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Estimating rooftop photovoltaics placement on administrative building using Building Information Modelling

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Abstract. The implementation of renewable energy sources and energy efficiency measures for administrative buildings, contribute for reduction of costs for electricity and other fuels.

For estimating the optimal rooftop photovoltaic placement on administrative building, a placement analysis is needed. This analysis enables designer to define the optimal placement of the PV modules on the roof using Building Information Modelling (BIM). BIM is based on digital technologies developed with the special purpose for creating a digital model of a building that contains all its physical and functional characteristics and enables easier development of PV system integrated in building. The selected administrative building has a very irregular roof divided on 14 separated rooftops with different orientation and slope. To obtain efficient PV system, the rooftop photovoltaics placement analysis is realised in three different scenarios when all 14 different rooftops are covered by PV modules, 10 rooftops facing north or the ones between other rooftops where shading is imminent, are exempt and 5 rooftops have longer exposure to sun light, or more than 1000 hours per year.

The PV system, designed on 5 selected rooftops contains 335 PV modules with a total power of 135 kW and estimated annual production of electricity of 144 074.26 kWh.

Key words. RES, BIM, Photovoltaics, placement analysis.

1. Introduction

The use of energy from renewable sources is increasingly becoming a significant part of total consumption worldwide.

Of particular importance is the application of renewable energy sources in buildings, because they use 40% of the electricity produced worldwide and are responsible for 36% of CO_2 emissions. Today, 35% of buildings in Europe are older than 50 years, and about 75% of them are energy inefficient [1]. Therefore, investing in energy efficiency and renewable energy sources such as photovoltaics, in a building can be compared to the costs that the same building would have for the energy it uses. Increasing the number of renovated buildings has the potential to lead to significant energy savings, and thus reducing total energy consumption in European Union countries by 5-6% and reducing CO_2 emissions by about 5% [2-4].

The installation of PV system on administrative buildings can significantly improve their energy efficiency and thus reduce the energy taken from the electricity distribution grid. Decentralized electricity generation has its advantages because the produced electricity is consumed locally and does not affect the capacities of the transmission lines in the electricity transmission system, which means that it can have more energy with the same electricity transmission infrastructure [5,6].

Building Information Modelling (BIM) is based on digital technologies developed with the special purpose of creating a digital model of a building that contains all its physical and functional characteristics, divided into groups, which allow independent, but at the same time synchronized realization of the project. The BIM model includes information that defines the entire life cycle of the building from: conceptual design, technical design, construction, management and maintenance [7,8].

If the investor is interested in installing PV system, the BIM model allows to explore all the characteristics of the environment and the intensity of solar radiation at a chosen location, which are essential for determining the potential for electricity generation. Regardless of whether it is more convenient to install a PV system on the roof or on the ground, the BIM model sets the parameters of solar radiation and the appearance of shadows during the year, which optimizes the installation of the PV system [9,10].

The placement analysis of the rooftop is very important on existing buildings, especially in those that have a specific roof architecture. This analysis indicates which of the existing roofs of the building are suitable for the installation of photovoltaic modules, i.e. how much and for how long it is exposed to sunlight, which allows to obtain the maximum utilization of solar radiation.

2. Rooftop photovoltaics placement analysis

The PV system is designed on an existing administrative building (Figure 1) used as an office and warehouse, located in Skopje, North Macedonia (42°01'47,4" N, 21°26'09,3" E), where there are more than 280 sunny days during the whole year. In North Macedonian natural gas as a fuel is not available in general, so almost all buildings are heated and cooled by electricity such as this building. It is heated in winter and cooled in summer using heating/cooling electrical systems, having yearly consumption of electricity around 1500 MWh. Occupation of the building in working hours during the day from 7:00 to 18:00 o'clock make it suitable for installing a rooftop PV system because during this time the majority of the electricity is spent, but also the sun is shining and the PV system can produce electricity, that is used for own consumption. PV system will reduce the electricity needs of the building from the distribution grid and will decrease the consumed electricity cost.

Fig.1. Photography of the rooftop on administrative building

In the recent months the price of the electricity has skyrocketed and the investment in photovoltaics is more profitable now than ever because of rising price of the electricity and energy sources in general.

BIM is a relatively new technology that allows in one model to manage information about the entire life of the building. The application of BIM technology in the construction sector reduces project implementation time and financial costs for it by automating routine operations in typical projects, and in complex ones reduces the possibility of errors, which will lead to significant losses during construction, or the operation of the facility.

If the building owner is interested in installing a photovoltaic system on a building, the BIM model allows to explore all the characteristics of the environment and the intensity of solar radiation at a given location, which are essential for determining the potential for electricity generation. The BIM model sets the parameters of solar radiation and the appearance of shadows during the year, which optimizes the placement of the photovoltaic system.

The electricity produced by the designed PV system is to be used for own consumption as the most profitable way for utilization of electricity form photovoltaics. This is because when the electricity is bought a tax and fees are payed to the distribution system operator that can be as high as one third of the whole price, but when the electricity is sold on the market only the price for the energy is received, so there is a difference in two prices.

If there is any surplus of electricity from PV system, it will be returned to the electricity grid, which is in line with building's purpose and their big consumption of electricity. The surplus of produced electricity will be kept at minimum, possibly only on weekends or late in the afternoon in the summer months when there is a sunlight well up to 8:00 o'clock.

Historically the building was used for different purposes, also it was upgraded and renovated several times. Many of the rooftops aren't made in the same time and there was no long-term planning of the purpose of the building. That is why some of the rooftops are shading each other. This is challenging for installing a rooftop photovoltaics on a building with such an irregular roof, so a placement analysis is made, to determine which of the rooftops are irradiated with enough light needed for the photovoltaics to be profitable.

Rooftop photovoltaics placement analysis is made in software ACCA Solaruis and its tool BIM Editor. ACCA Solarius is used for designing PV systems with all their elements and making a techno-economic analysis of it. It supports IFC (International Foundation Class) files and enables integration with BIM models. This enables engineer to design the PV system on the same model immediately after architect finishes the design of the building before the construction begins. Even if there isn't an existing BIM model for the already built object, ACCA Solarius provides a tool for creating a BIM model with the basic geometry of the building before PV system sizing.

Also, ACCA Solarius is using different databases for solar irradiation on the chosen location.

As a parameter for determination of placement and efficiency of PV modules is the full load hours (*FHL)* of the system. For calculating the parameters for annual produced energy and installed power on the whole roof, the ACCA Solarius software is used. For every separate rooftop it is considered that the whole area of it is covered with photovoltaics and ACCA Solarius is calculating the parameters for annual produced electricity E_{ann} and installed power P_{inst} of PV modules. Using these parameters, the full load hours *FLH* for PV modules projected on each rooftop is calculate by the equation:

$$FLH[\mathrm{h}] = \frac{E_{ann}[\mathrm{kWh}]}{P_{inst}[\mathrm{kW}]} \qquad (1)$$

The following algorithm of steps can be used as a placement analysis on every building with irregular and complex roof with different orientation and slope, such as the building in question in this paper.

The first step in the placement analysis is to determine the overall value of full load hours *FLH* of the whole building using equation (1) and parameter gained from ACCA Solarius. In this case PV modules are placed on every rooftop of the building and despite its position, the full load hours *FLH* is calculated.

The second step in the placement analysis is to examine the orientation and shading of the rooftops. In this case all the rooftops facing north are exempt. Also using ACCA Solarius a shading analysis is made so the rooftops that are between other where shading is possible are also exempt from the calculation. If the value of full load hours *FLH* is greater than the value of full load hours *FLH* in previous scenarios, it means that the rooftops that are exempt don't have good orientation or slope and may have a lot of shades.

The third and final step in placement analysis is made by comparing the full load hours *FLH* on each rooftop chosen in the previous step. The full load hours *FLH* are calculated form equation 1 and the parameters gained with ACCA Solarius. To maximize the efficiency of PV system, in this step for PV system on each roof to be efficient a value for the full load hours *FLH* on the roof should be greater than 1000 hours per year. This threshold value is set empirically from data for PV systems installed in the near region and similar solar irradiation.

Also, if the values of overall full load hours *FLH*, on rooftops having more than 1000 full load hours a year, is greater than the full load hours *FLH* calculated in the second step, it means that this is the most efficient and profitable way to place the PV modules on the building.

3. Results and discussion

For the design of PV system, monocrystalline silicon modules are used with power of 403 W. The PV modules cover entire rooftop surface and the tilt is following the slope. This model of installing PV modules enable to reduce the installation costs of the system.

In the first case of this rooftop photovoltaics placement analysis, for the biggest electricity production from PV system, it is considered that all of the rooftops on the building, 14 in total, are covered with PV modules. The BIM model of the building created in the software ACCA Solaruis with the placement of PV modules is shown on Figure 2.

Using ACCA Solaruis and equation (1), full load hours *FLH* are calculated for the whole system and the full load hours *FLH* of the modules on each rooftop separately. The results of the calculation are shown in Table I.

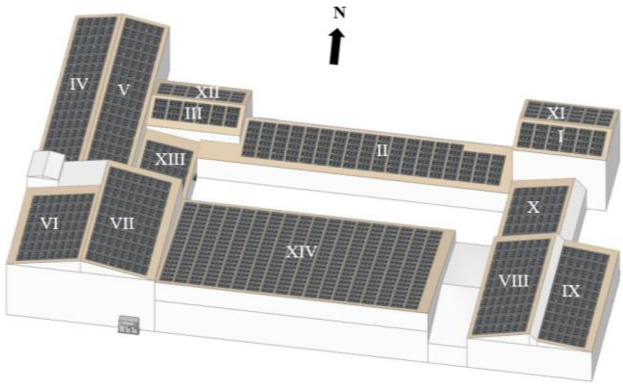

Fig.2. Rooftop placement of PV modules on all rooftops

The value of the full load hours *FLH* of the system on the building in the first case of the rooftop photovoltaics placement analysis is *FLH* = 1.024 h.

Table I. – Full load hours on each rooftop

ROOFTOP	*FLH* (h)
I	1.048,59
II	1.039,39
III	994,32
IV	1.019,85
V	965,79
VI	1.019,85
VII	965,78
VIII	1.015,25
IX	976,52
X	990,56
XI	959,82
XII	910,20
XIII	975,63
XIV	978,34

In the second case of the rooftop photovoltaics placement analysis, for better efficiency of PV system, firstly a shading analysis is made using ACCA Solaruis. In this analysis it is considered that all the rooftops facing north (rooftops XI, XII, XIV) are not suitable for installing PV modules.

Also, on every rooftop on the building the exposure to sun is analyzed. The analysis is made for all the days in the year at 08:00, 12:00 and 16:00 o'clock. The results show that all the roofs are evenly exposed to sunlight except rooftop XIII. Rooftop XIII is relatively small, and it is shadowed from rooftops VI and VII, as it is presented on Figure 3a for shadows at noon on 23.06.2022 and Figure 3b for shadows at noon on 23.12.2022.

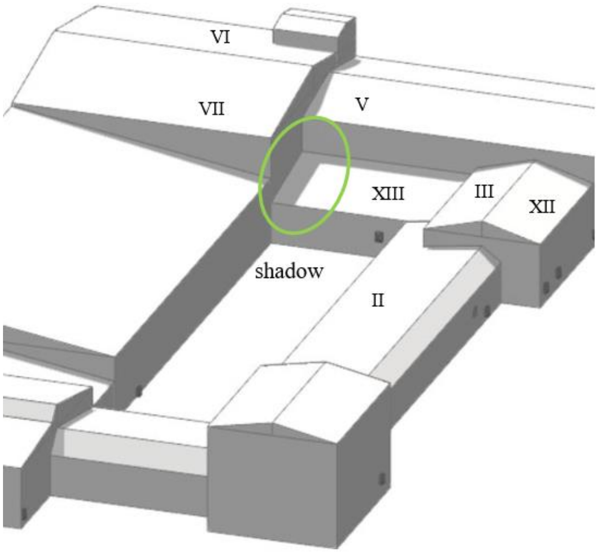

Fig.3a. Shadows on rooftop XIII at noon on 23.06.2022

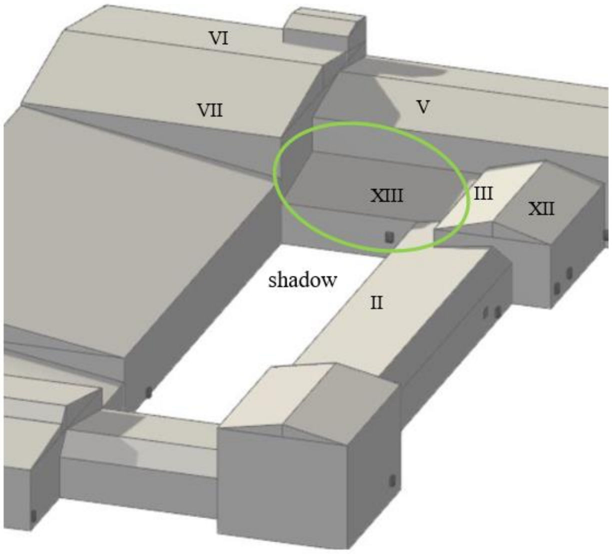

Fig.3b. Shadows on rooftop XIII at noon on 23.12.2022

After the shading analysis of the rooftops is performed, it may be concluded that more suitable rooftops for placement of PV modules are I – X, and their placement of modules are shown on Figure 4.

Value of full load hours *FLH* of the whole system on the building in second case of the rooftop photovoltaics placement analysis is *FLH* = 1.055 h, which determine better efficiency of the PV system than the first case.

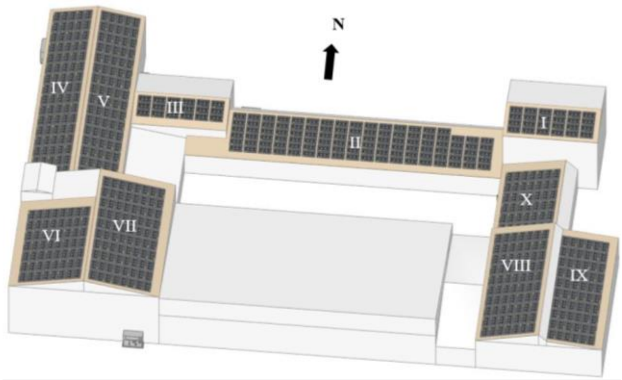

Fig.4. Rooftop placement of PV modules after the shading analysis

In the third case using The BIM model of the building created in the software ACCA Solaruis and its tool BIM Editor a rooftop photovoltaics placement analysis is made. The rooftops that are selected for analysis in the second case are marked from I to X on Figure 4.

Full load hours *FLH* for each selected rooftop from I to X are calculated by Equation (1), using the annual produced electricity E_{ann} and installed power P_{inst} of PV modules given in ACCA Solarius. Results for full load hours *FLH* for each rooftop, given in Figure 5 are used for photovoltaic placement analysis. The full load hours *FLH* values for rooftops I, II, IV, VII and VII are greater than threshold value of 1000 hours per year (Figure 4) and the PV system is designed on this considerations.

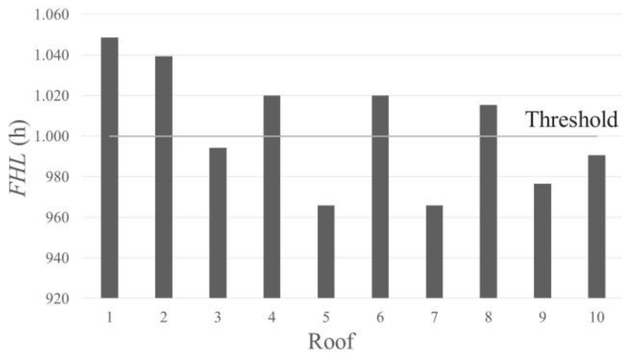

Fig.5. Full load hours *FLH* for PV modules on each selected rooftop

The value of full load hours *FLH* of the whole system on building in the third case of the rooftop photovoltaics placement analysis is *FLH* = 1.061 h, which is better efficiency than the first and second case and it is considered as the best placement case of this building.

The placement of PV modules on the roof after the rooftop photovoltaics placement analysis is shown on Figure 6.

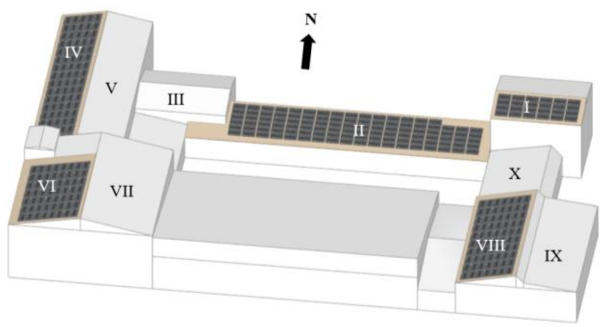

Fig.6. Placement of the PV modules on the roof after the rooftop photovoltaics placement analysis

Number of modules for each selected rooftop is shown in Table II. The total size of the PV system corresponding the 335 PV modules on selected rooftops is P_{inst} = 135 kW.

Table II. - Number of PV modules on each of selected rooftop

ROOFTOP	NUMBER OF PV MODULES
I	24
II	105
IV	80
VI	56
VIII	70

Using the software ACCA Solarius, the value of annual produced electricity E_{ann} = 144 074.26 kWh of the PV system is calculated.

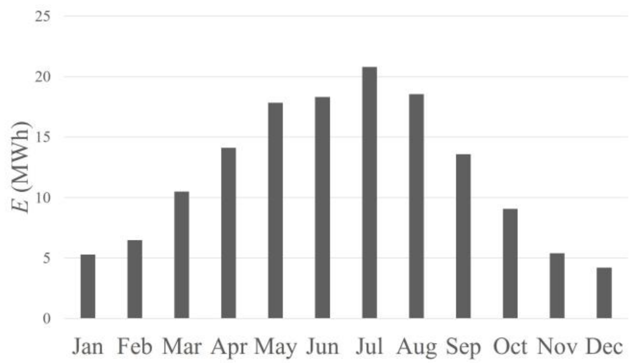

Fig.7. Monthly electricity production of the PV system

On Figure 7 values of monthly electricity production for each month of the year of the designed PV system are shown. As it is expected, the higher values of electricity are generated in the summer.

4. Conclusion

The rooftop photovoltaics placement analysis is a key challenge in designing more efficient PV system. BIM provides a new and easy tool for this analysis especially on new or existing buildings with a very irregular roof.

In this paper three cases are examined for the rooftop photovoltaics placement analysis. In the first case, for the biggest electricity production from PV system, it is considered that all 14 rooftops on the building are covered with PV modules. For second case a placement analysis is made to examine orientation and shading of the rooftops. From all of the rooftops four are chosen as not suitable for PV modules. The third and final case is where the full load hours *FLH* are calculated for each of 10 rooftops. The results show that five of ten rooftops can be selected for installing PV modules. These five rooftops have value of full load hours greater than 1000 hours.

In all cases, the value of full load hours *FLH* are calculated with ACCA Solarius Software on all considered rooftops in the case on the whole building and the results are:

- Case 1: *FLH* = 1.024 h;
- Case 2: *FLH* = 1.055 h;
- Case 3: *FLH* = 1.061 h.

In case 3, the total number of PV modules installed on the roof is 335 with a total power of 135 kW and annual production of electricity of E_{ann} = 144 074.26 kWh. Also, this PV system will produce more electricity in summer than winter as expected, and the electricity produced will almost entirely be used as own consumption due to design on the system.

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