Performance simulation of an off-grid photovoltaic power system using TRNSYS 17

Case study for Brasov, Romania

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***Abstract*—The simulation can be used especially in the study and design of some systems or the analysis of some processes finally providing information on the behavior of the given real systems. The simulation offers the possibility to change the conditions of entering the system at the desired time moments (using different simulation scenarios) and to study the effects of these changes at the output, which is impossible in real systems that have a high degree of complexity, and the parameters cannot be controlled in isolation. Simulating the performance of photovoltaic systems allows the analysis and observation of potential results due to various changes, but without changing the evolution of the real system. Different alternatives can also be explored and their results can be studied in a formal way. Under these conditions, the simulation can be used especially for the analysis of complex systems that cannot be solved with analytical techniques.**

Keywords—battery storage; energy consumption profile; performance simulation; solar photovoltaic power; Trnsys

I. Introduction

The acceptance on a wider and wider scale of simulation at performance level of photovoltaic systems involves a number of advantages and disadvantages.

The first and most important advantage of the simulation is that it allows the study of performance using the recorded data of meteorological parameters and not their average hourly, daily or monthly values. In this way, an analysis of the systems working can be performed even in conditions of atmospheric instability or weather fluctuations. For the areas with a temperate-continental climate such as Brașov (a city that under physical-geographical aspect is located at the junction of three large natural units: the Eastern Carpathians, the Southern Carpathians and the Transylvanian Plateau) there may be quite large differences, from year after year, of the values of solar radiation for the same period of year.

In these conditions, the simulation of the performances of an off-grid photovoltaic system is welcome for a sizing calculation as accurate as possible; also based on an economic calculation it may be establish the optimal variant for the number of PVs respectively of necessary batteries. It is envisaged the establishing a balance between two contradictory situations that may occur in the operation of the photovoltaic system, namely:

- its sizing for proper operation for a certain number of days during the winter periods when the solar radiation has the lowest values - a situation that leads to an oversizing of the photovoltaic panel system,
- compared to the summer operation situation when the power may be "wasted" or not collected due to full batteries.

The simulation allows a thorough analysis of the problem in order to obtain the necessary data; hidden relationships or future unknown imperfections of a system can be revealed through simulation. By using the simulation of different operating scenarios, respectively by modifying the input variables, one can determine the importance and weight of their influence on the performance parameters of the system.

The simulation, in general, allows the complicity of reality to be included in the problems, simplifications not being necessary. For example, simulating the performance of a photovoltaic system can use weather data recorded by a weather station from the site of the photovoltaic system implementation, without the need to approximate them by using mathematical models (which in their turn introduce a certain margin of uncertainty) or using weather databases specific to the area closest to the implementation area.

By simulation, a timesaving in terms of decision-making is obtained; respectively the simulation allows the observation in a few minutes of the long-term effect of the different operating scenarios. Decreasing the time duration in the decisions making in conjunction with increasing their accuracy ultimately leads to a relatively low cost.

However, it is mentioned that an efficient simulation model requires a correct formulation of the problem that needs to be solved, respectively correct input data; it should not be overlooked that the results of a simulation are very sensitive to the formulation of the model. It should also be borne in mind that the purpose of simulating photovoltaic systems is to direct the obtained performance / results to those obtained from the operation of a real system.

A more accurate calculation of photovoltaic systems involves solving the problems generated by the disadvantages of their use.

In this sense, it can be mentioned:

- the initial investment for the implementation of a photovoltaic system is relatively large, but if we take into account the continuous growth of this technology, its price could decrease in the future;

- the efficiency of photovoltaic systems is directly influenced by the weather; although photovoltaic systems can work even on cloudy days, their efficiency decreases during periods of unfavorable weather; in addition, at night the photovoltaic systems do not work at all;

- the amount of energy produced is directly proportional to the number of photovoltaic panels needed and often their installation on the roof of buildings may not provide the necessary space; in addition, the orientation of the panels is an important parameter in the calculation of photovoltaic systems;

- a last mentioned disadvantage refers to the storage in batteries of the energy produced and which is not consumed; off-grid photovoltaic systems use batteries that can be charged during the day and discharged during the day and night depending on consumption requirements; this energy storage solution is a good one but also an expensive solution.

In light of the above, this paper proposes to simulate the performance of a photovoltaic system for different sets of input data, in order to find the best option for the implementation conditions. In this regard, the performances of a photovoltaic system will be simulated fora different number of photovoltaic panels, different inclination angles of the panels and different variants of energy storage produced. In this way, by analyzing the performance of the photovoltaic system for different operating scenarios, the designer can choose the variant that best meets the requirements of the system. It is envisaged finding the most cost effective configuration of system, taking into account the differences between the amount of energy produced by the system during the winter and during the summer; in other words, it is desired to find the most efficient variant of operation for the two extreme situations:

- during the summer there is energy that cannot be stored and are lost due to lack of consumer and

- during winter, the energy produced and stored may be insufficient to cover demand for electricity consumption.

In this way, the designer can choose the most convenient version of photovoltaic system depending on the period of year for which it is desired to obtain the maximum performance in operation. By simulating several operating scenarios, a balance variant between the performance of the photovoltaic system and its cost can be chosen. Thus, the designer can choose between different variants of configurations, depending on the concrete requirements for the photovoltaic system, respectively:

- the investment option in a storage system for the off-grid operation on winter type of the photovoltaic system but with the loss of the surplus energy that cannot be stored during the summer; these situations may occur for houses in areas where there is no possibility of connection to the electricity grid but the building is occupied throughout the year and energy independence must be ensured throughout it;

- option of choosing a storage system of energy produced to cover consumption needs for a number of days (a system to ensure energy independence for a number of cloudy days); this situation can be encountered for the situations of holiday homes that have a degree of occupancy only during the summer; it can also be a question of ski huts that are occupied only on weekends.

Only two variants were mentioned above, but certainly the diversity is greater and depending on the consumption requirements at different times of the year, the designer can choose the most economical option for the photovoltaic system, finding a balance between the cost of investment and that of energy that is lost during the summer [4].

What is desired when designing photovoltaic systems is to find the combination of values of the input parameters so that the system meets the desired performance criteria for the desired period of the year.

The main objective of this paper is to simulate the performance of off-grid photovoltaic systems using Trnsys software. In this regard, the first part proposes to explore the implications of input data for meteorological data for energy performance calculations. The second part proposes the comparative analysis of the operating scenarios for different off-grid photovoltaic system configurations. The simulations will be performed for two areas of Brașov, Romania (urban area and extra-urban area).

II. The configuration of the chosen photovoltaic system and the Trnsys scheme for simulating energy performance

Given the subject of the work, for photovoltaic energy production system was chosen a configuration that can be implemented successfully in a home self-consumption (4kWh / day), off-grid. Therefore, for the components of the photovoltaic system, the following variant was chosen:

- 10 photovoltaic panels (5 in series and 2 in parallel), AE Solar, type AE250P6-60, Polycrystalline AE250P6-60, for each solar panel the maximum Power (Pmax) is 250W; array slope: 35^{o};

- 1 MPPT charging controller, 80A;

- 1 inverter / charger, 4Wp continuous;

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• 8 professional Lithium Ion batteries, 9000 Cycles at 50% DOD, 12V, 150Ah; total storage capacity of batteries: 14.4kWh.

The proposed photovoltaic system, with a total power installed in photovoltaic panels of 2500W is implemented in a project with a moderate energy consumption such as that of a permanent home or holiday home [6].

Transient System Simulation (Trnsys) software, developed by the University of Wisconsin (Madison, USA) was used to simulate the performance of the photovoltaic system [1, 2].

The following types of components were used to model the proposed photovoltaic system using Trnsys software (Fig. 1):

• the component Type 94 models the electrical performance of the photovoltaic array; this component allows the simulations involving electrical storage batteries, direct load coupling, and utility grid connections; for this component the following parameters were establish:
  • module voltage at max power point and reference conditions: 29.16V;
  • module current at max power point and reference conditions: 8.57A;
  • number of modules in series: 5;
  • number of modules in parallel: 2;
  • module area: $1.6368 m^2$;
  • array slope: 35^o;

• for the implementation of the measured weather data for both locations (urban area and extra-urban area Brașov) the Type 99 component was used because this component serves the main purpose of reading weather data in a user format; to implement the data provided by the Meteonorm databases, the Type 15 component was used, which reads weather data files in typical Meteorological Year (TMY) format (.TMY);

• the Type 48 component was used to model both the regulator and the inverter; the following parameters have been set for this component:
  • regulator efficiency: 0.78;
  • inverter efficiency: 0. 96;
  • high limit on fractional state of charge (FSOC): 0.95;
  • low limit on FSOC: 0.5;
  • inverter output power capacity: 14400kJ/h, respective 4kW;

• the batteries were modelled using the Type 47 component that operates in conjunction with solar cell array and power conditioning components; the following parameters have been set for this component:
  • Cell Energy Capacity: 1800Wh;
  • Cells in parallel: 2;
  • Cells in series: 4;
  • Charging efficiency: 0.9;

• the Type 41 component was used to model the daily power consumption schemes offered by the Type 14 components; the Type 41 component allows the specification of seven forcing functions, one for each day of the week; for this example only three forcing functions were used, one for Monday to Friday (M-F eqp/lgt), one for Saturday (Sa eqp/lgt) and one for Sunday (Su eqp/lgt);

• the Type 57 component was used for each situation where it was necessary to use the conversion routines of the units of measurement (components: Convertor C - K, Convertor W - kJ/hr, Convertor kJ/hr - W) or for situations where it was necessary to use calculation tools specific to equations (Q_solar, Efficiency, pLoad);

• Type 65d components have been used to display selected system variables while the simulation is progressing allowing the user to immediately check if the system is working as desired; if in addition it was desired to perform various processing of the displayed parameters, to save them in a file with the desired format the Type 65c component was used.

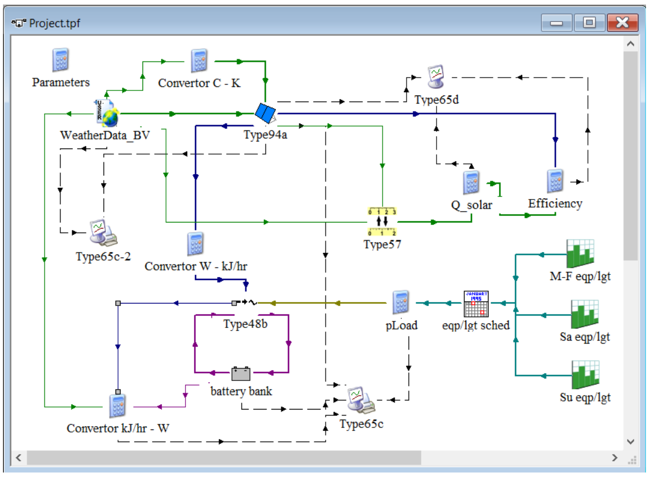


Fig. 1. *Trnsys scheme of the off-grid system*

III. Energy Consumption Scheme

Energy consumption is an important aspect in sizing the components of a photovoltaic system; on it depends both the number and the surface of the photovoltaic panels but also the dimensioning of the battery banks.

For electricity consumption, a standard charging profile was considered from a household from Brașov, consisting of two adults and a child. The load profile at an annual consumption is of 1513kWh.

For the present situation, a maximum daily consumption of 4kWh and an installed power of 4kWp were considered. Time-dependent profiles are defined by days, a profile from Monday to Friday, a profile for Saturday and a profile for Sunday, and then they are repeated (Fig. 2).

It is also mentioned that the sizing of battery banks also depends on the energy autonomy of the photovoltaic system; the days of energy autonomy are days when the solar system cannot generate energy because the weather does not allow this, but in the house, the energy consumption is not interrupted. For the correct sizing of the battery banks it is necessary to establish their necessary capacity depending on the number of days of energy autonomy (there may even be successions of days with cloudy skies in which the solar potential is low); for the proposed system configuration, two days of energy autonomy were considered.

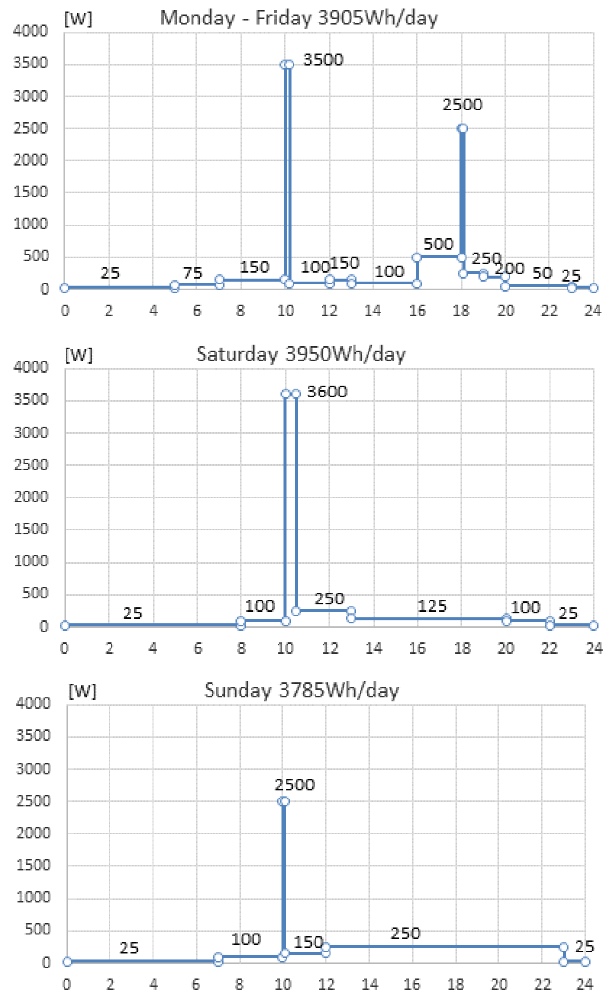


Fig. 2. *Scheme of the daily energy consumption profile*

IV. Results and Discussions

A. Influence of Measured/Simulated Weather Data on Evaluating the System Performance

In the first stage, a comparative analysis of the simulation results obtained with the meteorological data provided by Meteonorm and those measured for the two study areas (urban area and extra-urban areas Brașov) will be performed.

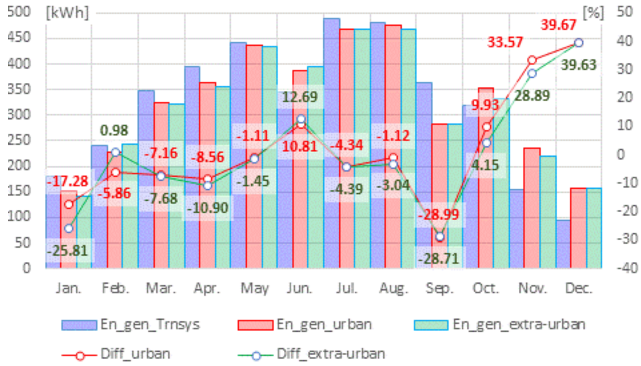


Fig. 3. *Monthly values of energy in/ from generation – simulations performed with the weather data provided by the Meteonorm software and the weather data measured in the urban and extra-urban area of Brașov*

In this sense, a first analysis refers to the values of energy from solar PV array. If we refer to the annual values of energy in/from generation, the following values were obtained: En_gen_Trnsys =3852.7kWh/year, En _gen_urban =3863.8kWh/year, En _gen_extra-urban =3821.3kWh/year.

If at the annual level the differences between the energy values generated by the system (calculated with weather data provided by Meteonorm databases and with weather data measured for the two areas of Brașov (urban area and extra-urban area)) are insignificant, however according to Fig. 3 the differences in the winter and autumn months are relatively high.

Thus, the highest differences are observed for November and December, the values of energies generated for the urban area being higher by 33.6% and 40% respectively than those offered by the Trnsys software and by 29% and 40% respectively in the case of the extra-urban area.

For January, the generated energy values calculated with the Trnsys software are overestimated by 26% compared to the values for the urban area and by 17% compared to the values calculated for the extra-urban area.

For the months of March and April, again there is an overestimation of the generated energy values offered by the Trnsys software, but this difference being in absolute value less than 11%.

Interestingly, however, that for June the values of energy generated calculated with the Trnsys software are underestimated compared to those obtained from simulations with measured weather data. Given that June is a summer month characterized by a high solar potential, an underestimation of the energy generated by about 11% for the urban area and 13% for the extra-urban area corresponds to differences of 42kWh / month and 50kWh / month respectively.

Another proposed comparative analysis concerns the energy lost due to full batteries. Thus, at the annual level for this were obtained the values: En_dump_Trnsys =1472.4kWh/year, En_dump_urban =1440.5/year, En_dump_extra-urban =1404/year.

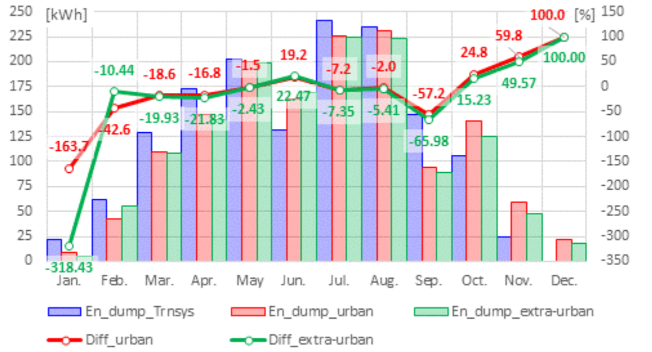


Fig. 4. *Monthly values of energy dumped due to full batteries for simulations performed with meteorological data provided by the Meteonorm software and those measured for urban and extra-urban areas Brașov*

If we refer to the dumped energy due to full batteries (Fig. 4), it can be seen that the simulations with the Meteonorm meteorological databases of the Trnsys software, lead to values that significantly underestimate the values obtained from the simulations with the measured weather data, both for the urban area and for the extra-urban area, for November and December. Thus, for November these differences are about 60% for the urban area and 50% for the extra-urban area; for December, however, it can be seen that the simulations with Meteonorm weather data lead to the conclusion that there is no energy generated by the photovoltaic system to be dumped due to the full battery. Even if it is autumn-winter months, for which the solar potential is lower, still these effective values of uncollected energy have significant values, these being of 35kWh/month (November) and respective 23 kWh/month (December) for the urban area and 23kWh/month (November) respective18 kWh / month (December) for the extra-urban area.

For March and April, simulations with Meteonorm databases lead to overestimations of dumped energy values. Thus, for the urban area these overestimations are about 19% (20kWh/month) for March and 17% (25kWh/month) for April and for the extra-urban area, of about 20% (21kWh/month) for March and 22% (31kWh / month) for April.

It should be noted that for June the simulations using the Meteonorm databases lead to underestimations of the dumped energy compared to its values obtained using the measured weather data. Thus, these differences are of 19% (31kWh/month) for the urban area and 22.5% (38kWh/month) for the extra-urban area.

Fig. 5. *Annual values of energy to load obtained from the simulations using Meteonorm weather databases and measured weather data for the urban and extra-urban area of Brașov*

To provide a complete picture of the values obtained from the simulations, in Fig. 5 are presented the annual values of the energy provided by the photovoltaic system to cover the energy consumption (energy obtained directly from generation and/or from batteries, En_to_load) and of the additional energy necessary to fully cover the necessary energy consumption. For all simulations, the daily distribution of energy consumption is identical, its annual value being of 1512.13 kWh/year (Load).

In the case of the simulations for which the databases provided by the Meteonorm software were used, it can be observed that only 91% of the energy required for consumption could be covered by the photovoltaic system. The simulations that used the measured weather data show that 94% of the energy needed for consumption can be covered by the photovoltaic system (both for urban and extra-urban areas).

B. *Conclusions of the comparative analysis*

What is interesting to note is that although January, February, October, November, December are the months for which an energy generated by low values is recorded, values that can not cover consumption for these months. However in these months there are also days in which the photovoltaic system produces energy that is dumped due to non-collection caused by the full state of the batteries.

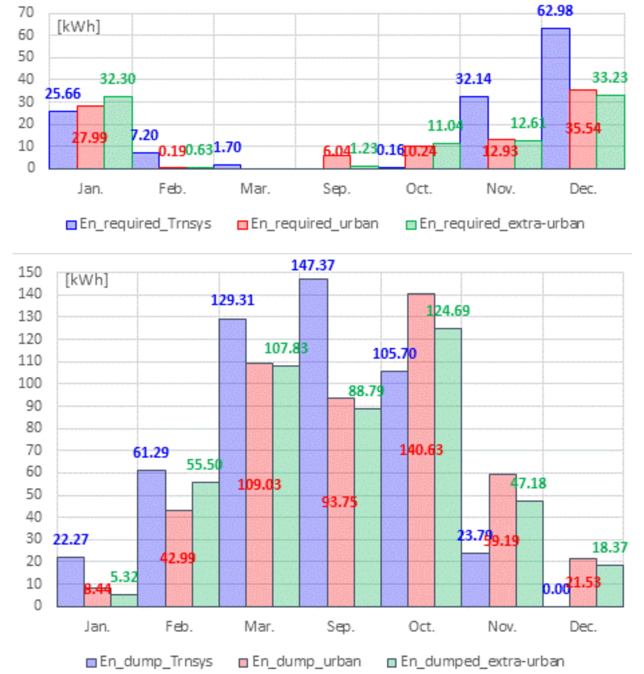


Fig. 6. *Monthly energy surplus values required to fully cover energy consumption and of the dumped energy due to full batteries*

Analysis of Fig. 6 leads to the following conclusions:

- for February month, the proposed configuration of photovoltaic system almost completely covers the energy required for the proposed consumption scheme (uncovered energy is below 1kWh/month - if we refer to simulations using measured weather data; however, even when using weather data generated with the software Meteonorm energy not covered by the system is less than 10kWh/month; remaining at February month it can be seen that although it is a winter month characterized by low solar potential, the values of energy dumped due to inability to store (full batteries) are relatively high compared to the values of the surplus energy needed to cover the necessary consumption;

- a situation similar to the one presented above is also encountered for the months of September, October and November (only for simulations with measured weather data for the urban area and the extra-urban area of Brașov); if we refer to the values obtained from the simulations with the weather data generated by the Meteonorm software, it is observed that there is an amount of energy dumped due to the full battery, its value representing approximately 75% of the energy required to cover entire consumption for November;

- for January and December there is indeed an amount of energy that is dumped and it cannot be stored due to the full battery but its values are low compared to the surplus energy needed to cover all the specific consumption of that month; the percentages of these values is about 30% for the urban area respectively 16% for the extra-urban area in case of January and of 60% for the urban area respectively 55% for the extra-urban area in case of December.

Another comparative analysis that could help in making a decision on the configuration of the photovoltaic panel system is shown in Fig. 7. These diagrams show for each situation and for each month, the number of days, in which the battery is empty (Low limit on FSOC =0.5) respectively the battery is full (fractional state of charge is 95%); thus the following aspects can be noticed:

- as expected for January and December, the highest number of days for which the battery is empty, is found (for the urban area about 9 days in January and 10 days in December and for the extra-urban area about 10 days in January and 9 days in December); unfortunately it is about 30% of the number of days of these months, in which all the energy produced by the system is transferred for consumption and the battery is empty; these days actually correspond to the situation where the energy produced by the photovoltaic system is not sufficient to cover energy consumption;

- for November it can be seen that the number of days when the battery is empty is relatively low, below four (for simulations with weather data measured for the two areas);

- it stands out though, the large differences between the values obtained for simulations using Meteonorm databases and those using measured weather data, in the case of November and December; thus, following the simulations with the Meteonorm weather data they resulted:
    - for November, approximately 9 days for which the battery is empty compared to the number of under four days obtained from the simulations using the measured weather data, and
    - for December approximately 18 days using Meteonorm data compared to the 9-10 days obtained using measured data;

therefore, the differences between these results are significant, which leads to emphasizing the importance of simulations using weather data as accurate as possible, especially for months with low solar potential;

- the simulations performed with the measured weather data highlighted the fact that from March to August the proposed photovoltaic system configuration fully covers the necessary for consumption (both for urban and extra-urban area);

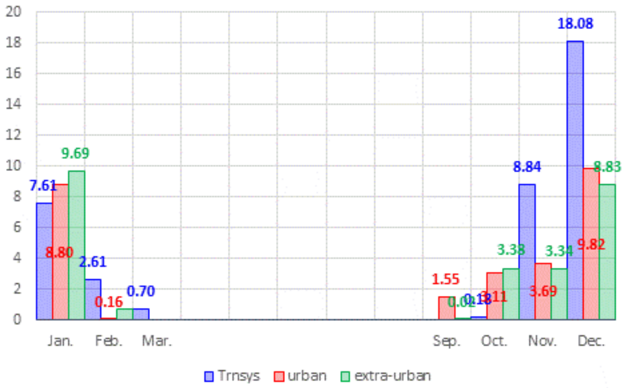
- for September it can be said that for the extra-urban area the proposed photovoltaic system covers energy consumption; for the urban area, however, there is a short period of 1.5 days in which the proposed photovoltaic system configuration does not cover consumption;

- from October to January the proposed photovoltaic system configuration cannot fully cover the adopted consumption scheme;

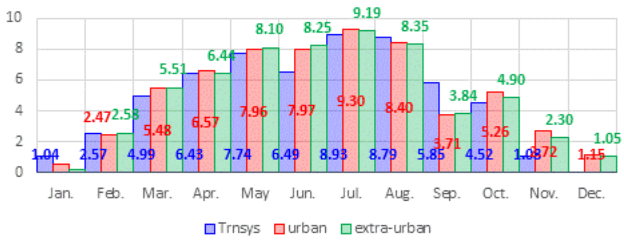
- interesting is that for February there was a period of less than a day for which the system could not meet consumption;

- it should be noted that simulations with measured weather data have led to the conclusion that for each month of the year there is even a very short period for which the photovoltaic system has a full battery; thus, with the exception of January (for which the period of time in which the battery is full is of the order of hours) for all the months it was obtained, as a time interval, over a day in which the battery is full;

- the maximum number of days for which the battery is full was recorded for July, over 9 days for both urban and extra-urban areas.



a. *Number of days with empty battery*



b. *Number of days with full battery*

Fig. 7. *The number of days per month for which the batteries are empty or full*

As expected, the winter and autumn periods are the periods for which there are significant differences between the energy values obtained from the simulations with the weather data provided by the Meteonorm databases and those obtained using the measured weather databases. Unfortunately, these periods are also the ones for which the results obtained from the simulations should be as close as possible to the real ones, because the interest in designing off grid photovoltaic systems consists in designing a system that covers the electricity needs during the periods of the year with the lowest solar potential. Basically, the number of photovoltaic panels and the number of batteries to cover the need for electricity consumption, results from performing sizing calculations for these periods; however, the choice of these periods as calculation periods leads to an oversizing of the photovoltaic system for the summer periods.

In view of these aspects, the decision on the calculation period chosen for the design of a photovoltaic system remains to be taken by the designer according to the concrete conditions. These conditions refer to monitoring of electricity production during the winter and decrease of consumption during periods of low solar potential or to the choice as a calculation period of a spring-autumn period, characterized by solar potential of average values). For example, in the case of holiday homes located in mountain areas, where there is no consumption during the whole week or the whole winter period, the design decision can be made based on the results of the simulations obtained only for the period of interest.

In general, the sizing calculations of a photovoltaic system are performed for average values of the solar energy potential for the period March-October. However, if the conditions specific to each situation in which the photovoltaic system will operate are taken into account, then the possibility of performing computer simulations may be of major importance in making the decision to choose its configuration.

The geographical location of the city of Brașov (described in [3]) in the central-eastern area of Romania, at 45°38 'north latitude and 25°35' east longitude in one of the largest intracarpathian depressions. The climate of Brașov has a temperate-continental specificity, characterized by the transition note between the temperate oceanic climate and the temperate continental climate: wetter and cooler in mountainous areas, with relatively low rainfall and slightly lower temperatures in lower areas.

The peculiarities of the relief and climate of the city of Brașov - due to its unique geo-climatic position inside the Carpathian arc - make finding models for estimating solar radiation somewhat difficult. For this reason, the recommendation of this paper is that if a location has a meteorological station, the simulations should be performed with the data measured at it [3, 7, 8].

Differences in meteorological data can lead for some months to significant differences in the results obtained for the performance of photovoltaic systems. Therefore, the meteorological data source must be carefully selected for simulation results as close as possible to those of real systems. As a suggestion, it can be proposed that for the locations near some meteorological stations, the simulation should be performed with the data collected from them.

As a last remark, it can be said that there are no important differences between the simulations performed for the urban and the extra-urban area.

C. The influence of the configuration of the photovoltaic system on its performances - simulations for the urban area Brașov

This chapter offers a more detailed analysis of simulation results obtained considering the measured weather data for urban Brasov. It also proposes several configurations photovoltaic system simulation, varying the angle of the solar panels, the number of photovoltaic panels and / or the battery.

Returning to the detailed analysis of the results for the urban area Brașov, Fig. 8 presents the diagrams energy in from generation (primary vertical axis), energy to load, energy dumped and energy to from battery (secondary vertical axis). These diagrams actually show a balance of energies in the photovoltaic system, respectively from the total energy generated by the photovoltaic system, a part represents the energy that will be delivered for consumption (En_to_load - not to be confused with the necessary for consumption), a part will be dumped due to full batteries (En_dump) and a part represents the energy from the photovoltaic system delivered to the batteries or taken from the batteries (P_batt, power to battery> 0) or from battery <0).

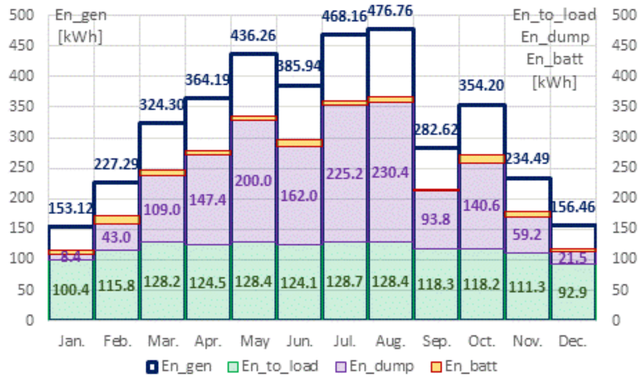


Fig. 8. *Monthly values of the energy in/from generation, energy to load, energy dumped, energy to from battery*

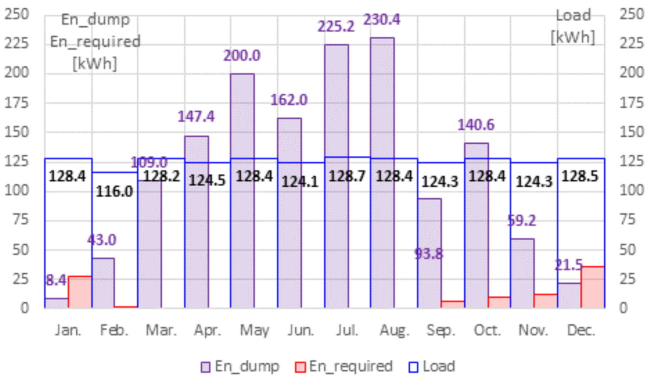


Fig. 9. *Monthly values of Load, En_dump and En_required*

The monthly values of energy in/from generation are presented in the vertical axis on the left and it can be seen that the sum of the monthly values of energies represented on the vertical axis on the right (En_to_load, En_dump, En_batt) is less than this. The difference between these values is represented by the losses in the photovoltaic system due to the efficiency of the inverter respective of the regulator (0.78 * 0.96). In fact, the following relation gibes the equilibrium equation: En_gen*0.78*0.96 = En_to_load + 0.96* (En_dump + En_batt).

Fig. 9 shows the diagrams of the monthly values of the energy dumped due to the full batteries, En_dump, of the energy necessary to supplement the proposed consumption scheme, En_required, in the left vertical axis and in the right vertical axis the monthly consumption scheme, Load. What it was wanted to highlight by this diagram is the fact that in April, May, June, July, August and October the value of energy dumped due to full batteries is even higher than the consumption on each of these months.

It also can be seen that for the months of January, February, September, October, November and December there are days when the PV system does not cover energy consumption. For February, September, October and November you can see an interesting phenomenon, respectively, although there are days for which the proposed configuration of the photovoltaic system does not meet the consumption, there are days for which the batteries are full and even energy is dumped due to this.

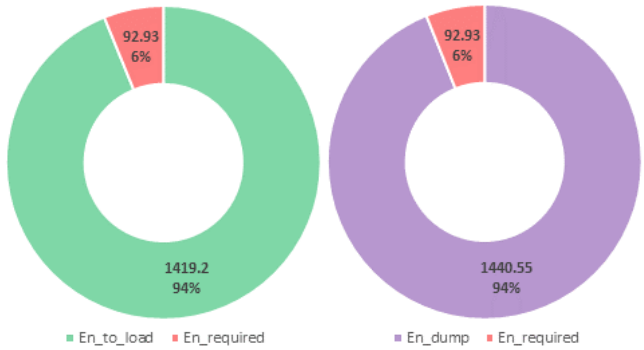


Fig. 10. *Annual values of energy delivered by the photovoltaic system for consumption (En_to_load), energy needed to cover annual consumption (En_required), energy lost due to full batteries (En_dump)*

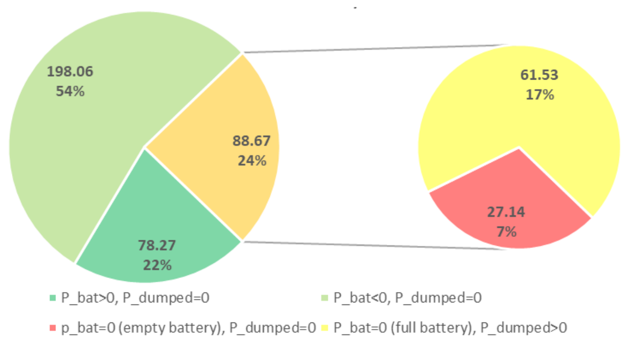


Fig. 11. *Annual number of days for different operating situations*

So these months can be characterized by sunny periods in which the photovoltaic system meets the consumption needs and even energy is dumped, but also by cloudy periods long enough for which the photovoltaic system does not meet the consumption.

If we analyze the annual values resulting from the simulations (Fig. 10) we can see that at an annual consumption of 1512kWh, 94% of it can be covered by the proposed photovoltaic system, 6% representing the value of energy that cannot be covered by the system. It can also be seen that the annual value of energy dumped due to full batteries is even higher than the value of energy supplied for consumption by the photovoltaic system.

For a more suggestive picture, Fig. 11 shows a diagram of the number of days in the year in which the photovoltaic system operates in different situations, namely:

- the energy generated by the photovoltaic system is used to cover consumption and to power the battery, without losing energy due to full batteries (P_batt >0, P_dump =0); this situation occurs for 22% of the annual number of days;

- to cover the consumption needs, all the energy generated by the photovoltaic system is used, but because this is not enough, the supplement is made by bringing energy from the batteries (P_batt >0, P_dump =0); operating situation corresponding to 54% of the days;

- P_batt =0, respectively
  - the batteries are empty and the photovoltaic system cannot cover the necessary consumption (P_dump =0); for 7% of the annual number of days the photovoltaic system cannot cover the proposed consumption scheme;
  - the batteries are full and the consumption needs are covered by the energy provided by the photovoltaic system, the surplus being dumped (P_dump> 0); for 17%, respectively 61.5 days a year, the photovoltaic system produces more than necessary for consumption and loses energy due to full batteries.

Figure 12 presents the monthly distribution of the number of days for which the photovoltaic system cannot cover the consumption needs. Thus it can be observed that most days for which the photovoltaic system does not generate enough electricity were registered for the months of January and December (from a percentage point of view, it can be said that these periods represent around 28-30% of the periods of these months).

Similarly, Fig. 13 shows the monthly distribution of the number of days for which the photovoltaic system produces too much energy, part of it being dumped due to full batteries. It can be observed that between May and August the longest periods in which energy is dumped due to full batteries are recorded; it can even be said that for periods longer than 25% of these 4 months the system produces energy that cannot be capitalized but lost.

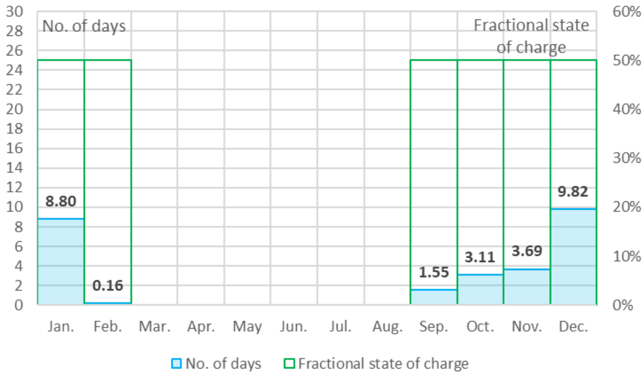


Fig. 12. *Monthly distribution of the number of days for which the photovoltaic system cannot cover the consumption needs*

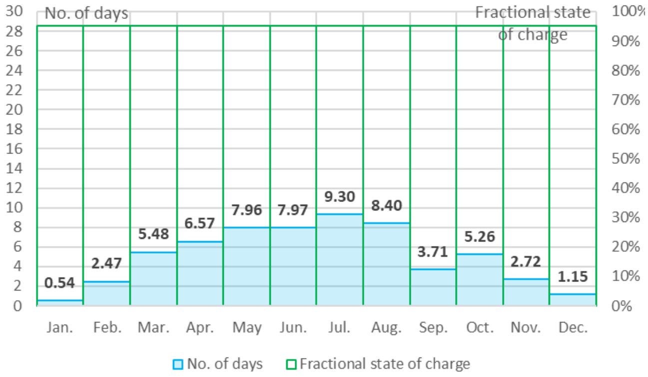


Fig. 13. *The monthly distribution of the number of days for which the photovoltaic system cannot collect the energy produced*

D. The influence of photovoltaic system parameters on its performance to cover energy consumption in winter

This section proposes the simulation of the photovoltaic system for the urban area Brașov, but varying a series of its characteristic parameters in order to find a configuration that corresponds as well as possible to the concrete conditions specific to its implementation location and the desired energy consumption scheme.

A first parameter refers to the photovoltaic panels array slope.

Basically, the angle of inclination of a photovoltaic panel is chosen so that to receive as much energy as possible. For the Brașov area, this angle varies between 22^o at the summer solstice and 69^o at the winter solstice.

The analysis of the previous diagrams shows that during the autumn-winter period, from September to January, the configuration of the photovoltaic system (having the array slope of 35^o) cannot cover the entire energy consumption; instead, during the spring-summer period (March-August) a significant amount of energy is dumped due to the impossibility of storage and consumption, respectively. Therefore, in view of these aspects, it is proposed that the following simulations to be performed for a photovoltaic system with the array slope set at 65^o (recommended value for the winter season).

The analysis of annual values of energies obtained from the simulations leads to the following conclusions (Fig. 14 compared to Fig. 10):

- the adoption of an photovoltaic array slop of 65^o does not lead to significant differences in terms of the annual value of energy to be delivered by the photovoltaic system for energy consumption (En_to_load);

- from an annual point of view, the amount of energy required to cover energy consumption is approximately the same regardless of the angle of inclination of the photovoltaic panels;

- the annual value of energy dumped due to the full battery is significantly lower at an inclination of photovoltaic panels of 65^o compared to the configuration having an angle of 35^o; this aspect is somewhat obvious because during the summer the amount of energy generated by the system is lower, and for an inclination of the photovoltaic panels of 35^o the amount of energy wasted during the summer was relatively high (Fig. 9 compared to Fig. 15).

If comparatively analysed Fig. 12 and Fig. 16 it is found that the increase in the angle of inclination has led to a decrease in the monthly number of days for which the batteries are empty for January and December, but an increase of this for February, September, October and November (which was expected because the value of this tilt angle is too large these periods).

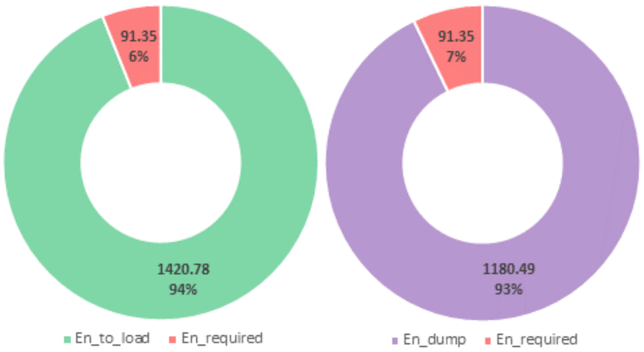


Fig. 14. *Annual values of energy delivered by the photovoltaic system for consumption (En_to_load), energy needed to cover annual consumption (En_required), energy dumped due to full batteries (En_dump) - array slope 65^o*

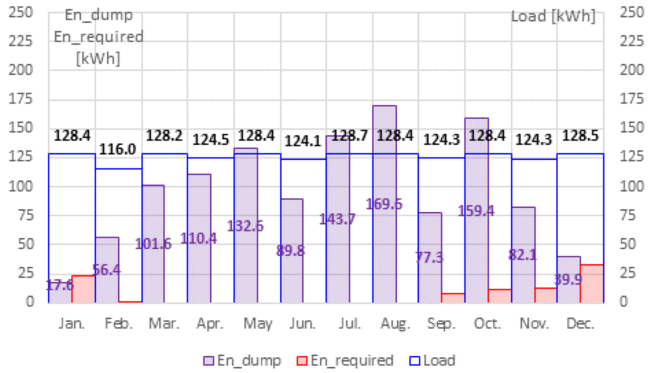


Fig. 15. *Monthly values of Load, En_dump and En_required – array slope 65^o*

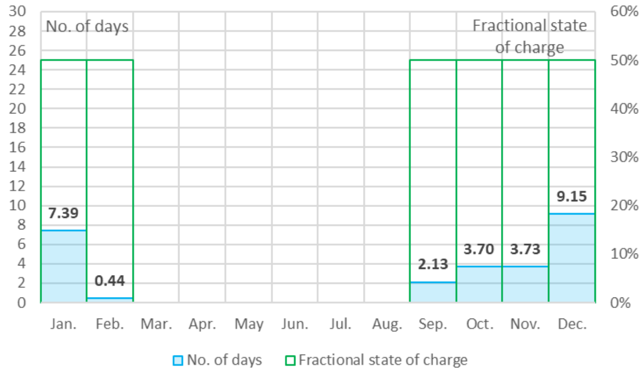


Fig. 16. *Monthly number of days for which the batteries are empty – array slope 65^o*

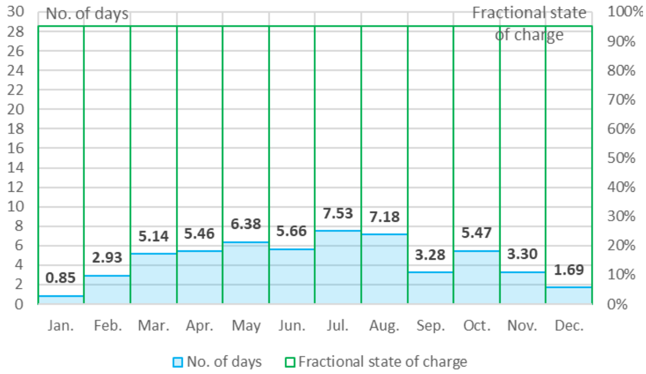


Fig. 17. *Monthly number of days for which the batteries are full – array slope 65^o*

Regarding the number of days for which the batteries are full, for a photovoltaic array slope of 65^o compared to an angle of 35^o, there is an increase of this for January, February, November and December and a decrease for the rest months of the year (Fig. 13 compared to Fig. 17).

However, the annual energy values required to cover energy consumption are approximately the same for both situations. Even if the energy demand decreases for January and December (Fig. 18), its increase for February, September, October and November makes the annual increase of the angle of inclination of photovoltaic panels to 65^o compared to 35^o not represent the most good solution.

However, on a closer analysis of Fig. 15 and Fig. 18, it is observed that for an inclination of photovoltaic panels by 65^o, the value of energy dumped due to full batteries - except in January - is less than the value of energy needed to fully cover energy consumption.

In these circumstances it can be proposed an increase of the storage capacity of the batteries from 14.4kWh (8 batteries) to 21.6kWh (12 batteries), Fig. 19. The analysis of these diagrams shows that for the months of January, November and December, the surplus energy needed to cover consumption decreases; the same decrease is registered for the months of February (the system works covering entirely the necessary), September and October. However, the question arises whether the increase in the cost of the photovoltaic system (due to the increase in the number of batteries) is justified by the gain of about 20kWh per year [4, 5].

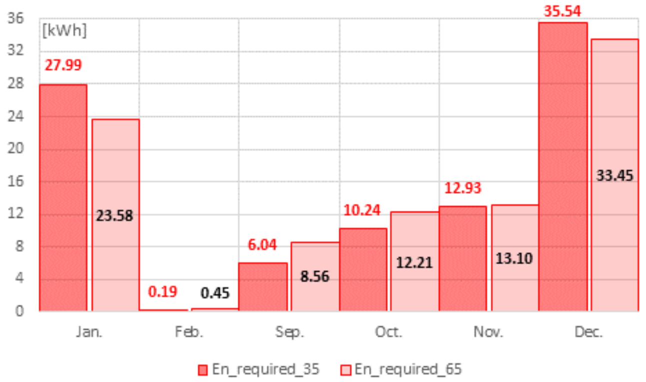


Fig. 18. *Monthly energy required to cover energy consumption for different angles of inclination of photovoltaic panels*

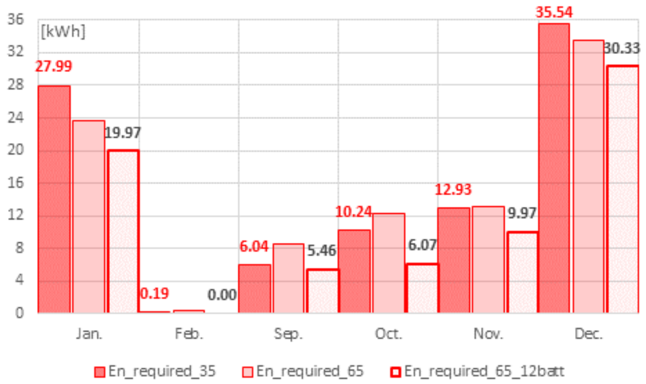


Fig. 19. *Monthly energy required to cover energy consumption for different photovoltaic system configurations*

E. The influence of the parameters of the photovoltaic system on its performances to cover the energy consumption and during spring-summer

However, if a photovoltaic system is desired for a holiday home, that has the proposed energy consumption only for the period March - August, the initial configuration may prove to be oversized for this period. A first proposal is to reduce the number of photovoltaic panels to 8 (number of modules in series 4, number of modules in parallel 2).

Analysing the diagram in Fig. 20 it can be seen that the losses due to full batteries decrease considerably compared to the initial version with 10 modules (Fig. 9) but for March there is a small amount of energy consumption (approximately 1kWh per month) that is not covered; however about 59kWh is dumped in March due to full batteries.

A decrease in losses due to full batteries during the summer implies either a decrease in the number of photovoltaic panels or an increase in the number of batteries for storage.

The decrease in the number of photovoltaic panels (3 modules in series and 2 modules in parallel) although leads to a reduction in losses due to full batteries, they still have significant values even for months when there is still a need for energy to cover consumption. From the analysis of Fig. 21, it can be seen that for the spring months of March and April there is a need of approximately 7kWh, respectively 3.6kWh, which does not cover consumption for these months.

In addition, for summer months with high solar potential, June and August, although about 38kWh are dumped, respectively 82kWh, there are about 1kWh per month that do not cover consumption.

The existence of operating situations in which the values of energy losses are higher than the surplus energy required to fully cover the consumption needs can lead us to the option of increasing the number of batteries (respectively the storage capacity in batteries).

Unfortunately, the second option of increasing the storage capacity of batteries, although expensive, does not always lead to a complete reduction of the additionally required to entirely cover energy consumption (Fig. 22, March).

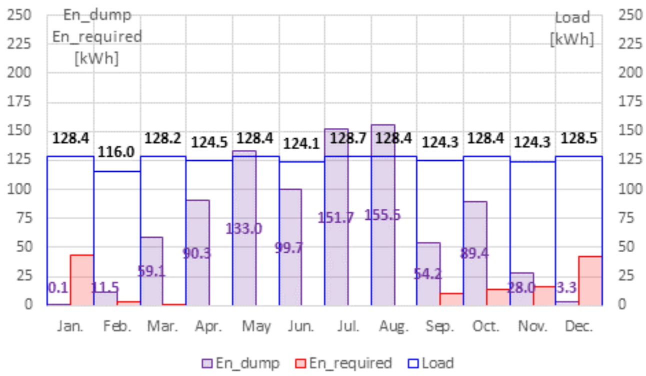


Fig. 20. *Monthly values of Load, En_dumped and En_required – 8 PV modules*

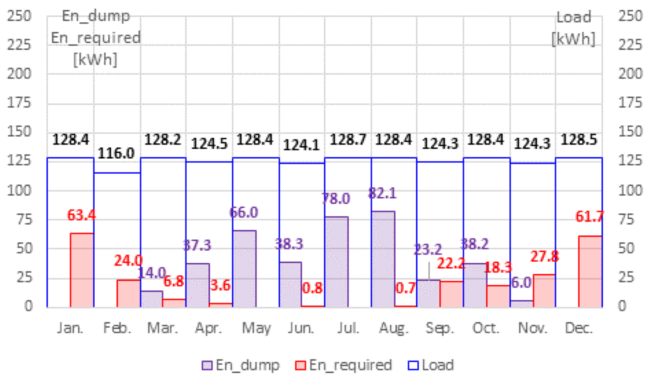


Fig. 21. *Monthly values of Load, En_dumped and En_required – 6 PV modules*

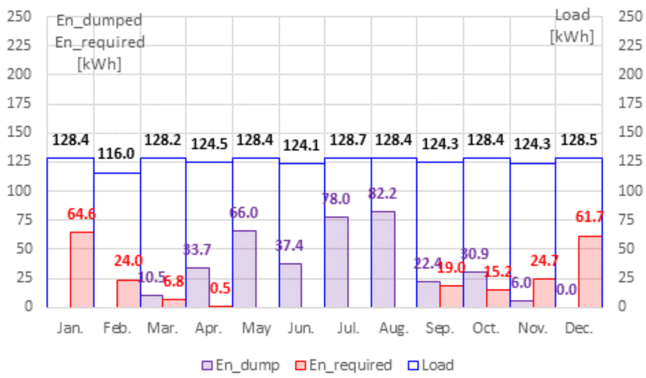


Fig. 22. *Monthly values of Load, En_dump and En_required – 6 PV modules, 12 batteries*

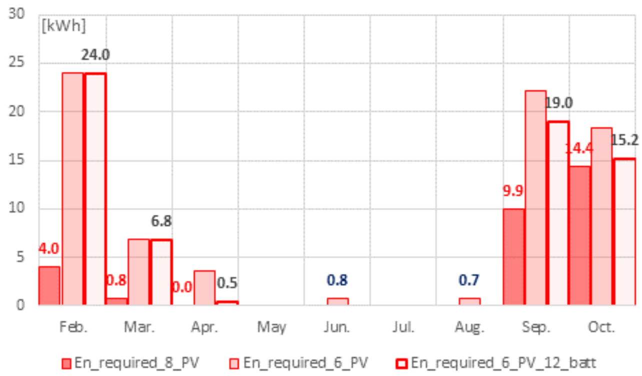


Fig. 23. *Monthly energy required to cover energy consumption for different photovoltaic system configurations*

The only more significant decrease of required energy to cover consumption can be seen for April (with 3.1kWh); however, the increase in the number of batteries from 8 to 12 may not justify the gain of about 5kWh for the period March-August.

Following the centralization of the three situations listed above, it can be seen that a photovoltaic system configuration consisting of 8 photovoltaic modules and 8 batteries is the most convenient for operation during the period March - August.

If the operating period is extended to the months February - September, the excess energy required for full coverage of electricity consumption has the values (for the entire period):

- for the version with 8 photovoltaic modules, 15kWh,
- if 6 photovoltaic panels are used, approximately 58kWh,
- and if in addition 12 batteries are used, 50kWh.

V. CONCLUSIONS

The computer simulations proposed by this paper aimed to predict the behavior of a photovoltaic system installed in the Brașov area. By simulating and running different configurations for the photovoltaic system model, it was wanted to explore and obtain information on estimating system performance.

However, it should be borne in mind that the accuracy of the input data is very important, as it can directly influence the final results. Thus the task of the designer is to use the initial parameters as correct as possible with reference in particular to the weather data and the technical characteristics of the equipment; thus the designer must check from the data entry phase and their veracity by immediately observing whether some of the input data are outside the usual working values.

It is appreciated that the fidelity of the simulations is a measure of the degree to which their results coincide with those obtained from the experiments and for this reason, the accuracy of the input data used is very important.

The simulation of photovoltaic systems can be an important resource of data on their performance and lately it has become a valuable tool for a wide range of experiments.

As presented by the variation of the input parameters within the usual limits, final results can be obtained in certain reference ranges, their interpretation being at the discretion of the designer.

Therefore, in situations where a location has weather data recorded at a weather station, it is recommended to use them instead of those provided by the software databases. Although weather data generation software is extremely complex, it still provides values that are in turn obtained from simulations; in other words, these values of the meteorological parameters are obtained following mathematical modelling processes designed to predict the results of a physical system.

REFERENCES

[1] S. A. Klein and W.A. Beckman, “TRNSYS 16, A transient System Simulation Program”, University of Wisconsin Solar Energy Laboratory, Madinson, USA, 2006.

[2] S. Alsadi and T. Khatib, “Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools”, in Applied Sciences, 8, 1761, 2018.

[3] D. Ciobanu D., E. Eftimie and C. Jaliu, “The influence of measured/simulated weather data on evaluating the energy need in buildings”, in Energy Procedia 48, 2014, pp. 796 – 805

[4] A. Gagliano, F. Nocera, and G. Tina, “Performances and economic analysis of small photovoltaic– electricity energy storage system for residential applications”, in Energy & Environment 2020, Vol. 31(1), pp. 155–175.

[5] J. Hoppmann, J. Volland, T. S. Schmidt and V. H. Hoffmann, “The Economic Viability of Battery Storage for Residential Solar Photovoltaic Systems - A Review and a Simulation Model”, in Renewable and Sustainable Energy Reviews, 39:1101-1118, July 2014.

[6] G. T. Klise and J. S. Stein, “Models used to assess the performance of photovoltaic systems”, in Sandia report, SAND2009-8258, December 2009.

[7] S. Manju and N. Sagar, “Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India”, in Renewable and Sustainable Energy Reviews 70 92017), pp. 298–313.

[8] D. F. Al. Riza, S. I. Ul. H. Gilani and Mohd. S. B. Aris, “Measurement and Simulation of Standalone Solar PV System for Residential Lighting in Malaysia”, EFEEA’10, International Symposium on Environment Friendly Energies in Electrical Applications, 2-4 November 2010, Ghardaïa, Algeria.