechanical Engeneering (2018) from the University of Split. He is currently working as a research and teaching assistant at the Department of Mechanical Engineering and Naval Architecture. He participates in teaching courses on Fluid Mechanics, Hydraulic Machines, Fluids Flow and Computational Fluid Dynamics. His fields of interest are Renewable Energy, Thermodynamics, Heat and Mass Transfer, Fluid Mechanics and Computational Fluid Dynamics

July 6

INVITED SPEAKER

MÜSLÜM ARICI, Kocaeli University, Turkey

COOLING PERFORMANCE ENHANCERS BY PASSIVE TECHNIQUES IN PV-PCM SYSTEMS: AN UPDATED REVIEW AND A CASE STUDY ON GEOMETRIC MODIFICATION OF PCM CONTAINER

A significant decrement in the efficiency of photovoltaic (PV) systems occurs with increasing operating temperature. Therefore, effective cooling methods are usually needed to limit the temperature rise on the PV panel surface, and passive methods are favorable for this purpose, due to their cost-effectiveness, low maintenance requirement, and simple design. Utilization of phase change materials (PCM) in this regard is a promising technique due to their high latent heat capacity which can absorb a significant amount of heat during phase change. PCMs are usually filled in enclosures or encapsulations with various geometric shapes and are mounted back to the panel in an appropriate order. At this point, geometric parameter of the enclosure and various heat transfer enhancers, such as fins, metal foams, and nanoparticles, play a remarkable role in the improvement of phase change rate as well as in the augmentation of natural convective heat transfer of melted PCM particularly during the melting period. This work reviews the latest numerical and experimental studies focusing on heat transfer enhancement techniques for the PV-PCM systems, including geometrical modifications on the enclosures. The recent studies are presented and discussed, and the challenges in the field are pointed out. A brief case study aiming at enhancement of natural convective flow of the molten PCM in the enclosure by geometric improvements is also carried out, and relevant future works are suggested with respect to the outcomes of this case study.

Müslüm Arıcı is a faculty member in Thermodynamics and Heat Technique Division of Mechanical Engineering Department of Kocaeli University, Turkey. He completed Diploma Course at von Karman Institute, Belgium in 2007. He received PhD degree from Kocaeli University in 2010. He worked in Fluid Mechanics Research Group, University of Zaragoza, Spain in 2014 and 2016-2017 as a visiting professor. He has co-author of more than 100 papers in refereed journal papers and presented numerous research papers in international conferences. He has served as a guest editor and has been in the editorial board of several international journals. His fields of interest are Energy Efficient Glazing Systems, Numerical Heat Transfer, Computational Fluid Dynamics, Thermal Management by Phase Change Materials, Solar Energy, and Nanofluids.

July 7

INVITED SPEAKER

EFFROSYNI A. GIAMA, Aristotle University of Thessaloniki, Greece

INDICATORS IN TERMS OF CIRCULAR ECONOMY AND LIFE CYCLE IMPACT ASSESSMENT OF PV ENERGY SYSTEMS

Renewable Energy Sources (RES) is undoubtedly a key issue in the Energy Policy of European Union. The EU aims to achieve at least a 32% share (not broken down into nationally binding targets) by 2030. Key instruments at EU level to promote RES include directives, such as the 2009 Renewable Energy Directive. The global growth in the energy industry increases the annual photovoltaic (PV) installations as well as the levels of PV waste. It is estimated by 2050 that there will be 60 and 78 million tonnes of PV waste. On the other hand circular economy challenges, opportunities, models set the base for the best available end of life management of energy systems considering waste management an issue to discuss when design and apply an energy system. Renewable technologies must be implemented in order to ensure decarbonization of the economy and minimize the effects of the climate change while reducing life cycle waste and environmental impacts (from raw-material sourcing, manufacturing, and poor dispositioning at end of life). Integrating solar photovoltaics (PV) and other renewable energy sources into the circular economy (CE) is important for sustainability and resilience. Taking as an opportunity this year Workshop, and having analysed the previous years the effectiveness of RES investments, our concern will be focused on the quantified results of the environmental as well as the energy footprint of PV energy systems in a life cycle approach. The different types of PVs will be presented in terms of technical characteristics, implementation opportunities and environmental impact analysis. The environmental impact as well as the carbon emissions related to PV systems life cycle are examined. The methodology adopted is the Life Cycle Analysis, which offers a holistic approach in the environmental evaluation of systems taking into consideration the production, the installation, the use and the final disposal of the system. Especially, for the disposal stage, quantified scenarios based on circular economy perspective are discussed proving the benefits as well as the restrictions mainly, due to cost effectiveness and technical feasibility.

Effrosyni A. Giama has a diploma in Mechanical Engineering (Dipl.-Eng.) at the Aristotle University of Thessaloniki 2001, ranking 1st of the year's students, a Master of Science in Environmental Science at the Physics Department, Aristotle University of Thessaloniki on 2004. She also has Doctorate in Mechanical Engineering, on the Integrated Environmental Evaluation of Buildings, at the Aristotle University Thessaloniki, 2010. She has participated in more than 28 research projects. Her main research activities are Energy and Environmental Building Management, Life Cycle Analysis, Carbon Footprint Analysis, Circular Economy and Environmental Economics. She also participates in teaching courses on Energy and Environmental Economics, Energy Design of Buildings, Environmental Tools and methodologies and Energy Audits. She is an author or co-author of more than 70 scientific papers published in national and international journals, articles in books and conference proceedings.

July 7

INVITED SPEAKER

DUJE ČOKO, University of Split, Croatia

DATA COLLECTION AND PROCESSING OF LONG-TERM MEASURMENT RESULTS

When it comes to investigating the novel cooling approaches, reliable measurement results are of utmost importance. This case study presents a measurement setup which is used for supervision and data logging in one of our ongoing experiments. This setup includes multiple temperature sensors, calorimeters, wattmeters, flow meters etc. All measured data is recorded in real-time over a six month period with one-minute sampling rate. A well-planned processing and analysis of such a large amount of data is a prerequisite for obtaining a reliable foundation to characterize the applied cooling technique.

Duje Čoko, PhD is an Assistant Professor at the Facultu of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB) at University of Split (Croatia), where he received his MSc and PhD degree in electrical engineering. His fields of interest include design, development and application of electronic circuits and systems, measurements and instrumentation in electronics, as well as design and testing of application-specific integrated circuits. He is an IEEE member since 2007.

July 7

INVITED SPEAKER

THEOCHARIS TSOUTSOS, Technical University of Crete

PROGRESS IN PHOTOVOLTAIC SYSTEMS: INTEGRATION, OPERATION, LIFE CYCLE ASSESMENT

Photovoltaics are globally recognized as a mature technology for power generation. Compared to electricity generation from fossil fuels, PV electricity emits less CO2 and other air pollutants such as NOx, SO2 and CO. As a result, PV systems have been adopted at exceptional scales, with solar PV farms installations being still on the rise.

Even though solar technology is market mature, there is still ample room for further research and development, particularly on the factors affecting building integration, efficiency, and introduction to microgrids and e-car charging.

For example, the PV panel temperature is considered a crucial factor since, through its proper management, the performance, useful life, and environmental profile can be improved. Specifically, a typical PV module converts from as low as 5% to as high as 40% of the incident solar irradiance into electricity.

Experimental results of energy and environmental performance of PV panel cooling when using phase-change materials (PCMs) are also presented. The life cycle assessment methodology revealed that PCM cooling only increases PV's total environmental footprint by ~11.7%.

In parallel, the paper addresses the problem of designing efficient shading devices for buildings. Results show methods that measure the energy produced by PV modules integrated into various external opaque shadings of typical office buildings in Greece.

Finally, PV applications for small grids and charging are offered, which are successful with high replicability potential.

Professor (Chemical & Environmental Eng School, Technical Univ. of Crete), Founder & Director, Renewable & Sustainable Energy Lab (ReSEL) (2005-); TUC Scientific Committee (Member, 2018-); TUC Lifelong Centre (Member, 2021-); Environmental Eng School Management Committee (Member, 2013-2017); Director, Graduate Programme "Environmental Engineering" (2014-2017); Coordinator, TUC-Energy Group (2013-2017); Circular Economy and Climate Change Institute, European Public Law Organization (Board Member, 2021-2022).

Chem. Eng. (National Technical Univ of Athens,1984); Economist (National & Kapodistrian Univ of Athens, Law School,1990); PhD (National Technical Univ of Athens,1990);

115+ publications in international scientific peer-reviewed journals, 20+ book chapters, 200+ conferences; 6,000+ citations; h-factor:33 (Scopus); 39 (Google Scholar)

RDD projects on RES, sustainable energy & mobility;40+ as coordinator,60+ as a partner; 100+ as an expert (FP5, FP6, FP7, H2020, IEE, THERMIE, MED, INTERREG, COST, Jean Monnet)

Editorial Board Member: Sustainable Cities and Society (Elsevier); Energy Efficiency (SpringerNature); Energy Sources-Part A (Taylor-Francis, 2022-); Energies (mdpi); Int. J. Sustainable Built Environment (Elsevier), AIMS Energy, Current Sust./Ren. Energy Reports (SpringerNature), Inventions (mdpi), Green Energy and Sustainability (Pivot Science Publication Corp)

His research work on photovoltaics focuses on integrating photovoltaics in the building skin, sustainability of their lifetime operation, technics to increase their efficiency under the Mediterranean conditions, and their practical use for greening the power systems and connection to e-mobility networks.

This Workshop has been supported by Croatian Science Foundation, under the project: ***„Smart hybrid cooling techniques for siliceous photovoltaic panels" (IP-01-2018)***

ABOUT WORKSHOP

LANGUAGE

The Workshop language is **English**

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