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The Comparison of the Measured Clearness Index for Different Locations in the Moderate Continental Climate Region

***Abstract**. The object of this research is to compare clearness index for different locations in same climate region, based on measurements. The clearness index is used in conventional analytical modelling of PV resources. Since these models use average values for every climate and geographical region, these parameters are usually provided from generic data bases available from World Wide Web. New empirical average value for clearness index of the researched region can be calculated from results of this research, and used for better modelling of PV resources.*

***Streszczenie.** Celem pracy była analiza przejrzystości powietrza dla różnych lokalizacji ogniw fotowoltaicznych. Badano indeks przejrzystości dla różnych lokalizacji na przykładzie klimatu śródziemnomorskiego – Chorwacji. (**Porównanie przejrzystości powietrza dla różnych lokalizacji ogniw fotowoltaicznych**).*

Keywords: PV plant, conventional analytical model, Grimm's algorithm, irradiation measuring system.
Słowa kluczowe: ogniwa fotowoltaiczne, przejrzystość powietrza, indeks przejrzystości

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Introduction

When assesing PV system electrical energy production various conventional models are used for modeling light resources available in specified location as in [1]. One of these models, very often used in such assesments, is Liu-Jordan-Klein model which was used in this research. It is mathematical model of Sun virtual movement trough sky ([2]) and light dispersing when passing trough atmosphere ([3]), and calculates irradiation on sloped surface of PV modules. The clearness index is one of many parameters used in this model. In this research the average hourly changes of clearness index is provided for four different microlocations, all placed in one macroclimate region ([4], [5]). Mediterranean continental climate is described by average parameters inside the model such as Homer ([6], [7], [8], [9], [10], [11]), and is valid for locations on which this research is conducted. The measured results indicates microlocations differences in clearness index, and can provide empirical average value for researched climate region. The method used in this research can significantly improve modelling of irradiation and PV resources on specific location, as in [12].

Measuring stations and systems

The region of North-West Croatia is characterised with temperate Mediterranean continental climate. The same modeling parameters for light resources and PV system posibilities are used in conventional models due to approach as macrolocation for this region. However, specific microlocation conditions will cause energy production deviations for PV systems placed on different microlocations. Four measuring stations are placed on different locations in researched region. Locations of measuring stations are shown in Fig. 1.

Measured results of irradiation on horizontal surface on Earth (H_o) are compared with theoretical irradiation on top of the Earth atmosphere (H_{on}). Ratio of these two irradiations will indicate how much of irradiation managed to pass from the Sun to specified point on Earth, as shown in equation (1) and [6]. The rest of the irradiation is lost due to reflection from atmosphere and path deflection while passing trough atmosphere.

$$k_t = \frac{H_o}{H_{on}} \quad (1)$$

where: H_o – irradiation on horizontal surface on Earth, H_{on} – theoretical irradiation on top of the Earth atmosphere, k_t – clearness index.

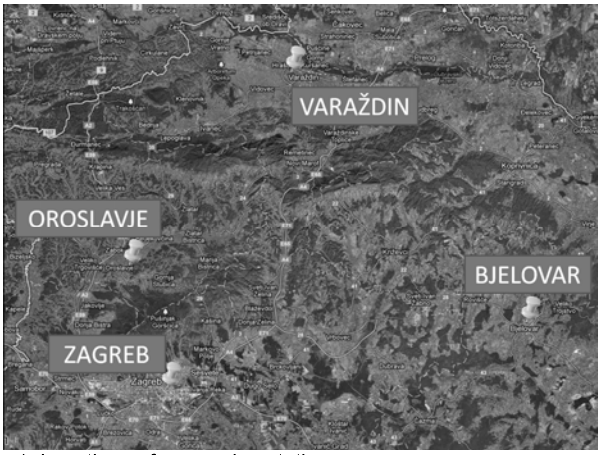

Fig.1. Locations of measuring stations

The first PV plant is installed on Technical School Ruđer Bošković in Zagreb (Fig. 2.) with approximate coordinates 16.028° East and 45.805° North. Immediate area of Zagreb [13] is located between river Sava and south downhill of Medvednica. Location height is 122 m, measured at Zrinjevac which is relevant value for this PV plant. Climate for city of Zagreb is moderate continental, same as in Varaždin, with temperatures averages of 20 °C in summer and 1 °C in winter.


Fig.2. SE Technical School Ruđer Bošković, Zagreb

PV plant is placed on flat roof of school, with 0° of azimuth and slope is adjusted to season optimum. In summer period slope is set to 19°, winter slope to 49°, while spring and autumn slope is equal and amounts 34°. For presented results slope was set to 19°. The power of PV plant is 1.2 kW.

The second PV plant SE Solvis (Fig. 3) is installed in city of Varaždin [14] on north of Croatia, with approximate coordinates 16.3245° East and 46.3245° North. City of Varaždin is located between river Drava and mountains of Zagorje, on edge of Pannonia Plain of alpine system. Location height is between 169 m and 173 m and is decreasing from south-west to north-east. Climate for city of Varaždin is moderate continental, which is relatively cold winter and worm summer with dominant changes of seasons and average daily temperatures. SE Solvis is commercial PV plant with fixed installation of PV modules, with 0° of azimuth and 70° of slope. PV system consists of 96 PV modules with power of 215 W. PV modules are connected in parallel series on inverters. Total PV plant power is 20.64 kW. Three inverters are connection between PV modules and AC distribution network. The catalog data for inverter efficiency is 98 %, but measured efficiency is not constant if operating power is changed, which will be taken into consideration. The PV modules used for this PV plant is Solvis SV 60-215 which is available as commercial product for PV systems.

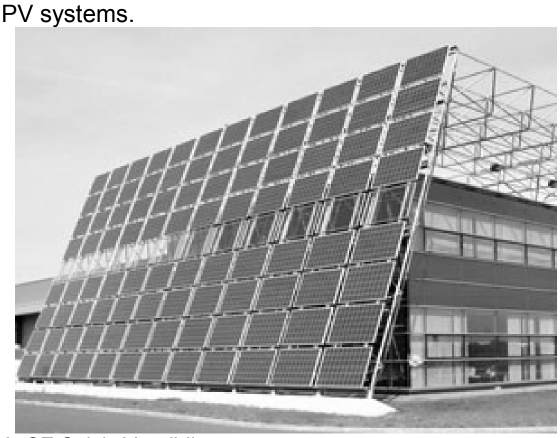

Fig.3. SE Solvis Varaždin

The third PV plant is installed on High School Oroslavje in Oroslavje (Fig. 4) with approximate coordinates 15.918° East and 45.994° North. The city of Oroslavje [15] is located in center of Zagorje, at height of 171 m. Climate for city of Oroslavje is also moderate continental with yearly temperature average of 11 °C. PV plant is placed on hip roof of school, with -20° of azimuth and slope of 30°. Additional losses are introduced due to side roofs which cast a shadow in early morning and late evening hours on PV modules.

Fig.4. SE High School Oroslavje, Oroslavje

For location of planed PV plant irradiation conditions are observed on roof of Technical college in Bjelovar. The building is placed on location of geografical longitude of 16°50'31'' East and latitude of 45°54'9'' North. The town of Bjelovar [16] is positioned 135 m above sea level, on a plateau that had formed at the location where the southern part of Bilogora meets the north-eastern edge of the Lonja-Ilova basin, on rivers Bjelovarska and Plavnička. Bjelovar is located in temperated continetal climate with relatively cold winters and warm summers. Average yearly temperature is 12 °C, and varies from average of -0.4 °C in january to +20.6 °C in july. Wiev for true South from top of the building of Technical college in Bjelovar is shown in Figure 5., and will provide value for albedo when modeling PV plant for this location. The albedo if estimated to 0.15 due to dominant influence of evergreen and deciduous trees in nearby park.

Empirical optimal parameters for planed PV plant in Bjelovar generated from network data of PVGIS [17] varies for different modes of operation of PV plant. Therefore, the optimum orientation for fixed instalation is -1° of azimuth and 34° of slope. If one-axis tracking would be selected optimal yearly parameters would be 53° of slope for azimuth tracking, respectively 0° of azimuth for slope tracking. These values are strictly empirical and not necessarily in any relation with theoretical values.

Measuring and modelling of clearness index

Clearness index is parameter used in Liu-Jordan-Klein model for describing quantity of Sun irradiance which in certain region will pass from top of atmosphere to a point on Earth surface [3]. Losses of irradiation are product of reflectance of irradiation while passing trough atmosphere. This part of irradiation is irretrievably lost and cannot be retrieved.

When attempting to evaluate clearness index values on top of atmosphere and on Earth surface must be known. In order to get these data mathematical model for calculation of irradiation on top of atmosphere is made using Grimm's algorithm and Liu-Jordan-Klein model, and measurement of horizontal irradiation on Earth surface were made. When these data are used in equation (1), clearness index will be calculated for every specific measured and modeled results of irradiation. Such results of clearness index can be used for advanced modeling and planning of PV plant in researched region as shown in Fig.5.

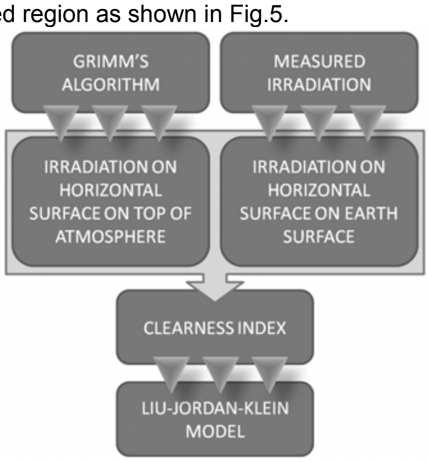

Fig.5. Modeling of clearness index

All of measured data from photovoltaic stations in Zagreb, Varaždin and Oroslavje are provided from module SMA Sunny WebBox [18]. Compact module enables supervision of working conditions, diagnosis and settings changes for photovoltaic system, error detection, e-mail or SMS error messages, measured data acquisition and online web access to photovoltaic system. Since it is compact module it will not be additionally discussed in this research.

Central module of the measurement system in Bjelovar is microcontroller which stores collected data of local horizontal irradiation and ambient temperature. The used module is NXP MBED [19], which is based on the NXP LPC1768 microcontroller with a 32-bit ARM Cortex-M3 core running at 96MHz. It also includes 512KB FLASH, 32KB RAM and interfaces. The analogue input pin P15 on the microcontroller is used to connect Digital illuminance meter ISO-TECH – 1332A [20]. The illuminance meter is fully cosine corrected for the angular incidence of light. The light sensitive device used in the instrument is a very stable long life silicon diode. The instrument is equipped with analogue 0-5 VDC output which is connected to the analogue input pin on the MBED module.

Maximum output DC voltage for the full scale reading on the instrument is 5 V. Full scale reading means that the instrument is measuring 2000 lux. Possible ranges are respectively 200, 2000, 20000 or 200000 lux. All measurements were made with the selected range of 200000 lux, and therefore all of the readings are multiplied with 100 in order to get the measured value of illuminance from integer value. Since only voltage values were measured, transformation using microcontroller is conducted from voltage to lux (1 mV equals 1 lux), and then multiply this result with 100. According to manual, accuracy of the instrument in selected range is ± 4% of the reading (± 0.5 on the full-scale). Measurements were made during 24 h period, with recording time period of 10 minutes. Measured data was saved in the memory of the microcontroller in the *.txt* file form, which is suitable for further data processing. The described assembled measurement system is shown in Fig.6. Measurement system also contained temperature sensor (DS1820) and is equipped with 6 V battery for powering MBED module.

Fig.6. Measurement system in Bjelovar

Measuring results

All measurements of the irradiation on horizontal surface on Earth were made in 21. 06. 2011. and 21. 06. 2012. All of measured results are provided with results of theoretical results of the irradiation on horizontal surface on top of Earth's atmosphere. Results are presented in Fig.7. for Zagreb, in Fig.8. for Varaždin, in Fig.9. for Oroslavje and in Fig.10. for Bjelovar. Grimm's algorithm provides results for selected locations using Sun constant H_{sc} of 1367 W/m².

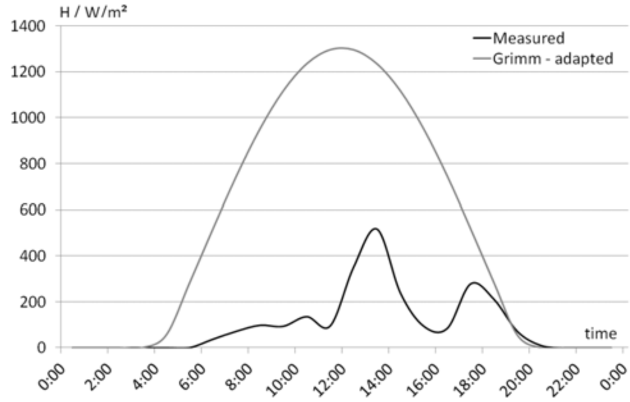

Fig.7. Location of *STS Ruđer Bošković* in Zagreb

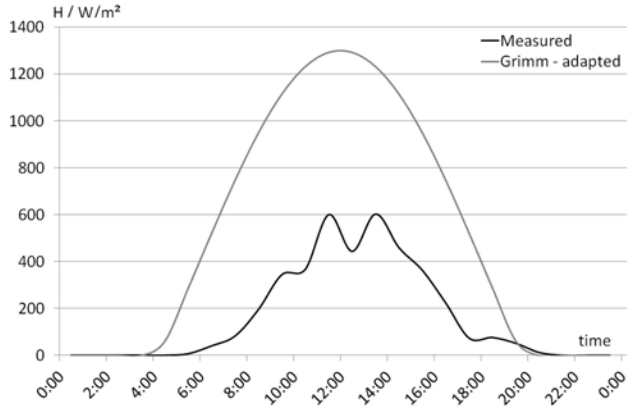

Fig.8. Location of *SE Solvis* in Varaždin

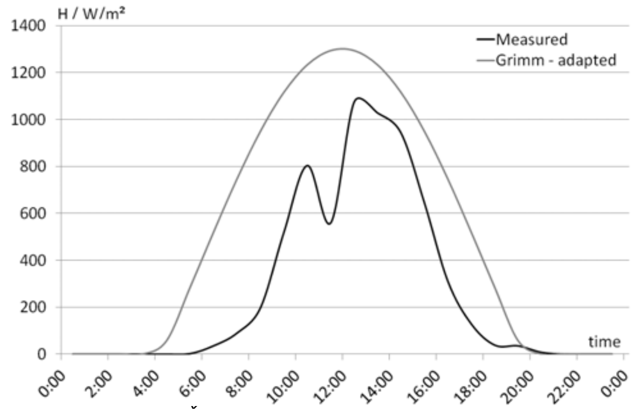

Fig.9. Location of *SŠ Oroslavje* in Oroslavje

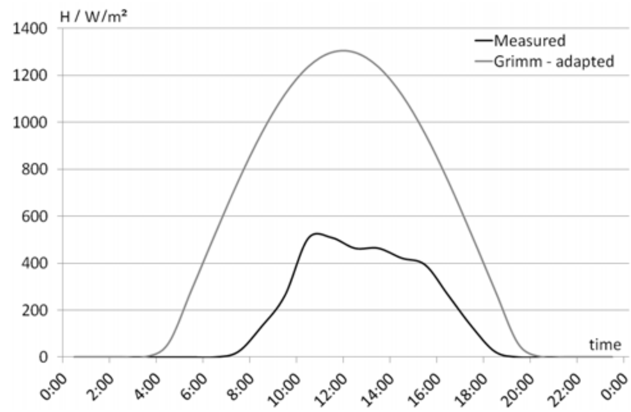

Fig.10. Location of *Technical college in Bjelovar*

When comparing results for all locations it can be seen that Zagreb has the highest losses, while Varaždin and Bjelovar are very similar and somewhat near the middle of the theoretical irradiation range. The location of Oroslavje has the lowest losses, and most of the time has very good passing of irradiation trough the atmosphere. It can also be concluded that development of the industry in the location surroundings has very high influence on irradiation resources of the location. High industrialization will determine low clearness index due to contaminated sky. Since Zagreb is industrial centre of Croatia it is expected to have lowest clearness index.

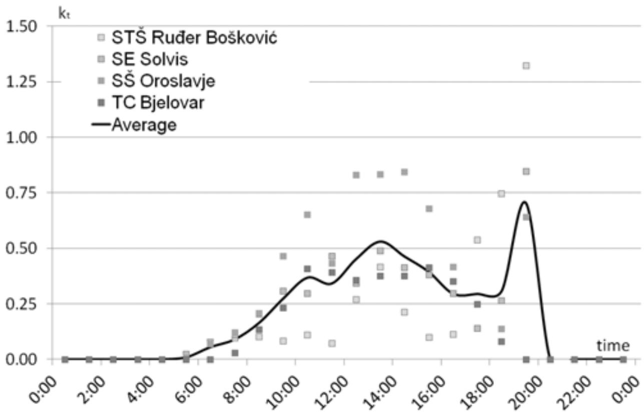

Fig.11. Hourly average of clearness index

In order to get general clearness index of this region, average daily value must be calculated from all these location measuring results. In this research, conducted on the date of 21. 06., clearness index for 15 hours of daylight is 0.315, measured from 05:00 till 20:00.

Conclusion

When using conventional analytical models for prediction of PV system energy production it is common approach to use constant average parameters for selected climate region. In most cases these average values are good enough for rough predictions of energy production of PV systems. If one requires very accurate prediction results, parameters for modelling specific location must also be very close to real state of selected location. In such case average region parameters are not accurate enough, and they must be obtained by measuring and post processing of measured results. Therefore, this research has significant influence on modelling of PV systems for a region on which it was conducted. Better models for predicting energy production will allow good planning and designing of PV plants and integration in electric energy distribution network.

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