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POLYCRYSTALLINE SILICON PV MODULES AS ELEMENTS OF BIPV SYSTEMS

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Abstract: In this paper, the basic information of BIPV systems and results of theoretical and experimental investigation of electrical energy generated by differently oriented PV modules as elements of BIPV systems in Banja Luka, are given. It was found that in the period from September 1, 2014 to August 31, 2015, optimally oriented polycrystalline silicon PV module of 50W_p generated 61.32 kWh, horizontal module 52.37 kWh, vertical module oriented toward the South 38.72 kWh, vertical module oriented toward the East 25.74 kWh, and vertical module oriented toward the West 24.98 kWh of electrical energy. For theoretical investigation of electrical energy generated with differently oriented PV modules, the PVGIS-CMSAF software is used. The obtained results can be applied in designing residential, commercial and other buildings with BIPV systems in the Republic of Srpska where such investigations have not been not been performed earlier.

Keywords: PV electricity generation, BIPV systems, PVGIS-CMSAF software.

1. INTRODUCTION

Photovoltaic (PV) conversion of solar radiation implies conversion of solar radiation energy into the electrical energy and it takes place in solar cells usually made of monocrystalline and polycrystalline silicon and rarely cells made of thin film materials. Photovoltaics constitutes a new study field for architects and engineers and new designs develop new forms of building façade, roof system installation, efficient operation and other practical aspects. In contemporary architecture, solar cells and solar modules are increasingly used as the roof and facade elements that embelish and simultaneously generate electrical energy for the given object and the net grid as well. Solar cells as the source of electrical energy are being increasingly used in buildings to maximally reduce the consumption of the electrical energy generated by power plants and to reduce the greenhouse gas emission. Contemporary architecture objects with solar cells are energy independent and environment friendly [1−5].

Solar cells can be incorporated into the façade of a building, complementing or replacing traditional view or spandrel glass. Often, these installations are vertical, reducing access to available solar resources, but the large surface area of buildings can help compensate for the reduced power. Also, solar cells may be incorporated into awnings and saw-tooth designs on a building façade. These increase access to direct sunlight while providing additional architectural benefits such as passive shading. The use of solar cells in roofing systems can provide a direct replacement for batten and seam metal roofing and traditional 3-tab asphalt shingles. Using solar cells for skylight systems can enhance economical use of PV and an exciting design feature [6−10].

2. BIPV SYSTEMS

Building integrated photovoltaic (BIPV) installations are able to serve as functional building materials in a number of applications, such as façades (cladding and curtain walls), roofing (solar tiles, slates, shingles and single-ply membranes), and windows (glazing, skylights and sunshades) [10]. A fundamental first step in any BIPV application is to maximize energy efficiency within the building's energy demand or load. Thus, the entire energy system can be optimized. Holistically designed

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BIPV systems will reduce a building's energy demand from the electric utility grid while generating electricity on site and performing as the weathering skin of the building. Roof and wall systems can provide R-value to diminish undesired thermal transference. Windows, skylights, and facade shelves can be designed to increase daylighting opportunities in interior spaces. PV awnings can be designed to reduce unwanted glare and heat gain. This integrated approach which brings together energy conservation, energy efficiency, building envelope design, and PV technology and placement, maximizes energy savings and makes the most of BIPV systems use [10−15].

Among various PV technologies presently available, monocrystalline, polycrystalline and amorphous silicon modules are the most commonly used for BIPV installations. From a design perspective, the choice of technology type will depend not only on the efficiency and cost, but also on the flexibility of application and integration. As well, when considering BIPV systems, various factors must be taken into account such as shading, installation angle and orientation, but most important are available solar irradiation and local climate conditions. Worldwide BIPV systems have been increasingly used for the energy independence of the residential and other objects. Therefore, an issue of the electrical energy generated by BIPV systems in relation to their orientations on the objectcs and local climate conditions is of a vital importance [8−15].

In the existing literature, there are scarce data regarding the amount of generated electrical energy by PV solar modules in the Republic of Srpska, especially for PV solar modules with different geographical orientations and the tilt angle. Moreover, the results of the measured electrical energy generated by five differently oriented solar modules in real climate conditions in Banja Luka (Republic of Srpska) are presented in this paper. In addition, PVGIS-CMSAF software was used for the calculation of the average monthly electrical energy generated by five differently oriented PV modules in Banja Luka and data were compared. Presented data are important to encourage the application of BIPV systems in the Republic of Srpska and to serve as the useful information for neighboring countries with similar climate conditions.

3. EXPERIMENT

The experiment was performed in the Solar Energy Laboratory at the Academy of Sciences and Arts of the Republic of Srpska (ASARS) in Banja Luka (44°46'0" North Latitude and 17°10'59" East Longitude) in the course of one year from September 1, 2014 to August 31, 2015. To determine the amount of electrical energy generation of five differently oriented solar modules at the same time in real meteorological conditions, an experimental solar system (*SolarBox*) was constructed, as shown in Figure 1.

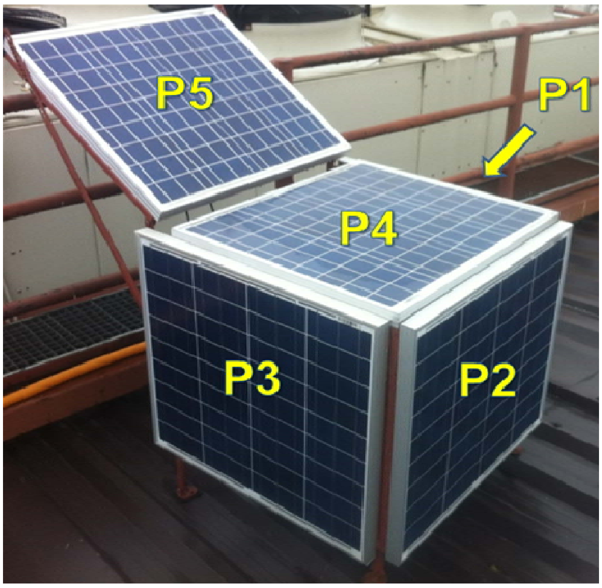

Figure 1. Experimental system (SolarBox) with five differently oriented solar panels installed in the Solar Energy Laboratory at the ASARS in Banja Luka

The SolarBox is composed of five polycrystalline silicon solar panels, single power of $50W_p$ and surface of 0.407 m^2 (PV module area), which are attached to the roof steel structure and oriented in the following way:

Panel 1 – positioned vertically and oriented towards the East (P1-East 90°),

Panel 2 – positioned vertically and oriented towards the South (P2-South 90°),

Panel 3 – positioned vertically and oriented towards the West (P3-West 90°),

Panel 4 – horizontally placed (P4-Horizontal),

Panel 5 – oriented towards the South and tilted at the angle of 33°, which is the yearly optimum tilt angle for a fixed solar module in Banja Luka and which was determined by classic PVGIS (P5-South 33°)

For the measurement I-V characteristics of the solar panels, a *PV-KLA* analyser (Ingenieurbüro Mencke & Tegtmeye, Germany) and a device for automatic measuring control *SolarUsb,* were used. Electrical data aquisition was performed each 15 minutes. Besides, *SolarControlM* (MetteringSolutions, B&H) computer software, which controls this device automatically, monitors the conditions, reliability, synchronization, control, data and archiving of all measurings from all modules, as well as sending notifications of the measuring system interruption.

The measurements were performed in the course of one year (from September 1, 2014 to August 31, 2015) because later some other investigations were performed in the Solar Energy Laboratory at the ASARS.

4. PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM (PVGIS)

In the world market, there is an apparent extent of software programs available for analyzing PV systems, some commercially available and some not. Solar software simulators on the market are designed with different goals in mind and have various limitations for solving certain problems. The desirable features of softwares for manufacturing simulation depend on the purpose of their use. Each software works in its specific area of application in PV systems. As more PV systems are installed, there will be an increased demand for software that can be used for design, analysis and troubleshooting [16].

PVGIS, as part of the SOLAREC action which aimed at contributing to the implementation of renewable energy in the EU, has been developed as the tool for the performance assessment of PV systems and an easy estimation of the PV electricity generation potential for the selected specific locations in Europe, Africa and South-West Asia. PVGIS provides a map-based inventory of solar energy resource and assessment of the electricity generation by PV systems. The methods used by PVGIS to estimate PV system output have been described in a number of papers [16−25]. PVGIS software packages can produce the following data: average daily, monthly and yearly values of the solar radiation taken on square meter of the horizontal surface, or the surface tilted under a certain angle in relation to the horizontal surface, as well as the performances of off-grid and/or on-grid PV systems (free-standing and building integrated) [16−25].

In this paper, the PVGIS-CMSAF software was used for the calculation of the average monthly electrical energy generated by five differently oriented solar modules used in the experiment.

5. RESULTS AND DISCUSSION

This section gives the results obtained upon the study of the experimental and theoretical comparison of electrical energy generated by five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015. In the period mentioned above, the yearly average insolation was 2473 hours and the total solar radiation falling on a square meter of the horizontal surface was 2177.96 kW/m^2.

Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF software for five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015, are given in Figures 2, 3, 4, 5 and 6, respectively.

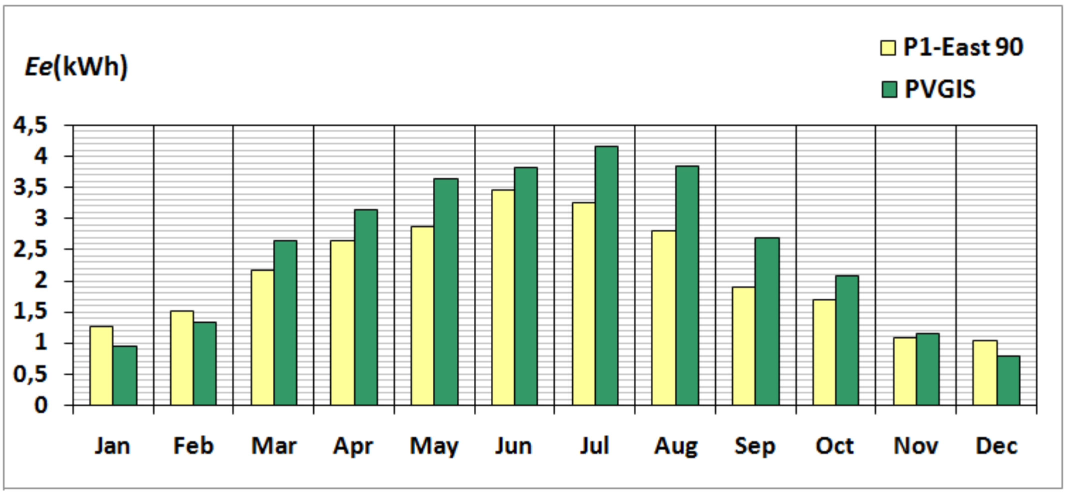

Figure 2. Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF for PV module positioned vertically and oriented towards the East (P1 − East 90°)

Figure 2 shows that the average monthly measured values of the electrical energy generated by vertical PV module oriented toward the East range from 1.04 kWh (December) to 3.47 kWh (June) and the average monthly values of the electrical energy calculated by PVGIS-CMSAF range from 0.795 kWh

(December) to 4.17 kWh (July). Also, the measured values of the electrical energy generated by the vertical PV module oriented toward the East were on average by 14.97% lower than the values of the electrical energy calculated by PVGIS-CMSAF. The biggest difference in data was observed in January (35.4%) and the smallest in November (6.5%).

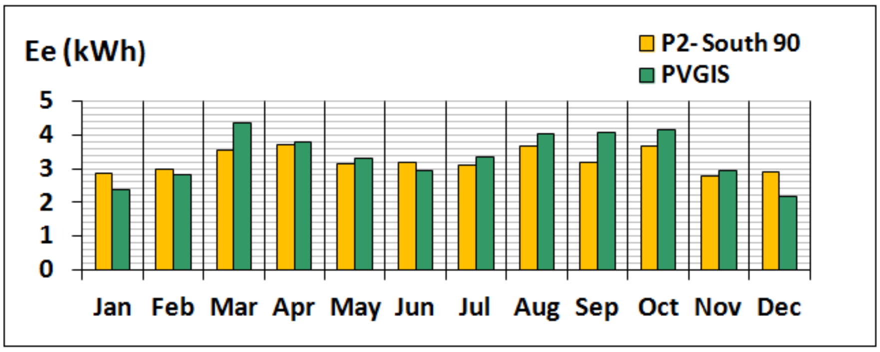

Figure 3. Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF for PV module positioned vertically and oriented towards the South (P2 − South 90°)

Figure 3 shows that the average monthly measured values of the electrical energy generated by the vertical PV module oriented toward the South range from 2.77 kWh (November) to 3.7 kWh (April) and the average monthly values of the electrical energy calculated by PVGIS-CMSAF range from 2.18 kWh (December) to 4.34 kWh (Marth). Also, the measured values of the electrical energy generated by the vertical PV module oriented toward the South were on average by 4.02% lower than the values of the electrical energy calculated by PVGIS-CMSAF. The biggest difference in data was observed in December (33.5%) and the smallest in April (1.55%).

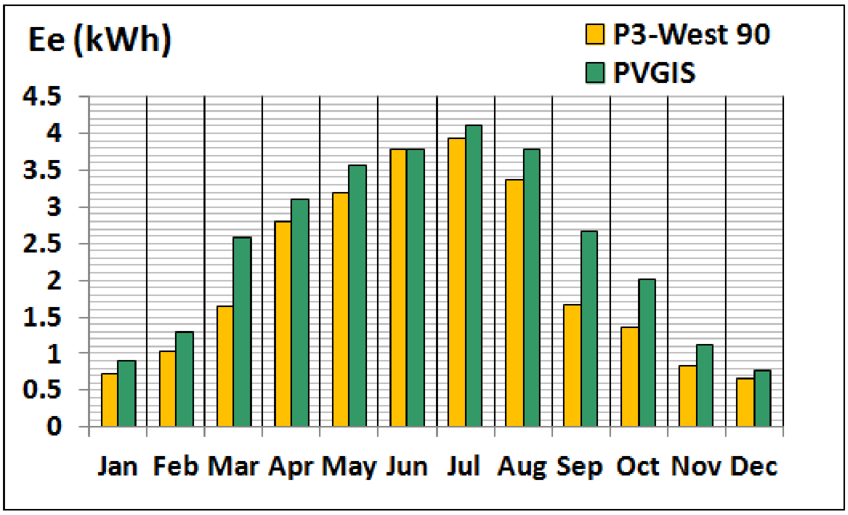

Figure 4. Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF for PV module positioned vertically and oriented towards the South (P3 − West 90°)

Figure 4 shows that the average monthly measured values of the electrical energy generated by the vertical PV module oriented toward the West range from 0.65 kWh (December) to 3.93 kWh (July) and the average monthly values of the electrical energy calculated by PVGIS-CMSAF range from 0.765 kWh (December) to 4.11 kWh (July). Also, the measured values of the electrical energy generated by the vertical PV module oriented toward the West were on average by 15.8% lower than the values of the electrical energy calculated by PVGIS-CMSAF. The biggest difference in data was observed in September (37.9%) and the smallest in June (0.23%).

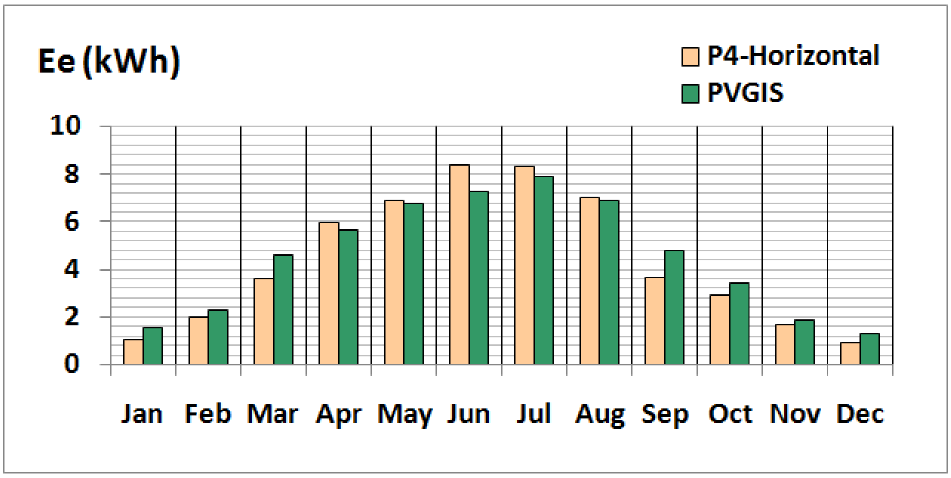

Figure 5. Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF for PV module horizontally positioned (P4 − Horizontal)

Figure 5 shows that the average monthly measured values of the electrical energy generated by the horizontally positioned PV module range from 0.91 kWh (December) to 8.4 kWh (June) and the average monthly values of the electrical energy calculated by PVGIS-CMSAF range from 1.3 kWh (December) to 7.86 kWh (July). Also, the measured values of the electrical energy generated by the horizontal PV module were on average by 3.55% lower than the values of the electrical energy calculated by PVGIS-CMSAF. The biggest difference in data was observed in January (33.8%) and the smallest in August (1.24%).

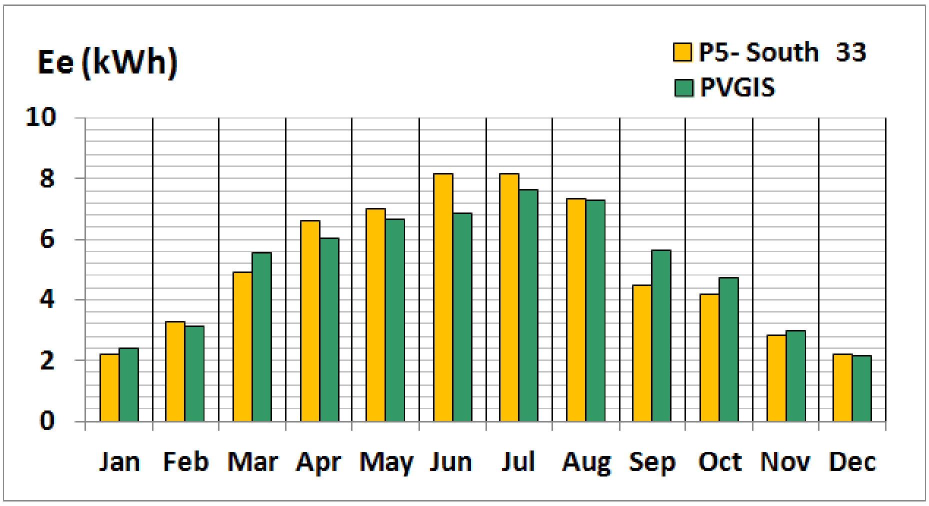

Figure 6. Average monthly measured electrical energy and the energy calculated by PVGIS-CMSAF for PV module optimally positioned and oriented towards the South (P5 - South 33°)

Figure 6 shows that the average monthly measured values of the electrical energy generated by the PV module optimally positioned and oriented towards the South range from 2.2 kWh (December) to 8.15 kWh (July) and the average monthly values of the electrical energy calculated by PVGIS-CMSAF range from 2.15 kWh (December) to 7.62 kWh (July). Also, the measured values of the electrical energy generated by the PV module optimally positioned and oriented towards the South were on average by 0.55% higher than the values of the electrical energy calculated by PVGIS-CMSAF. The biggest difference in data was observed in September (20.6%) and the smallest in August (0.95%).

Average monthly changes of the measured values of the electrical energy generated by five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015, are given in Figure 7.

Total electrical energy generated by five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015 is shown in Figure 8.

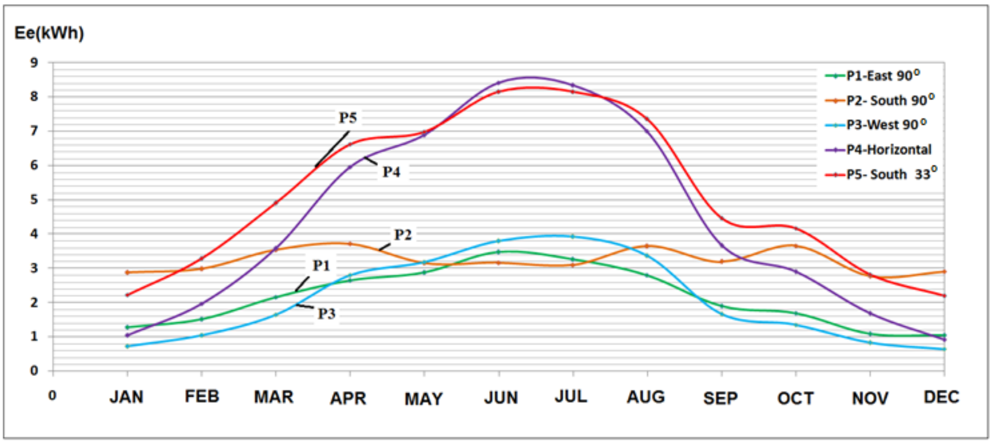

Figure 7. Average monthly changes of the measured values of the electrical energy generated by the five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015

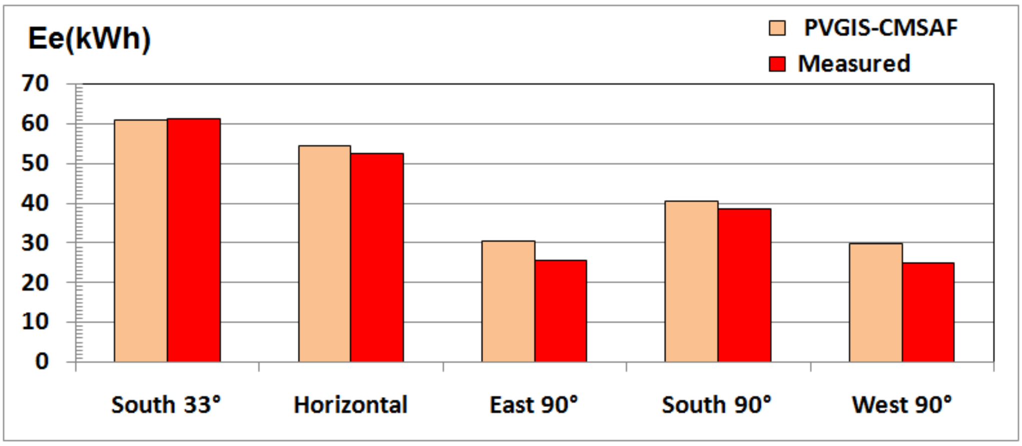

Figure 8. Total electrical energy generated by five differently oriented PV modules in the period from September 1, 2014 to August 31, 2015

The measurements showed that in the period from September 1, 2014 to August 31, 2015, the most of electrical energy was generated by PV module oriented toward the South at the angle of 33° (61.2 kWh), followed by horizontal PV module (52.37 kWh), vertical PV module oriented toward South (38.72 kWh), vertical PV module oriented toward East (25.74 kWh) and vertical PV module oriented toward West (24.98 kWh).

The obtained results are in agreement with the results in the references.

6. CONCLUSION

On the basis of all aforementioned, it can be concluded that nowadays solar cells have increasingly been playing an important part in the aesthetic shaping of the facades of the modern residential and other types of objects, and are providing electrical energy for them, or giving it to the utility grid. Worldwide, BIPV systems have been installed efficiently on numerous old and modern objects converting solar energy into the electrical energy. Having in mind that solar cells have been increasingly used in modern architecture, it is quite obvious that in the cities of the future they will represent an important façade element and an independent source of electrical energy generation. In this connection, it is important to investigate the electrical energy generated by differently oriented PV modules as facade elements. Based on the presented results, it can be concluded that in the period from September 1, 2014 to August 31, 2015:

- Optimally oriented polycrystalline, PV module of 50 W_p generated 61.2 kWh, horizontal module 52.37 kWh, vertical module oriented toward the South 38.72 kWh, vertical module oriented toward the East generated 25.74 kWh, and vertical module oriented toward the West generated 24.98 kWh of electrical energy.
- The difference in generated electrical energy by the vertical PV modules oriented toward

East and West can be attributed to the local climate conditions (afternoon clouds and fog).

- For cities and regions for which there are no measured data, it is possible to use, as a guide, the information provided by the PVGIS-CMSAF software.
- Difference between the theoretical and experimentally obtained values of the generated electrical energy by five differently oriented PV modules ranges from 0.55 (P5- South 33°) − 15.8% (P3- West 90°).

The obtained results can be applied for designing residential, commercial and other buildings with BIPV systems in the Republic of Srpska, where similar investigations were not performed.

7. ACKNOWLEDGEMENT

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ПВ МОДУЛИ ОД ПОЛИКРИСТАЛНОГ СИЛИЦИЈУМА КАО ЕЛЕМЕНТИ БИПВ СИСТЕМА

Сажетак: У раду су дате основне информације о фотонапонским системима интегрисаним у зграде (БИПВ) и резултати теоријског и експерименталног одређивања износа електричне енергије добијене помоћу различито оријентисаних фотонапонских соларних модула (ПВ модула) као фасадних елемената БИПВ система у Бањој Луци. У раду је показано да је у периоду од 1. септембра 2014. године до 31. августа 2015. године оптимално оријентисани ПВ модул од поликристалног силицијума снаге од $50W_p$ генерисао 61,32 kWh, хоризонтални модул 52,37 kWh, вертикални модул оријентисан према југу 38,72 kWh, вертикални модул оријентисан према истоку 25,74 kWh; а вертикални модул оријентисан према западу 24,98 kWh електричне енергије. За теоријско испитивање електричне енергије добијене помоћу различито оријентисаних ПВ модула, коришћен је PVGIS-CMSAF програм. Добијени резултати могу се примијенити код пројектовања стамбених, пословних и других зграда и објеката са БИПВ системима у Републици Српској.

Кључне ријечи: ПВ генерисана електрична енергија, БИПВ системи, PVGIS-CMSAF.