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ASSESSMENT OF THE POSSIBILITIES OF BUILDING INTEGRATED PV SYSTEMS OF 1 kW ELECTRICITY GENERATION IN BANJA LUKA

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Abstract: The paper focuses on the analysis and assessment of the possibilities of building integrated PV (BIPV) systems of 1 kW electricity generation in Banja Luka in the Republic of Srpska. Special attention was paid to average monthly sum of global solar irradiation per square meter received by horizontally, optimally and vertically inclined and south-oriented solar modules of 1kW BIPV system and total for year electricity production from 1 kW BIPV system with horizontally, optimally and vertically inclined and south-oriented solar modules of different materials for Banja Luka, obtained by PVGIS. In addition, comparison was made of total for year electricity production of 1kW BIPV system with horizontal, optimal and vertical inclination and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka. The research estimated the proportion of BIPV systems power generation according to different types of PV modules and installation methods. The data could serve as a useful reference for the application of BIPV systems in buildings.

Keywords: solar energy, building integrated PV systems, PVGIS

1. INTRODUCTION

Energy, which is on top of the agenda of our world, is of crucial importance for humanity. Solar energy can take a vital place in the energy system of a country because it represents a renewable and inexhaustible energy source. The energy of the Sun is clean energy from the point of the environment, and the energy technologies in exploitation do not contaminate the environment. Solar energy is obviously environmentally advantageous in comparison to any other energy source, it is the milestone of any serious sustainable development program. It does not deplete natural resources, does not cause CO_2 or other gaseous emissions into air, nor does it generate liquid or solid waste products [1−3].

One of the most popular techniques of solar energy generation includes installation of photovoltaic (PV) systems using sunlight to generate electrical power. The electricity from photovoltaic cells can be used for a wide range of applications, from power supplies for small consumer products, to large power stations feeding electricity into the grid. The paper [2] states that the world photovoltaic industry has shown an average growth rate of 49,5% over the past 5 years.

In order to enhance sustainable development of the Republic of Srpska urban areas, electricity could be generated by BIPV systems in hotels, health centers, and spas, private households, and other housing objects. The use of BIPV system would considerably increase energy independence and sustainable development in the Republic of Srpska towns.

The paper emphasises the environmental importance of use of PV systems for the electricity generation. Special attention is paid to BIPV systems on residential and some other facilities for electricity generation. This paper also provides an assessment of the possibilities of building integrated PV systems of 1 kW electricity generation in Banja Luka using on-line PVGIS calculator. The data could serve as a useful reference for the application of BIPV systems in buildings in Banja Luka. The

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figures and table can serve as guidelines for the basic necessary data for solar radiation, electricity production and design of on-grid BIPV systems in Banja Luka.

2. BUILDING INTEGRATED PV SYSTEM (BIPV SYSTEM)

In contemporary architecture solar cells are increasingly used as roof and facade elements that decorate and at the same time generate electrical energy for both the given object and the net grid. Thus, blocks of flats can be turned into small scale generators and distributers of electrical energy, which is widely useful. Solar cells as a source of electrical energy are being increasingly used in buildings so as to maximally reduce the consumption of electrical energy generated by power plants and to reduce the greenhouse gas emission. They are also used in schools and in government objects for the education of student population and the citizens to use the solar cells for the electricity generation. Contemporary architecture structures with the solar cells are energy-independent and environment friendly [4–6].

The PV system is a system by which solar irradiation is converted into electrical energy and distributed to the direct and/or alternating current consumers. PV system can function independently of the electric power network (off grid) or it can be connected to it (on grid). Depending on the components that comprise it, off grid PV system can supply the consumers with DC current or AC current. Off grid PV system that gives consumers DC current is composed of solar cells, batteries and battery charge controllers. An off-grid PV system providing consumers with AC current consists of solar cells, battery charge controllers, batteries and DC to AC inverter. An on-grid PV system consists of solar cells, inverter, monitoring system, distribution boxes, switches and related connections. On-grid PV systems represent one of the ways to decentralize the electric power network grid. Electrical energy is generated by these systems nearer to the locations in demand for the electricity and not only by thermo power plants, nuclear power plants or huge hydro power plants. Over time these systems will reduce the need to increase the capacity of transmission and distributive lines [7–11].

The BIPV system (off-grid or on-grid BIPV system) means a PV system where solar modules are installed on the object itself. Solar modules can be installed on the existing roof or the facade or they can directly substitute the roof or the facade of the object. Besides, solar modules can be used as shades in the objects i.e. as a protection from the sun radiation intake. To achieve maximal energy efficiency solar modules are mostly inclined towards the south [4,5] and [8].

The paper [9] claims that the advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost can be offset by reducing normal construction costs of building materials and labor for parts of the building replaced by BIPV modules. These advantages make BIPV one of the fastest growing segments of the photovoltaic industry [12].

A layout of some possible installation modes of the solar modules on the object is presented in Figure 1.

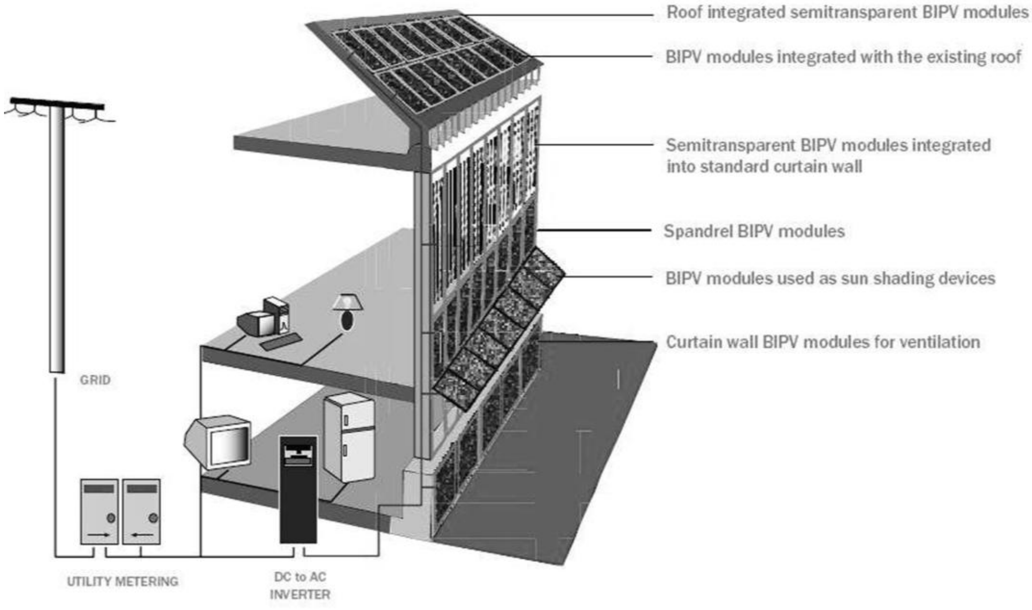

Figure 1. A layout of possible installation modes of the solar modules on the object [8]

PV systems mostly use solar modules made of monocrystalline and polycrystalline silicon, and modules made of thin film materials such as amorphous silicon, CdTe and Copper-Indium-Diselenide (CIS, $CuInSe_2$). Efficiency of the commercial monocrystalline silicon solar cells is 15%, of polycrystalline silicon is around 12%, of amorphous silicon is around 5% and from CdTe and CIS is around 8%. Monocrystalline and polycrystalline silicon solar modules are more suitable for the areas with predominantly direct sun radiation, while solar modules of thin film are more suitable for the areas with predominantly diffuse sun radiation [7], [9], [12−14].

From architectural, technical and financial aspects, BIPV systems have the following characteristics:

− They do not require separate additional land and can be used in densely populated urban settlements,

− They do not require additional infrastructural installations,

− They provide electricity during peak demand and thus lower the workload of the grid,

− They can completely or partially provide electricity for any given building,

− They can substitute conventional construction materials,

− They enhance new aesthetic abilities in innovative ways,

− They can be connected to maintenance, control and functioning of other installations and systems in the building,

− They can reduce costs of electricity generation.

Since facade photovoltaic modules can substitute conventional construction materials, the difference in price between the solar elements per unit of the surface and materials that they can substitute is of vital importance. Thus, the price per unit of the surface of facade photovoltaic system connected to the distribution grid, is almost the same as the price of high quality facade materials such as marble or decorative stone; in this way practical additional benefits of electricity generation by photovoltaic systems is that its price is almost null [8].

3. PVGIS

PVGIS (Photovoltaic Geographical Information System–PVGIS © European Communities, 2001–2008) is a part of the SOLAREC action aimed at contributing to the implementation of renewable energy in the EU. SOLAREC is an internally funded project on PV solar energy for the 7th Framework Programme. PVGIS provides data for the analysis of technical, environmental and socio-economic factors of solar PV electricity generation in Europe and supports systems for solar energy decision-making by EU countries.

In practice, PVGIS on-line calculator is used to calculate solar irradiation that falls on the horizontal plane or a plane tilted at a certain angle in relation to the horizontal plane, ratio of diffuse to global solar irradiation, optimal tilting angle of PV module and reflector of solar irradiation and temperature for any given location in Europe and North Africa. These data are very important when doing calculations of profitability of BIPV systems.

PVGIS methodology comprises solar radiation data, PV module surface inclination and orientation and shadowing effect of the local terrain features (e.g. when the direct irradiation component is shadowed by the mountains). Thus PVGIS represents an immensely important PV implementation assessment tool that estimates dynamics of correlations between solar radiation, climate, atmosphere, the earth's surface and the PV technology used. Several fast web applications enable an easy estimation of PV electricity generation potential for selected specific locations in Europe.

In this paper PVGIS- CMSAF is used. The PVGIS-CMSAF has been recently introduced which uses the new databases for the solar radiation data provided by the Climate Monitoring Satellite Application Facility (CMSAF) from the period 1998-2010 [7,9,13−20].

4. RESULTS AND DISCUSSION

In this section we present an analysis of the average monthly sum of global irradiation per square meter received by the modules of the BIPV system of 1 kW with horizontally, optimally and vertically inclined and south-oriented solar modules and electricity generated by 1kW BIPV systems with monocrystalline silicon, CdTe and CIS solar modules in Banja Luka, processed by the PVGIS-CMSAF.

The paper [13] states that yearly average ratio of diffuse and global solar radiation in Banja Luka is around 0,49; the optimal angle of solar modules in BIPV systems is 33°; the solar irradiation on optimally inclined plane annually yields 4000 Wh/m^2 and is 13% higher than the solar irradiation on horizontal plane and 52% higher than solar irradiation on vertical plane.

Figure 2 shows a comparison of average monthly sum of global irradiation per square meter received by the modules of the BIPV system of 1 kW with horizontally, optimally and vertically inclined and south-oriented solar modules obtained by PVGIS-CMSAF, for Banja Luka.

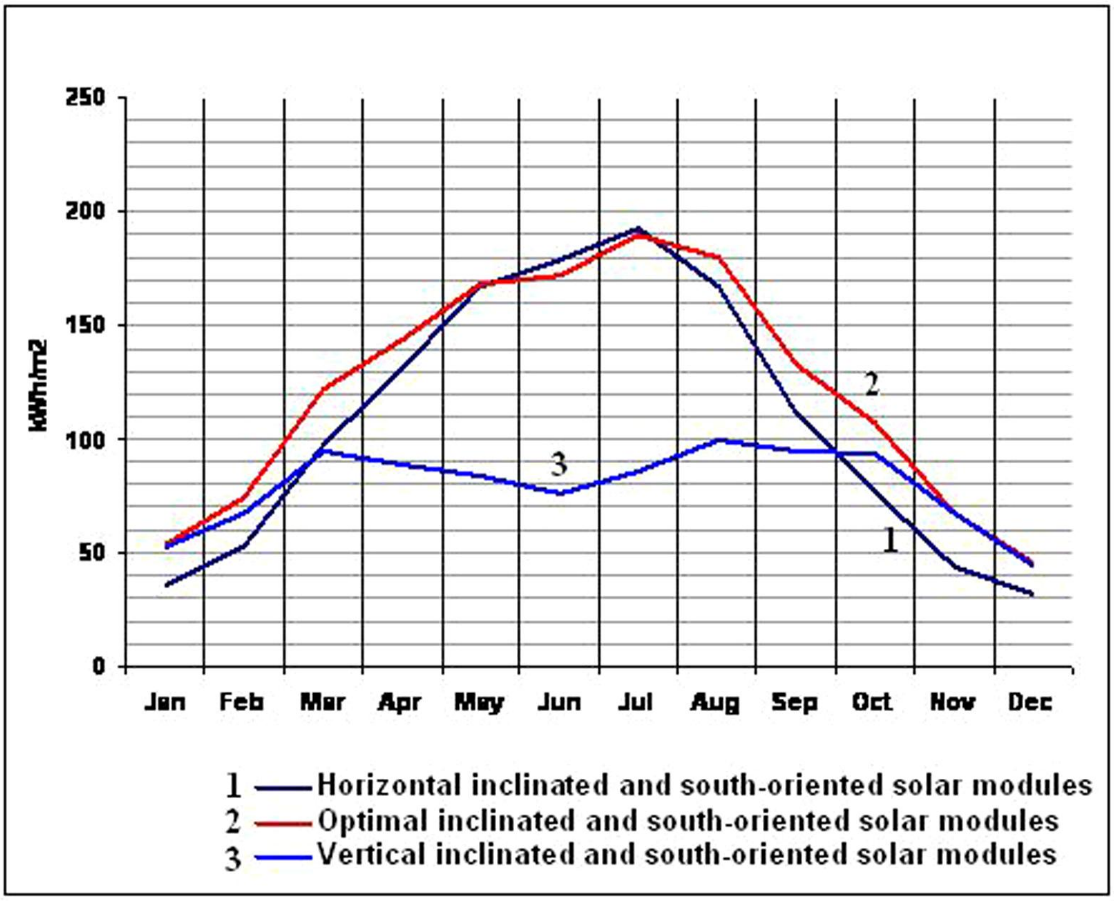

Figure 2. Comparison of average monthly sum of global irradiation per square meter received by the modules of the BIPV system of 1 kW with horizontally, optimally and vertically inclined and south-oriented solar modules obtained by PVGIS-CMSAF, for Banja Luka

Figure 2 shows that:

1. Total for year sum of global irradiation per square meter received by the horizontally inclined and south-oriented 1kW BIPV systems is 1290 kWh/m^2,

2. Total for year sum of global irradiation per square meter received by the optimally inclined and south-oriented 1kW BIPV systems is 1460 kWh/m^2,

3. Total for year sum of global irradiation per square meter received by the vertically inclined and south-oriented 1kW BIPV systems is 952 kWh/m^2 and

4. In Banja Luka BIPV systems of 1kW with optimally inclined and south-oriented solar modules intake 13,2% more solar irradiation compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules and 53,4% more solar irradiation compared to 1kW BIPV system with vertically inclined and south-oriented solar modules, while 1kW BIPV systems with horizontally inclined and south-oriented solar modules intake 35,5% more solar irradiation compared to 1 kW BIPV system with vertically inclined and south-oriented solar modules.

The average monthly electricity production of 1kW BIPV system made of different materials and with horizontally, optimally and vertically inclined and south-oriented solar modules obtained by PVGIS-CMSAF, is given in Table 1.

Estimated losses in 1 kW BIPV systems in Banja Luka obtained by PVGIS-CMSAF are presented in Table 2.

Table 1. Average monthly electricity production of 1 kW BIPV system with different materials of horizontally, optimally and vertically inclined and south-oriented solar modules obtained by PVGIS-CMSAF [28]*

Month	Average electricity production from the BIPV system of 1 kW with south-oriented monocrystalline silicon solar modules (kWh)			Average electricity production from the BIPV system of 1 kW with south-oriented CdTe solar modules (kWh)			Average electricity production from the BIPV system of 1 kW with south-oriented CIS solar modules (kWh)		
	inclination of modules is 0°	inclination of modules is 33°	inclination of modules is 90°	inclination of modules is 0°	inclination of modules is 33°	inclination of modules is 90°	inclination of modules is 0°	inclination of modules is 33°	inclination of modules is 90°
Jan	27,8	42,4	41,3	31,0	46,0	44,7	28,1	43,0	42,1
Feb	41,1	57,3	52,4	45,5	62,5	57,0	41,4	58,3	53,2
Mar	74,0	90,7	71,5	82,6	100	79,4	75,0	92,9	72,7
Apr	96,7	104	64,7	109	116	73,9	98,9	107	65,8
May	119	118	58,3	135	133	68,6	123	121	58,7
Jun	125	118	51,0	143	135	61,1	129	122	50,9
Jul	134	129	57,7	153	148	68,8	138	134	57,6
Aug	117	123	68,5	135	140	80,5	121	128	69,3
Sep	80,4	94,5	68,7	92,0	107	78,8	81,9	97,4	70,0
Oct	57,0	78,4	69,7	64,9	87,8	78,3	57,5	80,5	71,3
Nov	32,7	52,1	51,7	37,0	57,5	57,0	32,8	52,9	52,7
Dec	24,3	36,4	35,0	27,5	39,6	38,0	24,7	36,9	35,7

* For the monocrystalline silicon estimates PVGIS has based the calculations on data from a number of different PV modules measured indoors. The data from all the modules have been combined and used to make an estimate for an "average" crystalline PV module. The results show that there is no significant difference in the behaviour of monocrystalline and polycrystalline modules. The spread in values between modules have a standard deviation of 1,25%, meaning that with 90% probability the deviation of a given module from the estimated value will be less than 2%. The estimate is only valid for "classic" monocrystalline silicon and not for the new types of heterojunction modules that came to the market in the last few years. For CIS modules the estimate is based on outdoor measurements performed in Ispra on three different modules from two different manufacturers. The modules were measured over a four months period during spring and summer. All the modules are rather new, produced in 2006/07, and should therefore be representative of the current state of the technology

Table 2. Estimated losses in BIPV systems of 1kW in Banja Luka obtained by PVGIS-CMSAF [28]

Types of solar modules		Estimated losses due to temperature (using local ambient temperature) on: (%)	Estimated loss due to angular reflectance effects on solar modules: (%)	Other losses (cables, inverter etc.): (%)	Combined PV system losses on: (%)
c-Si solar modules	**inclination of modules is 0° and orientation is 0°**	12,1	3,8	14	27,3
	inclination of modules is 33° and orientation is 0°	14,0	2,7	14	28,1
	inclination of modules is 90° and orientation is 0°	10,5	5,1	14	27,0
CdTe solar modules	**inclination of modules is 0° and orientation is 0°**	0,7	3,8	14	17,8
	inclination of modules is 33° and orientation is 0°	3,8	2,7	14	19,5
	inclination of modules is 90° and orientation is 0°	-1,1	5,1	14	17,5
CIS solar modules	**inclination of modules is 0° and orientation is 0°**	10,2	3,8	14	25,7
	inclination of modules is 33° and orientation is 0°	11,6	2,7	14	26,0
	inclination of modules is 90° and orientation is 0°	9,4	5,1	14	26,0

**The estimated system losses are all the losses in the system, which cause the power actually delivered to the electricity grid to be lower than the power produced by the PV modules. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the modules and so on. PVGIS has given a default value of 14%. Due to really high-efficiency inverter, default value of 14% may be reduced a little [28].

Comparison of average monthly electricity production of 1kW BIPV system with horizontally inclined and south-oriented solar modules of mono-crystalline silicon, CdTe and CIS in Banja Luka is shown in Figure 3.

Figure 3 shows that in Banja Luka total for year electricity production by 1kW BIPV systems with horizontally inclined and south-oriented solar modules of monocrystalline silicon is 930 kWh, with CdTe solar modules it is 1060 kWh and with CIS solar modules it is 951 kWh.

Comparison of average monthly electricity production of BIPV system of 1kW with optimally inclined and south-oriented solar modules of mono-crystalline silicon, CdTe and CIS in Banja Luka is shown in Figure 4.

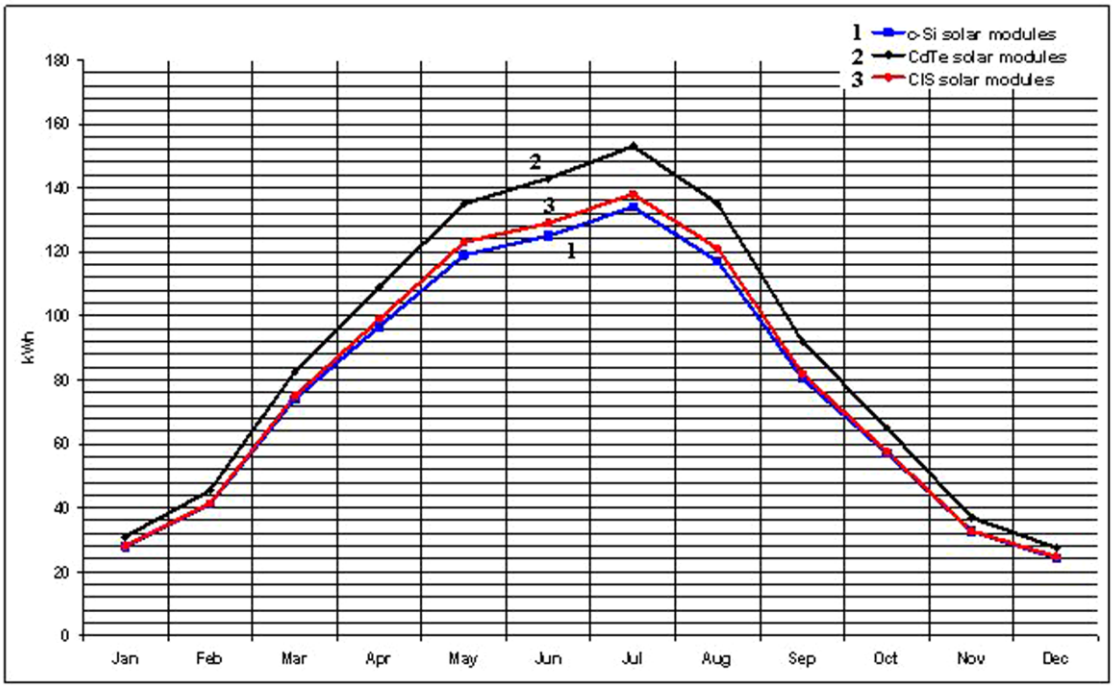

Figure 3. Comparison of average monthly electricity production of 1kW BIPV system with horizontally inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka

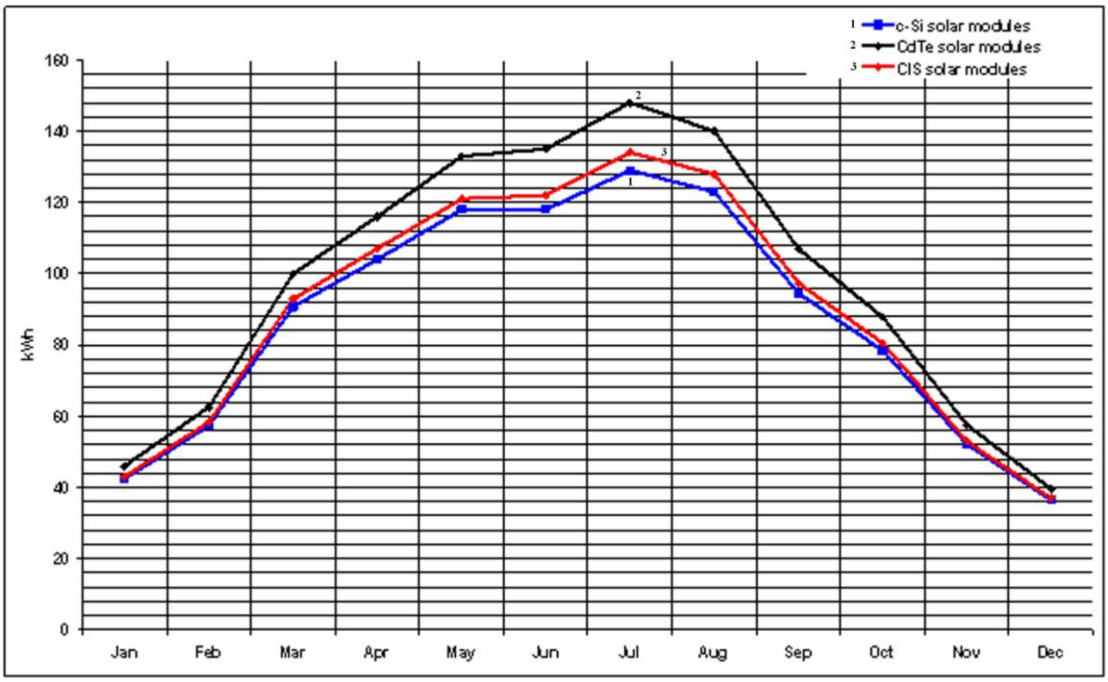

Figure 4. Comparison of average monthly electricity production of 1kW BIPV system with optimal inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka

Figure 4 shows that total for year electricity production by the 1 kW BIPV systems with optimally inclined and south-oriented solar modules of monocrystalline silicon is 1040 kWh, with CdTe solar modules it is 1170 kWh and with CIS solar modules it is 1070 kWh.

Comparison of average monthly electricity production of 1kW BIPV system with vertically inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka is shown in Figure 5.

Figure 5 shows that total for year electricity production by 1kW BIPV systems with vertically inclined and south-oriented solar modules of monocrystalline silicon is 691 kWh, with CdTe solar modules it is 786 kWh and with CIS solar modules it is 700 kWh.

Comparison of total for year electricity production of 1kW BIPV system with horizontally, optimally and vertically inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka is shown in figure 6.

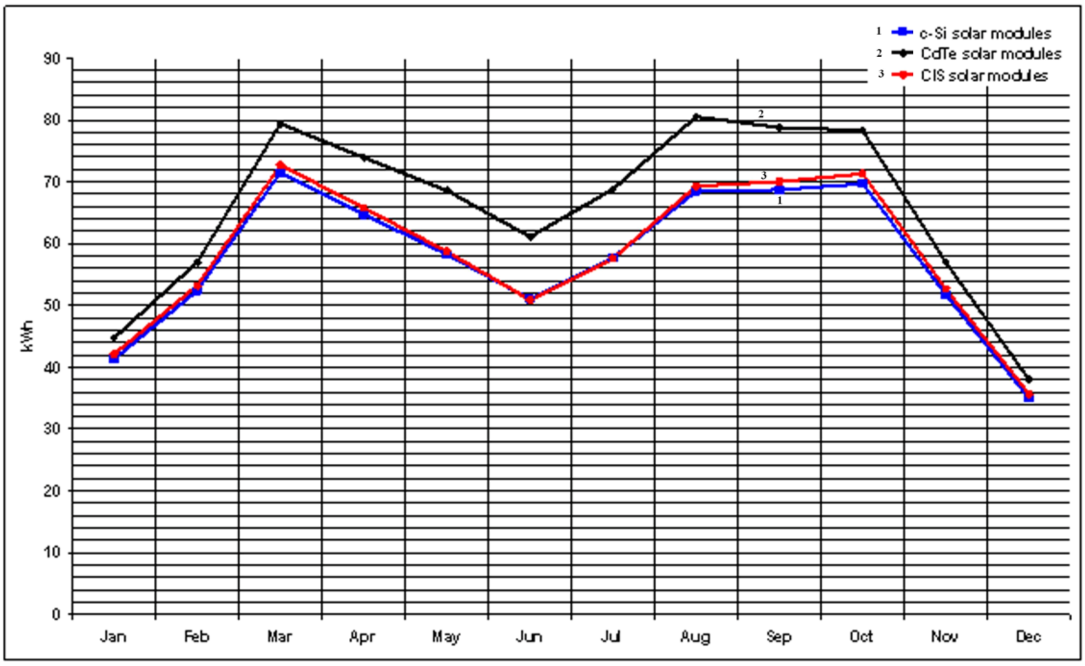

Figure 5. Comparison of average monthly electricity production of 1kW BIPV system with vertically inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka

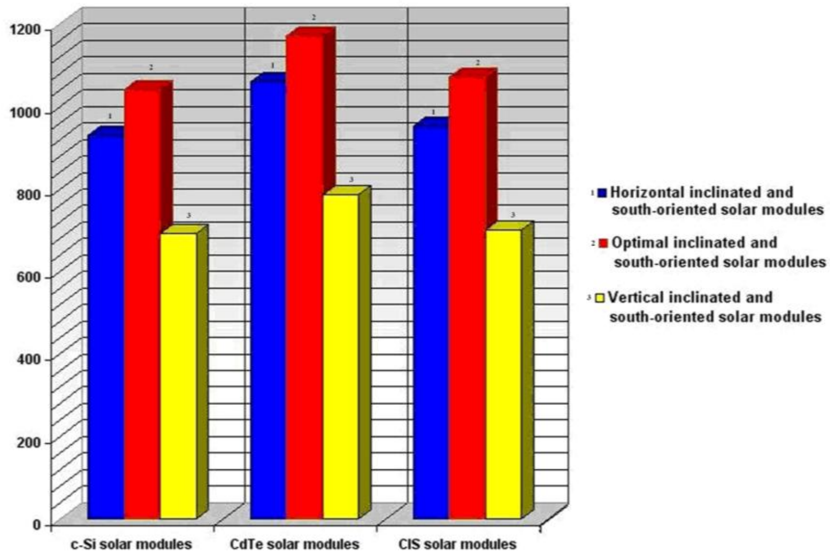

Figure 6. Comparison of total for year electricity production of 1kW BIPV system with horizontally, optimally and vertically inclined and south-oriented solar modules of monocrystalline silicon, CdTe and CIS in Banja Luka

Figure 6 shows that:

1. In Banja Luka by means of 1kW BIPV system with horizontally inclined and south-oriented CdTe solar modules 13,98% more electrical energy is generated compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules of monocrystalline silicon and 11,46% more electrical energy is generated than in the case of 1kW BIPV systems with horizontally inclined and south-oriented CIS solar modules. By 1kW BIPV system with horizontally inclined and south-oriented CIS solar modules 2,26% more electrical energy is generated compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules of monocrystalline silicon.

2. In Banja Luka by means of 1kW BIPV system with optimally inclined and south-oriented CdTe solar modules 12,5% more electrical energy is generated compared to 1kW BIPV system with optimally inclined and south-oriented solar modules of monocrystalline silicon and 9,35% more electrical energy is generated than in the case of 1kW BIPV systems with optimally inclined and south-oriented CIS solar modules. By 1kW BIPV system with optimally inclined and south-oriented CIS solar modules 2,89 % more electrical energy is generated compared to 1kW BIPV system with optimally inclined and south-oriented solar modules of monocrystalline silicon.

3. In Banja Luka, by means of 1kW BIPV system with vertically inclined and south-oriented CdTe solar modules 13,75% more electrical energy is generated compared to 1kW BIPV system with vertically inclined and south-oriented solar modules of monocrystalline silicon and 12,29% more electrical energy is generated than in the case of 1kW BIPV systems with vertically inclined and south-oriented CIS solar modules. By 1kW BIPV system with vertically inclined and south-oriented CIS solar modules 1,3% more electrical energy is generated compared to 1kW BIPV system with vertically inclined and south-oriented solar modules of monocrystalline silicon.

5. CONCLUSION

In the light of all aforementioned one can conclude that:

− In contemporary architecture solar cells are increasingly used as roof and facade elements that decorate and at the same time generate electrical energy for the given object and the net grid as well,

− The advantage of integrated photovoltaics over more common non-integrated systems is that the initial cost can be offset by reducing normal construction costs of building materials and labor for parts of the building replaced by BIPV modules,

− PVGIS provides data for the analysis of the technical, environmental and socio-economic factors of solar PV electricity generation in Europe and support systems for EU countries solar energy decision-makings,

− Total for year sum of global irradiation per square meter received by the horizontally inclined and south-oriented 1kW BIPV systems is 1290 kWh/m^2 in Banja Luka,

− Total for year sum of global irradiation per square meter received by the optimally inclined and south-oriented 1kW BIPV systems is 1460 kWh/m^2 in Banja Luka,

− Total for year sum of global irradiation per square meter received by the vertically inclined and south-oriented 1kW BIPV systems is 952 kWh/m^2 in Banja Luka,

− In Banja Luka 1kW BIPV systems with optimally inclined and south-oriented solar modules intake 13,2% more solar irradiation compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules and 53,4% more solar irradiation compared to 1kW BIPV system with vertically inclined and south-oriented solar modules, while 1kW BIPV systems with horizontally inclined and south-oriented solar modules intake 35,5% more solar irradiation compared to 1 kW BIPV system with vertically inclined and south-oriented solar modules,

− Irrespective of the type of BIPV systems most electrical energy is generated if CdTe modules are used in Banja Luka,

− Total for year electricity production by 1kW BIPV systems with horizontally inclined and south-oriented solar modules of monocrystalline silicon is 930 kWh, with CdTe solar modules it is 1060 kWh and with CIS solar modules it is 951 kWh in Banja Luka,

− Total for year electricity production by 1 kW BIPV systems with optimally inclined and south-oriented solar modules of monocrystalline silicon is 1040 kWh, with CdTe solar modules it is 1170 kWh and with CIS solar modules it is 1070 kWh in Banja Luka,

− Total for year electricity production by the 1kW BIPV systems with vertically inclined and south-oriented solar modules of monocrystalline silicon is 691 kWh, with CdTe solar modules it is 786 kWh and with CIS solar modules it is 700 kWh in Banja Luka,

− In Banja Luka by means of 1kW BIPV system with horizontally inclined and south-oriented

CdTe solar modules 13,98% more electrical energy is generated compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules of monocrystalline silicon and 11,46% more electrical energy is generated than in the case of 1kW BIPV systems with horizontally inclined and south-oriented CIS solar modules. By 1kW BIPV system with horizontally inclined and south-oriented CIS solar modules 2,26% more electrical energy is generated compared to 1kW BIPV system with horizontally inclined and south-oriented solar modules of monocrystalline silicon,

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6. ACKNOWLEDGEMENT:

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ПРОЦЈЕНА МОГУЋНОСТИ ИЗГРАДЊЕ ИНТЕГРИСАНОГ ФВ СИСТЕМА 1 kW ЕЛЕКТРИЧНЕ ЕНЕРГИЈЕ У БАЊОЈ ЛУЦИ

Сажетак: У раду су дате анализа и процјена могућности примјене ФВ система од 1 kW интегрисаних у објектима (BIPV система) у Бањој Луци. Посебна пажња је посвећена анализи сунчевог зрачења које пада на 1 m^2 површине постављене под хоризонталним, оптималним и вертикалним углом у односу на хоризонталну раван и количини електричне енергије која се у току године добија помоћу BIPV система од 1 kW са соларним модулима од монокристалног силицијума и танкослојним CdTe и CIS соларним модулима постављеним у хоризонталном, оптималном и вертикалном положају у односу на хоризонталну раван. За израчунавање енергетске ефикасности BIPV система коришћен је PVGIS програм.

Кључне речи: соларна енергија, BIPV системи, PVGIS.