URBAN AND ARCHITECTURAL CHARACTER OF THERMAL AMBIENT INFLUENCES IN OPERATION OF PHOTOVOLTAIC PANELS ON BUILDINGS

by

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This paper presents some basic urban and architectural requirements regarding the installation of solar panels for electricity production on buildings. These requirements are usually design – aesthetic and functional – constructive. However, from the thermal ambient aspect, constructor's solution is often not in accordance with requirements of architectural and urban planning profession. It is a known fact that thermal environment impacts the yield in the solar panels production. The aim of this paper is to show, based on experience of solar power plant DOMIT, city of Leskovac, Serbia, what is the expected effect in that aspect, in order to choose the optimal solution with regard to the character of the building. The most favorable production have solar power plants built on buildings where the panels on the underside are completely open because they have the best ventilation, and therefore cooling.

Key words: *urban planning, architecture, construction, solar power plant, thermal environment impacts*

Introduction

Energy potential of solar radiation in Serbia is for 30% higher than in Central Europe and the intensity of solar radiation is among the highest in Europe. Particularly favorable are the conditions for usage of solar energy in southeast Serbia where the annual average of global radiation on a horizontal surface amounts is more than 4.2 kWh/m^2 per day. The use of RES used as heating and electric energy has been progressively increasing globally. In order to set clear goals and define strategies for each country, European Parliament adopted directives in 2001 and 2009 which defined share of energy produced from RES and the predictions are that by the end of this decade this share will be 20%. [1, 2] Even potentials for renewable sources usage is really great in our country, until now only hydro potential is the most exploited, while biomass, solar, geothermal and wind energy are underused. In order to encourage usage of RES, government has adopted National Renewable Energy Action Plan which predicts that share of energy from RES in total energy consumption amount is about 27% by the 2020 and it is planned that by 2015, the installed capacity of solar power plants is 5 MW.

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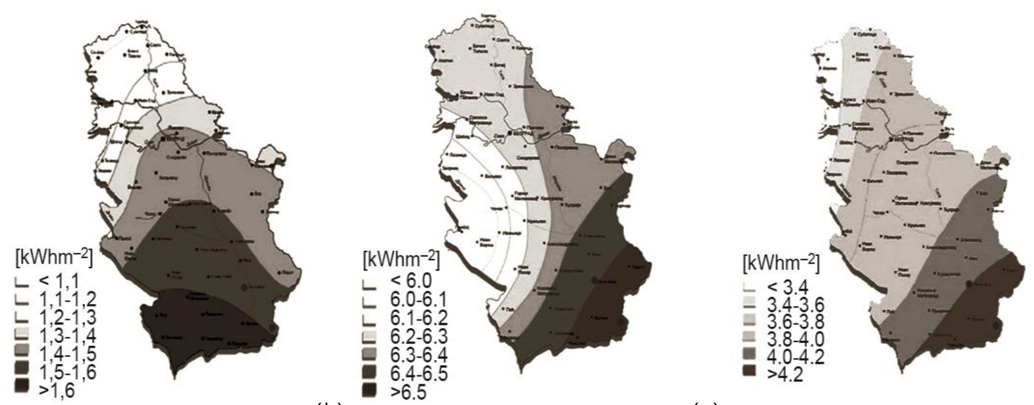
Energy Development Strategy of the Republic of Serbia was addopted and predictions are that until 2030 projected capacity of solar power plants will be up to 200 MW [3]. According to article 4 of Directive 2009/28/EC all states members of EU are in obligation to adopt National Renewable Energy Action Plans in order to set goals and define strategies for usage of RES. Use of RES in Europe is increasing rapidly and goal that was set for 2020 was already reached in 2014 when energy produced from RES reached about 88.4 GW [4].

Regarding solar energy, Serbia has very huge potential and compared to other European countries it could produce more energy thanks to its favorable geographical location and topography. The total installed capacity do not correspond with the natural availability of solar radiation resources, so the most of PV capacity is installed in the German territory where the value of global radiation equals the European average, and it is considerably lower than the value for Serbia. The average solar energy of global radiation on the flat surface during the winter season ranges between 1.1 kWh/m^2 in the north of the country and 1.7 kWh/m^2 in the south, and during the summer season between 5.4 kWh/m^{2}in the north and 6.9 kWh/m^2 in the south. For comparison, average value of global radiation for the German territory is around 1000 kWh/m^2, while the average value of global solar radiation energy in Serbia ranges between 1200 kWh/m^2 a year in the north-west and 1550 kWh/m^2 in the south-east, while in the central area it is around 1400 kWh/m^2 per year. The highest value of annual sum of global solar radiation in Germany (1130-1240 kWh/m^2), coincides with the lowest vale in the north of Serbia (< 1240 kWh/m^2) [5, 6].

According the study of Energy potential of Serbia for the use of solar radiation and wind energy, the most favorable location for installing photovoltaic (PV) panels and construction of solar power plants is on the south-eastern part of our country. Values of solar radiation on horizontal surface in summer, winter and annual average are shown on maps in fig. 1 and it is obvious that solar radiation has highest values in south-eastern part of Serbia where is located *DOMIT* power plant. Results of the conducted study show that the highest amounts of energy on the northern hemisphere are available in the period between April and September, and the energy influx on a certain surface depends on its inclination and orientation in respect to the Sun rays. In case of Serbia, the most favorable orientation with highest annual energy gains is towards south and has a 30° angle in the spring and summer months. During winter months the most favorable inclination is 60° orientated towards south [7].



(a) (b) (c)

Figure 1. Average energy of global radiation on the horizontal surface [kWhm^{-2}]; (a) in January (b) in July, (c) annual average [7]

This paper discusses requirements in terms of urban and architectural planning regarding installation of PV panels and generation of energy. The PV solar power plants that are integrated within the buildings are an important segment in the process of planning of zero energy cities and one of the almost unavoidable element in design of energy efficient buildings. The advantage of use of the PV panels is that there is wide range of materials that can be used and the development of technology can integrate the panels into the design of buildings or completely redesigned the old façade, in order to meet aesthetic requirements. On the other side, thermal environment is one of the main factors which affect energy production and because of that construction of power plants cannot always meet all the requirements in terms of urban-architectural planning. There are many modes in setting PV panels and depending on their position towards south but also towards building – distance and inclination, there is a difference in amounts of generated energy. The aim of this paper is to analyze solar power plant *DOMIT* as an example in order to demonstrate influence of thermal environment on energy production of solar panels. As the result optimal solutions regarding characteristics of the object for PV panels installation will be presented. According measurements that were taken on the object and data from hydro-meteorological institute results were shown and discussed and main conclusion are drawn regarding influence of thermal ambient on energy generation during different months and depending on different position of PV panels on the roof of the objects and different materials of roof cover. Measurements of production were done in period 2013-2017 and taking into account average temperature for the region where *DOMIT* power plant is located, optimal temperature for production was determined.

Importance of thermal ambiance effect from the aspect of town planning and architecture

When a location for construction of mini solar power plants (MSPP) on buildings like the *DOMIT* is selected, there are numerous limitations which make achieving the maximum gains in electric power generation difficult. Choosing the location for construction of power plants, in terms of space and planning, hilly and mountainous regions with better solar exposition should be chosen, since they have better ventilation and less fog [8]. Because of monthly variations in solar radiation and ambient temperature there are oscillations in energy production. In order to precisely define characteristics and position of PV panels for one object it is necessary to accurately predict influence of the specific location and also exact performance of PV panels in given conditions, and to plan and design systems that are cost effective before on-site installation. Constructing power plant in the city core has some limitations regarding air pollution because air pollution, as well as the increasing concentrations of the ground-level ozone in Serbia, have impact on solar radiation intensity and solar cells efficiency, and could result in their values decrease [9]. According to conducted research main cause for decrease of power and total electricity, in terms of air pollution, is most due to carbon soiling, soil particles soiling and least due to calcium carbonate soiling [10]. Because of possible pollution, it is important to take all the aspects of urban environment – both physical and created when choosing location for PV system installation. On the other side, some researches show that sometimes PV energy generation is higher in urban than in rural areas and that greater yield is possible in cold climate locations because of lower temperature of PV panels [11, 12].

These full gains are more easily achievable on the open locations and with the power plants which are built on the ground, because the influential factors for creation of an optimal system are a lot simpler to select. In the built-up urban area, such possibilities for selection do not exist in most of the cases, so the design process is approached with a due complexity so that the site potential would be fully employed. In this particular case, we had to consider an existing structure, narrow land lot and inability to form a new matrix of future structures which would be more favorable in terms of orientation and inclination of roof slopes of solar panels themselves. The PV panels that are integrated on the roofs of the buildings have also impact on the roof surface regarding temperature in summer months. There is a difference between surface under the panels and surface exposed to the Sun in terms of cooling energy and there is a positive daily rooftop cooling effect of shaded surface during certain summer period [13].

It was decided to retain the existing direction in which the building extends, and to use the spaces under the roof planes for installation of panels in a multi-functional way. It was intended that the panels would not spoil the architecture of the building, but to have them concealed and fitted so as if they are the finishing roof cover. This practically meant that the space between the panels and the actual roof cover must be minimal, 3-5 cm, which is not the most favorable in terms of ventilation and cooling of the panels.

On the other hand, the thermal effects were examined, regarding the manner in which they cover the building and their ventilation regarding the air tightness of the space under the roof.

The system of MSPP *DOMIT*

The PV solar plants represent environmentally friendly way of generating energy. Solar power plants consists of various elements – PV modules, inverters, *etc*., during operation it does not produce any noise and it does not emit harmful electromagnet radiation into the environment. Serbia has very favorable conditions regarding generation of solar energy but at the moment there are not many examples of using solar power for private objects or governmental facilities. A building integrated PV (BIPV) system represent system of PV panels that is part of the building structure most often as a part of the roof or façade. In order to provide best solution in terms of energy efficiency, when using BIPV it is important to take into account their orientation and inclination because there are differences between vertical, horizontal, and optimally inclined panels in terms of amount of generated energy, value of efficiency and embodied energy payback. Also, it is important to consider available solar irradiation and local weather conditions [14, 15]. Installing a PV system of solar panels is possible on the roofs of individual houses in order to reduce the consumption of electricity for air conditioning and water heating. According to conducted study [16] it was found that installing a solar system on the roof of the house, with the appropriate level of the roof slope and roof orientation, it is possible to reduce the cost of electricity for more than 51% and thus decentralized model of generating electricity can be achieved. When installing PV modules on the building,

By the mid 2012, the company Designing-Engineering center *DOMIT* Ltd. constructed on its business-industrial building in city of Leskovac, Serbia MSPP. In topographical terms, the city of Leskovac is characterized by the flatland gradually declining towards northeast where elevation varies between 210 m and 240 m above sea level. The climate of Leskovac is moderate-continental, characterized by moderately warm summers and moderately cold winters, with two transitional periods, spring and autumn. This was the first MSPP in the south of Serbia, and its power is 30 kW. After that, in the mentioned compound at this location, another six solar power plants of the same power were built, until 2016, figs. 2 and 3. The layout displays all *DOMIT* MSPP 1-6 which were subsequently constructed. They are designed to constitute an integrated MSPP system of a total power of 210 kW. Main characteristics regarding PV modules and data regarding installed power and invertors are shown in tab. 1.

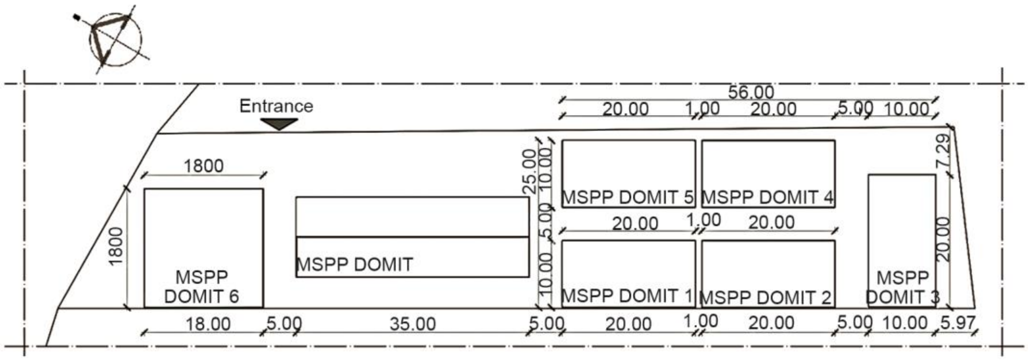


Figure 2. Layout of the power plant system *DOMIT* (by author)

Figure 3. The MSPP *DOMIT*, the first phase of MSPP system in city of Leskovac (by author)

Table 1. Main data about MSPP – PV modules description, data about installed power, data regarding invertors

Elected MSPP	PV module type/power/number of modules	Installed power	Invertor type
MSPP *DOMIT*	HYM 260W, SEASUN/260 Wp/132	34.320 kW	SCHNEIDER Electric, Conext TL 15000 E, nominal power 15 kW
MSPP *DOMIT* 2	Yingli Solar, YL255P-29b/255Wp/120	30.600 kW	Invertor Power-One TRIO-27.6-TL-OUTD
MSPP *DOMIT* 5	JA SOLAR/260Wp/120	31.200 kW	Invertor Power-One TRIO-27.6-TL-OUTD

After years' long experience and successful operation, on this occasion certain tests were carried out and measurements were taken in order to indicate some of the characteristics and issues regarding primarily the ambience temperature and town planning and architectonic characteristics. Installing solar PV system has high level of return on investment and it is one of the most effective systems for use of natural resources that are certainly paid off over the years. Setting plants is possible almost everywhere and level of electricity generation depends on climatic conditions and insolation. Unlike some other systems, with solar power panels setting up properly and the possibility of integrating with the facility, can reduce the need for additional investments and reduce losses.

Correlation of mean monthly temperature and production

For five years of operation of *DOMIT* MSPP, we established that the average monthly production has greatest value in the month of July. However, since the average monthly temperatures according to the data of the Republic Hydrometeorological Service of Serbia were not the same for the mentioned years [17, 18], we attempted to define the dependence using a comparative analysis, tab. 2.

Table 2. Correlation of the maximum average monthly temperatures for the month of July and total monthly production

Year of measurement	2013	2014	2015	2016	2017
Average temperature [°C]	29.8	29.3	32.6	30.8	31.8
Total production [kWh]	5555	5214	5452	5663	5540

The mentioned data indicate that the production does not increase in proportion with the increase of the monthly temperature. The lowest total monthly production occurred in 2014, when the lowest monthly temperature was the lowest. But the higher temperature was not realized in the year when the average temperatures of the month of July were the highest, in 2015. An in-detail analysis shows that the highest total production was realized in 2016 when the average temperature was 30.8 °C. It was the closest value to the average temperature for the month of July in the mentioned years, which is 30.86 °C. Therefore, we can conclude that for the designed and constructed facility, this is the optimal average temperature for the hottest month in a year. The comparative fig. 4 displays it.

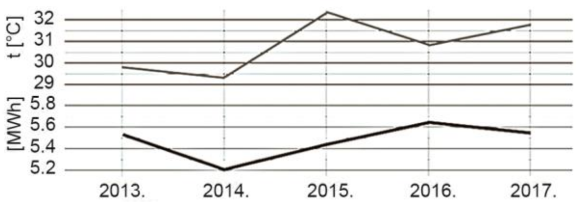


Figure 4. Comparative display of maximum average monthly temperature for the month of July and total monthly production of electric energy for *DOMIT* MSPP

The average monthly temperatures are provided in [°C], and a total monthly production of the observed solar power plant in [MWh]. It is evident that the total maximum production was realized in July 2016. Figure 3 features the appearance of *DOMIT* MSPP. Because of very favorable geographical location, and great values of solar irradiation, for the territory of the Republic of Serbia ranges from 1200 kWh/m^2 per year in Northwest Serbia to 1550 kWh/m^2 per year in Southeast Serbia, use of solar energy is increasing. More than 200 independent PV solar power plants of 1-60 kWh have been installed in Serbia, and several small rooftop PV solar power plants connected to the grid were installed so far [19].

Effects of roof cover on the solar panel production

Regarding the fact that the architectonic structure of the roof with a roof cover for all seven solar power plants was constructed in three different ways, it provides an opportunity to test the effects of those designs on the thermal ambience of solar panels, *i. e.* on their production of electric energy. Three power plants with different substructure and degree of ventilation of the space under the roofs at average heights between three and five meters were selected. Those are: MSPP *DOMIT* – TR sheet metal with thermal insulation, MSPP *DOMIT* 2 – TR sheet metal, and MSPP *DOMIT* 5 – without roof cover. The production is presented at the moment of measuring per [kWh] of designed power of MSPP, and the results are provided in tab. 3. Because system of *DOMIT* power plants is built at the same location, in the relatively same period, but with different equipment and total installed power, total production at the moment of measurement per unit of installed power is shown in column 3. In column 4 the ratio of the manufactured production for the power plants indexed in relation to MSPP *DOMIT*, tab. 3.

Table 3. Correlation of the solar power plant production and the design of roof cover

Selected MSPP	Roof cover	Production at the moment of measurement	Index MSPP *DOMIT* 100%
MSPP *DOMIT*	TR sheet metal with thermal insulation	0.659674	100
MSPP *DOMIT* 2	TR sheet metal	0.700641	106
MSPP *DOMIT* 5	Without roof cover	0.719608	109

Date of measuring 1st July 2017. Measured air temperature at 13.00 hours is 36 °C

The results presented in the table indicate the following status.

– The solar power plants constructed on the roof of the building with a minimal distance from the roof cover of TR sheet metal with thermal insulation in the month of July (with the highest monthly temperature) show the lowest production of electric energy than other analyzed designs, which is the case with the power plant MSPP *DOMIT*.
– The MSPP built on construction of an open building covered with TR sheet metal with the solar panels installed on top of them, MSPP *DOMIT* 2, have for 6% higher production than the previous structure.
– The best production, 9% higher than the thermally insulated roof have the solar power plants where the panels are fully open on the bottom, because they have the best ventilation and thus the cooling, such as MSPP *DOMIT* 5.

It is evident that panel overheating reduces their production.

In order to extend lifetime of the installed PV modules it is important to apply some of the cooling techniques. There are various techniques for passive and active cooling of the PV modules but they are not all environment friendly and economic viable. Regarding active cooling techniques, due to climate change, air cooling based techniques are one of the most harmful for natural environment, and use of water based cooling techniques can increase output of PV modules, on the other hand, these techniques are not followed by economic viability [20].

Effects of external air temperature on production

In order to examine the influence of the outside air temperature on the electricity production of PV panels, measurements made in different days for the period from July 1st until September 12th 2017 were used. Moment of maximum daily temperature and also the greatest insolation values are used here. Table 4 gives results for MSPP *DOMIT* and measured production amount is read from the inverter display. Air temperature from the meteorological station in city of Leskovac was read at the moment of measurement data from the inverters at the production plants.

Measured extreme temperatures values in the specified period are: the highest on July 11th 2017 is 39 °C and the lowest on August 21st, 2017 is 18 °C. However, with parallel observation of the outside air temperature and the production of the PV power plant at that

Table 4. An overview of the influence of outside air temperature on the production of PV panels MSPP *DOMIT*. Production in [kWh] at the moment of measurement at 13.00 hours

Date	*t* [°C]	Production [kW]
July 1st, 2017	36	22.640
July 8th, 2017	34	22.124
July 9th, 2017	35	22.702
July 11th, 2017	39	19.288
July 28th, 2017	28	30.556
July 29th, 2017	33	23.380
July 30th, 2017	35	23.602
July 31st, 2017	38	21.390
August 1st, 2017	37	21.904
August 3rd, 2017	33	23.074
August 7th, 2017	30	21.406
August 9th, 2017	37	20.576
August 15th, 2017	28	22.950
August 18th, 2017	33	19.292
August 21st, 2017	18	24.926
August 26th, 2017	26	22.120
August 30th, 2017	29	21.920
September 5th, 2017	22	27.470
September 10th, 2017	28	21.608
September 12th, 2017	26	23.768

moment they do not show the administrative proportionality. But it is not reversed either, namely, the results show that the minimum production of 19.288 kWh is read at the time of the maximum outside temperature, but the maximum production is not at the time of the minimum temperature. More detailed analysis shows that there is an optimum outdoor temperature when the PV panels give maximum yield. In our case, this was recorded on July 28th 2017, when the current production was 30.556 kWh and the air temperature was 28 °C.

Conclusions

The basic urban and architectural requirements regarding the installation of solar panels for the production of electricity on construction sites, often do not correspond with the technical recommendations of the manufacturer, especially with regard to their inclination and orientation. On the example of the MSPP *DOMIT*, it is concluded that a greater total production amount would have been achieved if the investor and the designer did not favor the designer-aesthetic and functional-constructor requirements. But that was known in advance. However, this work deals more with the ambient-thermal aspect in relation to the built-up structures of the objects. The fact is that the thermal environment has an impact on the yield in the production of solar panels. This paper presents the results of the conducted measurements that highlight following important conclusions.

- For five-year observation July is the period of the greatest total monthly production, but the optimal average monthly temperature for the area of Leskovac city was 30.86 °C in July.
- The most favorable production have solar power plants built on buildings where the panels on the underside are completely open because they have the best ventilation, and therefore cooling.
- Analysis of the measurement result has shown that there is an optimum outdoor temperature when the PV panels give maximum yield. In our case, the current production was maximal at an outside air temperature of 28 °C.
- In general, PV panels do not give the same production in all ambient conditions and outside temperatures. It is recommended to apply the principles of their cooling, which gives a chance for using heat energy for other useful purposes. Results from this research can be used in future construction of building integrated PV modules because they can help in increasing energy generation. Also, they can be useful for architects and civil engineers in order to plan sustainable houses and buildings, and to use PV modules as elements of the façade with their best orientation and inclination. This study was conducted on the example of Leskovac, city in Serbia, but results are applicable to other regions with moderate climate in Serbia or other countries.

References

[1] ***, European Parliament and the Council of the European Union, Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market, *Official Journal of the European Communities* L283, 2001
[2] ***, European Parliament and the Council of the European Union, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC, *Official Journal of the European Union*, L 140/16, 2009
[3] ***, Ministry of Energy, Development and Environmental Protection, The Energy Development Strategy of the Republic of Serbia for the Period until 2025 with Projections until 2030, Ministry of Energy, Development and Environmental Protection, Belgrade, Serbia, 2013 b
[4] ***, European Commission, PV Status Report 2014, European Commission, Luxemburg: Publications Office of the European Union, 2014
[5] Pavlović, T., *et al.*, Comparison and Assessment of Electricity Generation Capacity for Different Types of Photovoltaic Solar Plants of 1 MW in Sokobanja, Serbia, *Thermal Science, 15* (2011), 3, pp. 605-618
[6] Pavlović, T., *et al.*, Possibility of Electricity Generation Using PV Solar Plants in Serbia, *Renewable and Sustainable Energy Reviews, 20* (2013), Apr., pp. 201-218
[7] ***, Institute of Interdisciplinary Research, Study of the Energy Potential of Serbia for the Use of Solar Radiation and Wind Energy (Studija energetskog potencijala Srbije za korišćenje sunčevog zračenja i energije vetra, in serbian), University of Belgrade, Institute of Interdisciplinary Research, 2004
[8] Mitković, M., *et al.*, Analysis of Electricity Generation Results of First Mini Solar Power Plants in the South of Serbia with Varying Inclination of Photovoltaic Panels and Different Environmental Conditions, *Proceedings*, 3rd International Academic Conference on Places and Technologies – Places and Technologies 2016, Beograd, 2016, pp. 183-191
[9] Radivojević, A., *et al.*, Influence of Climate and Air Pollution on Solar Energy Development in Serbia, *Thermal Science, 19* (2015), Suppl. 2, pp. S311-S322
[10] Radonjić, I., *et al.*, Investigation of the Impact of Atmospheric Pollutants on Solar Module Energy Efficiency, *Thermal Science, 21* (2017), 5, pp. 2021-2030
[11] Biyik, E., *et al.*, A Key Review of Building Integrated Photovoltaic (BIPV) Systems, *Engineering Science and Technology, an International Journal, 20* (2017), 3, pp. 833-858

[12] Tian, W., Effect of Urban Climate on Building Integrated Photovoltaics Performance, *Energy Conversion and Management, 48* (2007), 1, pp. 1-8
[13] Kapsalis, V., *et al.*, Simulation of the Cooling Effect of the Roof-Added Photovoltaic Panels, *Advances in Building Energy Research, 8* (2014), 1, pp. 41-54
[14] Pantić, L., *et al.*, A Practical Field Study of Performances of Solar Modules at Various Positions in Serbia, *Thermal Science, 19* (2015), Suppl. 2, pp. S511-S523
[15] Pantić, L., *et al.*, Electrical Energy Generation with Differently Oriented Photovoltaic Modules as Façade Elements, *Thermal Science, 20* (2016), 4, pp. 1377-1386
[16] Jovanović, G., *et al.*, A Model of a Serbian Energy Efficient House for Decentralized Electricity Production, *Journal of Renewable and Sustainable Energy, 5* (2013), ID 041810
[17] ***, Republic Hydrometeorological Institute of the Republic of Serbia: Meteorological Yearbook 1 – Climatological data (for different years), Belgrade
[18] ***, https://www.accuweather.com/sr/rs/leskovac/298334/july-weather/298334
[19] Milosavljević, *et al.*, Current State of the Renewable Sources of Energy Use in Serbia, *Contemporary Materials (Renewable Energy Sources), 2* (2015), 6, pp. 170-180
[20] Nižetić, S., *et al.*, Comprehensive Analysis and General Economic-Environmental Evaluation of Cooling Techniques for Photovoltaic Panels, Part II: Active Cooling Techniques, *Energy Conversion and Management, 155* (2018), Jan., pp. 301-323

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