Analyzing the method of determining the energy output of photovoltaic roof tiles

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Abstract: **The paper presents a mathematical method of determining the energy output of photovoltaics roof tiles on the basis of generally available data. The results obtained were compared with the ones generated by a program sponsored by the European Commission.**

Keywords: **renewable energy, photovoltaics, BIPV, energy output.**

I. INTRODUCTION

Building integrated photovoltaics (BIPV) is not yet considerably popular with domestic construction investors, though a wide range of elements is available. It is possible to reduce the total cost of a building and photovoltaic installations by using modules integrated with construction elements rather than traditional solar panels. The popularity of these solutions is hampered by the high prices of the BIPV system elements and by the fact that governments of particular countries cut down green energy grants for investors, in order to reduce budget deficits [1].

The extent of sun exposure is another important limitation, an inhibition that affects the amount of solar system energy, which is intended to be determined in this paper.

II. METHODOLOGY OF DETERMINING THE ENERGY OUTPUT OF A PHOTOVOLTAIC ROOF TILE

Relying on the power of a photovoltaic cell and the geographic location of an installation makes it possible to accurately determine the output of electric energy converted from solar energy. The indispensible data can be found on the webpage of the Ministry of Infrastructure, concerning sun exposure in a given place (solar energy per area unit) with regard to an inclination angle of a panel of 30, 45, 60 and 90 degrees, and the directions of the world. The average sum of total monthly sun radiation intensity (ITH [Wh/m^2]), referring to a horizontal surface in relation to the plane of the earth, needs yet to be converted into the corresponding inclination angle of a module, which usually faces south. For this reason, the indices referring to the south and the main inclination angles can be used in further calculations. It is possible to use appropriate mathematical formulas so as to determine sun exposure for intermediate angles [2].

In order to calculate the average intensity of sun radiation (power density) for a given period – a month, for example – it is necessary to divide sun exposure by the sum of hours from sunrise to sunset. The length of daytime in a particular location can determined by means of the following formula [2]:

$$H = \frac{\mathrm{acos}\{[-\tan(Q\cdot\frac{\pi}{180})]\cdot[\tan(N\cdot\frac{\pi}{180})]\}}{7{,}5\cdot\frac{\pi}{180}} \qquad (1)$$

where:

N – stands for latitude,

Q – stands for solar declination, which can be calculated by means of the following formula [2]:

$$Q = -23{,}45\cdot\cos\left[\left(2\cdot\frac{\pi}{360}\right)\cdot(D+10)\right] \qquad (2)$$

where:

D – stands for another day of the year.

With the data on sun exposure and the length of daytime it is possible to determine the average intensity of sun radiation for a particular month.

The energy output E [kWh] obtained with a photovoltaic installation is determined by means of the following formula [2]:

$$E = T\cdot\frac{I_{śr}}{1000}\cdot E_p \qquad (3)$$

where:

T – stands for the number of daytime hours in a month [h],

$I_{śr}$ – stands for the average sun radiation intensity in a given month [W/m^2],

E_p – stands for installed capacity [kWp].

An analysis was made for Poznan (of a latitude of 52,25^{o}N and a longitude of 16,51^{o}E) [3] with the TEGOSOLAR PVL68 photovoltaic tile of a power of Ep≈60 [Wp] and 1m^2 of active flak [5], the installation facing south and its inclination being 30^o. After the necessary calculations had been made on the basis of the data on the webpage of the Ministry of Infrastructure [4], Table I was developed to list monthly lengths of daytime (number of daytime hours), average intensities of radiation, energy outputs.

TABLE I
Values for Poznan

Month	Sun exposure [Wh/m^2]	Number of daytime hours T [h]	Average radiation intensity $I_{śr}$ [W/m^2]	Energy output E [kWh]
1	36561	250	146.16	2.1937
2	44727	270	165.56	2.6836
3	88066	361	243.86	5.2840
4	115121	413	278.83	6.9073
5	150049	483	310.74	9.0029
6	150239	494	304.12	9.0143
7	142918	493	290.13	8.5751
8	122480	440	278.45	7.3488
9	90529	363	249.28	5.4317
10	53441	310	172.28	3.2065
11	35283	248	142.44	2.1170
12	21235	233	91.01	1.2741

The yearly sun exposure amounts to 1050 [kWh/m^2] approximately, a value that slightly exceeds the total sun exposure in Poland presented by the map shown in figure 1. The result is that a total yearly energy output obtained with 1m^2 of a photovoltaic roof tile is approximately 63 kWh, daytime hours being 4358.

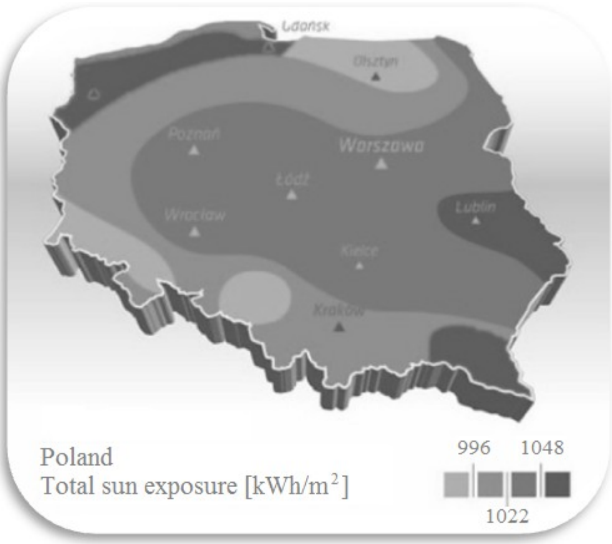

Fig. 1. Total sun exposure in Poland [3]

The above considerations do not allow for the type of a panel, losses made by the inverter and connections, ambient temperature, wind mass, and light reflected by a cell surface. If the total loss of a photovoltaic installation was assumed to be 20% approximately, as the European Commission does, the obtained amount of energy would be approximately 50 [kWh] a year [2, 6].

In addition to the consideration of all the losses that were omitted in this paper, it is necessary to look up the power of a solar cell given in the specification for a particular radiation intensity (the dependence between the two values is not linear) and use it in the following formula to obtain more accurate results [2]:

$$E = T \cdot E_{p\ I_{\acute{s}r}} \qquad (4)$$

where:

$E_{p\ I_{\acute{s}r}}$ – is the power of a solar cell for a particular radiation intensity [kWp].

III. A COMPARATIVE ANALYSIS OF THE MATHEMATICAL METHOD AND THE PROGRAM OF THE EUROPEAN COMMUNITY

In order to check the correctness of the above considerations and the results obtained, it is possible to use the interactive program that calculates the efficiency of photovoltaic systems, one that was funded by the European Commission. Assuming that the initial conditions – the BIPV system, geographical location, installed capacity and the surface of the roof tile - were identical, comparative values were obtained, listed in table II. The program additionally allowed for losses as regards temperature, reflected light, cables, inverters, and the like, at a level of 23.3%.

TABLE II
Energy output as based on the EC program [6]

Month	**Energy output E [kWh]**
1	1.38
2	2.48
3	4.25
4	5.78
5	7.43
6	6.67
7	7.32
8	6.61
9	4.69
10	3.54
11	1.63
12	1.04

It was calculated that the total energy output was 53 kWh approximately, a value that corresponds to the ones obtained earlier, despite discrepancies in particular months of a year. This is shown in the diagram in figure 2.

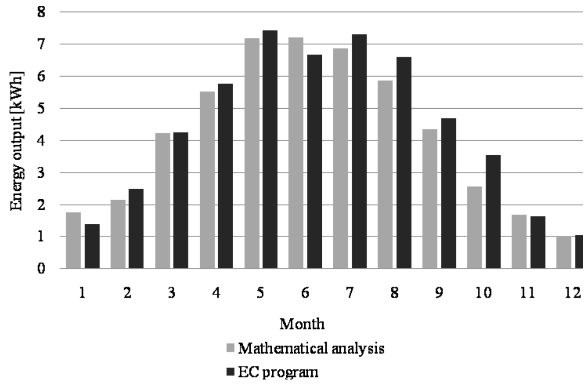

Fig. 2.Monthly energy outputs determined by means of the mathematical analysis and the EC program.

The mathematical analysis in figure 2 allows for an energy loss of 20%. As can be seen, the largest discrepancies occur from July to October. The values in the remaining months may be regarded as being comparable. Moreover, the yearly outputs are at a similar level.

IV. CONCLUSION

The methodology presented of calculating the energy output of a photovoltaic roof cell makes it possible to satisfactorily determine the energy output for any conditions in which a photovoltaic installation operates.

V. REFERENCES

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