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Performance simulation of a grid connected photovoltaic power system using TRNSYS 17

Case study for Brasov, Romania

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***Abstract*— Currently, sustainable development strategies are predominantly designed as solutions to the ecological crisis and the continuous degradation of the environment, with the main objective of preserving the quality of the environment. In this sense, on the ecological level, sustainable development has the task of avoiding environmental degradation, which implicitly leads to the superior capitalization of renewable resources. The widespread use of energy from natural resources is a key factor in protecting the environment and reducing greenhouse gas emissions (i.e. reducing pollution and acid rain). Therefore, in the current conditions, the implementation of renewable energy in the built environment has become a global concern.**

***Keywords*— dynamic simulation; photovoltaic; solar energy; Trnsys**

I. Introduction

If we refer to the use of solar energy conversion systems, it should be mentioned that the climatic parameters (solar radiation - the main input date in solar equipment design, temperature, humidity, wind speed) specific to the implementation area, exert a special influence on their design.

More specifically to the subject of this paper represented by photovoltaic systems for electricity generation, the solar radiation represents the main input parameter necessary for their design; given this aspect, the use of input weather data as close as possible to the real values represents a necessity for the design of photovoltaic systems and the simulation of their performance.

Currently, the literature offers a series of mathematical models for estimating solar radiation; although some of these models have the advantage of simplicity and ease of application, they have the major disadvantage of large errors compared to real values (the accurate estimation of diffuse radiation is currently a difficult problem to solve). Moreover, most of the time, empirical models (which are determined based on measurements from a certain location) are specific to a single location. Another disadvantage is represented by the fact that most models estimate solar radiation in clear sky conditions and there are no simple mathematically accurate models to estimate solar radiation in real sky conditions (variable).

Considering the above aspects, the paper proposes for the beginning a comparative analysis of some specific meteorological and climatological parameters specific for two locations of the Brașov area (urban area and extra-urban area Brașov). A comparative analysis of the weather data recorded for Brașov (from the urban area and from the area adjacent to the city) with the data generated using different specialized software (PVSOL, PVGIS, METEONORM) is also performed. However, the main objective consists in the comparative analysis of the performances of a photovoltaic system connected to the grid, whose operation is simulated for different sets of weather data (recorded data and data generated with the software mentioned above).

II. Meteorological Data

The city of Brasov is located in an area with a relatively high solar potential, with about 210 days of sunshine per year and an annual solar flux between 1000 kWh/m^2/year and 1200 kWh/m^2/year [1]. From this, it can be said that around 600-800 kWh/m^2/year is 100% feasible, that makes the use of any solar panel for electricity production very interesting.

For the correct assessment of the solar potential of an area, databases containing direct measurements of radiative parameters containing records over at least one year are required.

Currently, although the literature proposes a series of maps of solar energy potential, they are obtained based on an inventory of data on global solar radiation (W/m^2) and information obtained from the processing of the satellite product SIS-SARAH (Surface Incoming Solar Radiation).

However, for a correct assessment of solar energy production it is necessary to take into account a lot of factors of geometry of the solar trajectory, of the relief and meteorological factors [2, 3].

In addition to those mentioned above, the evolution that both the hardware and software component have had in the last decade, has made possible the development of specialized software and applications that generate and process a very large volume of data.

One of them is PVSOL [4], software for calculating photovoltaic panel systems. For the purpose of as efficient as possible custom design of photovoltaic systems, PVSOL software takes into account a number of factors such as the geographical location and its meteorological profile, system size and orientation, annual consumption and load profile of electrical equipment, the type PV and inverters, etc.

Another software for assessing the solar electricity production is the PVGIS software [5]. This specialized software allows both the evaluation of direct and diffuse radiation and the evaluation of performances of photovoltaic systems, either grid-connected or off-grid.

A transient analysis software is the Trnsys software; it uses the METEONORM database [6] as the default weather database. However, that in the case of energy simulations using Trnsys software, the use of weather data generated by METEONORM software involves the selecting from the database of the closest location to Brasov (the paper will also propose the implementation of measured weather data in Trnsys subroutines).

The proposed comparative diagrams refer to the monthly values of global solar energy, air temperature and wind speed.

A. Solar resource potential

Value measured at the two locations – urban and extra-urban Brașov area

From the point of view of the solar potential (Fig. 1), it can be seen that the values recorded at the two weather stations are very close. Only during February, June, September and December the values recorded at the weather station in the extra-urban area are higher than those in the urban area are (the maximum difference was recorded during February and is about 3.4kWh/m^2).

For the other months of the year, in which the solar potential has higher values for the urban area, the maximum difference registered for October has the value of 4.3kWh/m^2.

Next, to compare the recorded data with the simulated values with the generation and simulation software, the values recorded in the urban area were chosen.

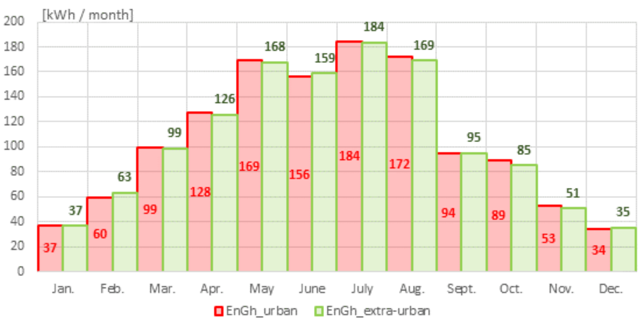


Fig.1. *Monthly global horizontal irradiation for urban and extra-urban area Brașov*

Monthly variation of solar irradiation using PVSOL software

Figure 2 presents the comparative study of the monthly mean values of the solar potential, registered values and values generated with the PVSOL software. As can be seen for the months January, February, March, June, November and December, the values generated by PVSOL overestimate the values recorded at the Brașov weather station; the largest difference in overestimation is observed for December, this having a percentage value of 75%. For the other months, the generated values underestimate the registered values; the largest difference is about -20% for August.

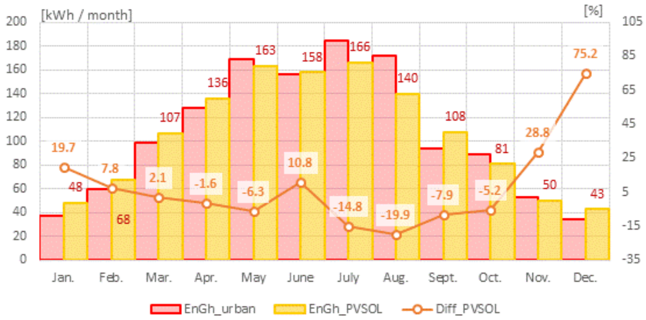


Fig. 2. *Monthly mean values of global energy - the comparison weather data recorded for Brasov and weather data generated with PVSOL software*

Monthly variation of solar irradiation using PVGIS Software

When comparing the recorded values of solar energy with those obtained after generation with the PVGIS software, it can be seen that the percentage differences are between -32.4% and 2.7% (Fig. 3). It is interesting that only for December the estimated value is higher than the real one, for the rest of the year, the generated values underestimating the real ones. As a percentage, this underestimation is relatively high for January (-24%), February (-32.4%), March (-25.4%), June (-20.5%), August (-13.4%), September (-12.9%) and November (-12.2%). The best-obtained estimation is for December (an overestimation of 2.7%) and April (an underestimation of -4.4%).

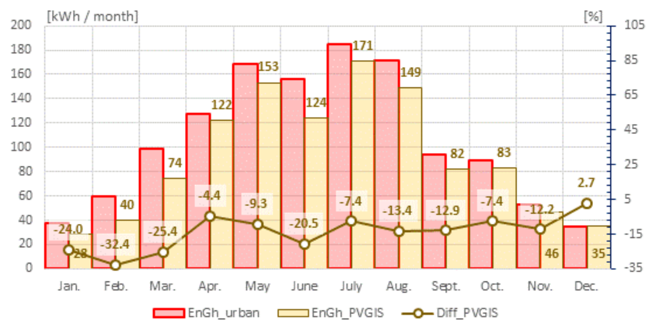


Fig. 3. *Monthly mean values of global energy - the comparison weather data recorded for Brasov and weather data generated with PVGIS software*

Monthly variation of solar irradiation using METEONORM database from Trnsys software

If we refer to the values of solar energy obtained from the simulations with the Trnsys software (software that uses the METEONORM databases) it should be mentioned that the city of Brașov is not among the sites in the weather database and for the simulation, the closest site to Brașov was selected, namely the city of Cluj-Napoca.

The percentage differences obtained between the data generated by the Trnsys software compared to the values recorded by the weather station are between -28.4% and 24.5% (Fig. 4). However, it can be noted that only for the months of November and December there was an underestimation more than 20% (-26.6% and 28.4% respectively) of the real values (it should be noted that for the two months the solar energy values have the lowest values, and a difference of 10kWh/m^2 can mean a difference of 25%). The highest value of overestimating the real values is registered for September, this having the value of 24.5%. For the other nine months, the percentage differences obtained are in absolute terms less than 9%.

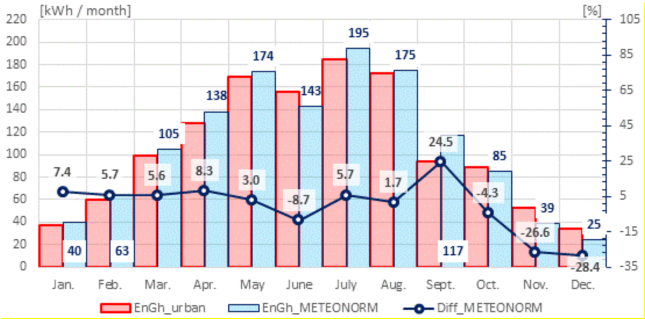


Fig. 4. *Monthly mean values of global energy - comparison of recorded weather data for Brasov and generated weather data with METEONORM software for Cluj-Napoca*

B. *Mean and maximum monthly temperatures*

An analysis of the monthly mean values of the temperatures recorded for the two stations, shows a quite similar variation in both the qualitatively and quantitatively (Fig. 5). This analysis shows that for the urban area, there is a slight increase in mean temperature values (maximum 0.6^{o}C for January and December) but this difference was predictable given the two types of areas, urban and extra-urban. The climatic effects induced by the continuous urbanization of the cities are considered, problems approached increasingly both in applied climatology studies and studies of urban development.

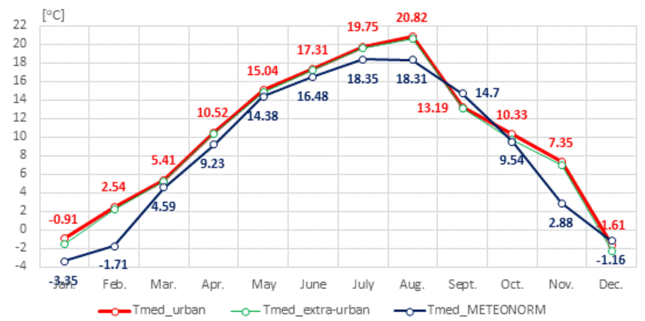


Fig. 5. *Monthly mean temperatures for urban and extra-urban area Brașov and monthly mean temperatures obtained by simulation with METEONORM software*

The main consequence of the increase of urban areas leads to the intensification of the island of urban heat (climatological phenomenon manifested by the concentration of higher temperatures in densely populated and built-up urban areas, compared to the surrounding rural areas [7]) above the city, respectively to an increase of its temperature.

Regarding the differences between the mean values of temperatures, generated with the METEONORM software, these underestimate the recorded values, except for September. The largest observed differences between the generated values and those recorded, there are for January (2.44^{o}C for urban area and 1.8^{o}C for extra-urban area), February (4.25^{o}C for urban area and 3.9^{o}C for extra-urban area) and November (4.47^{o}C for urban area and 4.12^{o}C for the extra-urban area).

Regarding the maximum values of temperature, they are significantly higher in the extra-urban area compared to the urban area, the maximum difference of 1.2^{o}C being recorded for April (Fig. 6).

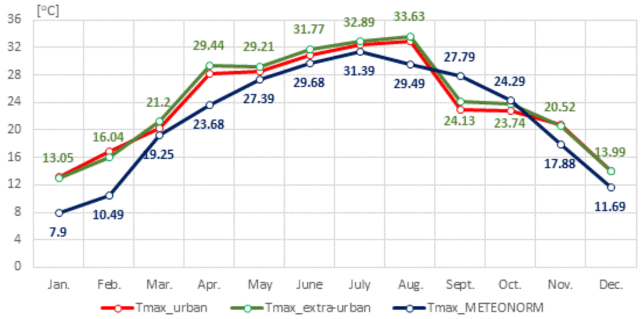


Fig. 6. *Monthly maximum temperatures for urban and extra-urban area Brașov and monthly maximum temperatures obtained by simulation with METEONORM software*

Regarding the maximum temperature values, the generated values by the METEONORM software are lower than those recorded (except for September and October), the differences being for the urban area between -6.33^{o}C (underestimation for February) and 4.8^{o}C (overestimation for September). For the extra-urban area the differences are between -6.76^{o}C (underestimation for April) and 3.66^{o}C (overestimation for September). The January, February, April, August and September months record the largest differences (for these months the generated data show larger differences in absolute values of 3.5^{o}C compared to the recorded values).

It is noted that the PVSOL software also provides information on the monthly mean values (Fig. 7); unfortunately, the differences between the mean values generated and the mean recorded values are large (the generated values underestimate the recorded values for the whole period of the year), varying between 6.4^{o}C (December) and 14.5^{o}C for April.

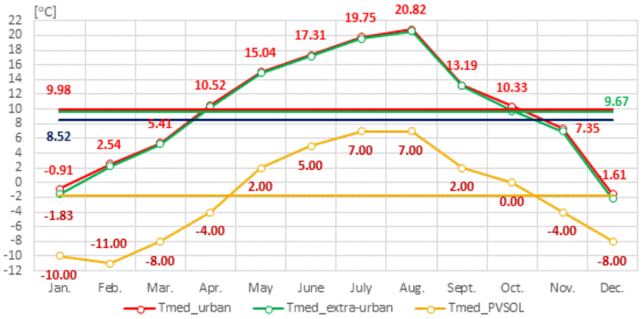


Fig. 7. *Monthly mean temperatures for urban and extra-urban area Brașov and monthly mean temperatures obtained by simulation with PVSOL software*

If we refer to the mean annual values of temperature, the recorded value in the extra-urban area is -0.3°C lower than that recorded for the urban area (Fig. 7).

If we compare the mean annual value obtained using data generated by the METEONORM software with the mean annual value in the urban area, the difference is 1.46°C and for the mean annual value in the extra-urban area the difference is 1.15°C.

The differences between the mean annual value of the temperature obtained with the help of PVSOL software and the values of the mean annual temperatures recorded - for the urban and extra-urban area - are 10.8°C and 10.5°C, respectively.

A comparison of the mean monthly temperatures recorded with those generated by the PVGIS software (Fig. 8), leads to the conclusion that the PVGIS software makes a very good estimation of them. Thus the differences fall, for the urban area between -0.99°C (overestimation for June) and 3.01°C (underestimation for March) and for the extra-urban area between -1.16°C (overestimation for May) and 2.83°C (underestimation for the month March).

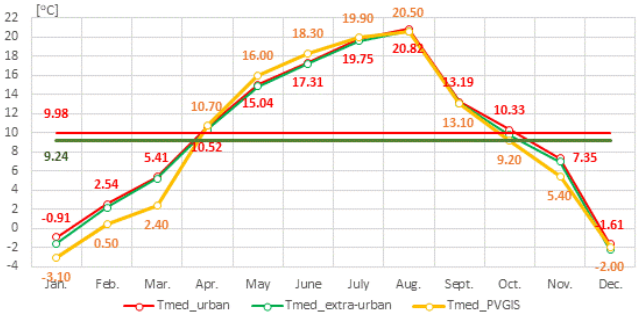


Fig. 8. *Monthly mean temperatures for urban and extra-urban area Brașov and monthly mean temperatures obtained by simulation with PVGIS software*

Regarding the mean annual values of temperatures, the difference between the mean annual value recorded and that generated with the PVGIS software is 0.74°C for the urban area, respectively 0.42°C for the extra-urban area.

C. Mean and maximum monthly speeds

Regarding the mean and maximum monthly wind speeds, the next stage presents the variation diagrams of the values registered for the two areas of Brașov and of the values generated with the Trnsys software.

During the year considered for study, the highest values of mean wind speeds were recorded during March and September (Fig. 9), both in the urban area (1.68m/s and 1.71m/s respectively) and in the extra-urban area (2.79m/s and 2.85m/s respectively). However, that the highest values of mean monthly speeds were not recorded during the cold period of the year. It must say that a variation of the wind speed qualitatively similar to the one presented for the chosen time period (both for the urban and for the extra-urban area) was observed over the periods of several years [8].

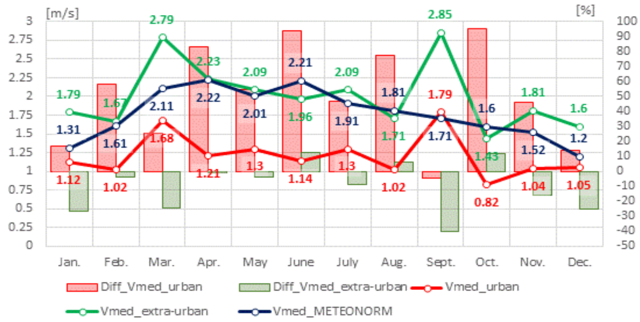


Fig. 9. *Variation of the mean monthly wind speed, values registered for the urban and extra-urban area of Brașov and the values generated by the Trnsys software*

Concerning the values of the mean monthly speeds generated by the Trnsys software (METEONORM weather database), they are closer to the values recorded for the extra-urban area.

The mean values of the wind speed generated are much higher comparatively to the values recorded for the urban area, for the longest period of the year. The percentage differences being between (less for September when the difference is -4%, by the way the only month for which the values generated are below the recorded values) 14% (December) and 95% (October).

For the extra-urban area, there are months for which the generated values are quite close to those recorded (February, April, May, August) the percentage differences being between -3% and 5%, for the rest of the months the percentage differences are between -40% (September) and 12% (June).

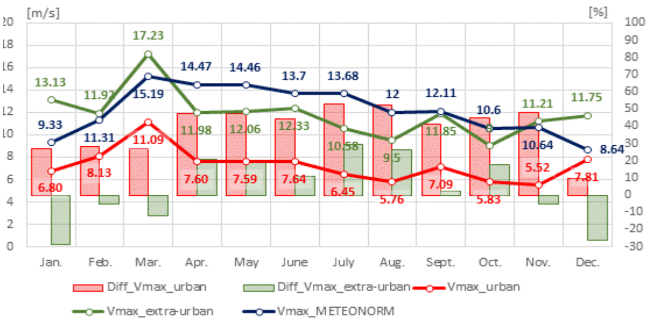


Fig. 10. *Variation of the maximum monthly wind speed, values registered for the urban and extra-urban area of Brașov and the values generated by the Trnsys software*

When referring to the maximum recorded wind speed, these were recorded during the month of March (11m/s for urban area and 17.23m/s for the extra-urban area), Fig. 10. It is obvious that in the extra-urban area the values of wind speeds are much higher comparatively to those recorded for the urban area.

It must say, however, that the differences between the maximum values obtained by generation and the values recorded for the two locations are higher for the urban area.

In the case of the urban area, the maximum values obtained by generation are much higher than those recorded (throughout the year), the percentage differences fitting between 10% (December) and 53% (July).

As mentioned above, the percentage differences between the values recorded for the extra-urban area and the values generated are smaller, ranging between -29% (January) and 30% (July).

D. Conclusion

The comparative analysis of the variation diagrams of the climatic parameters leads to the conclusion that for the locations where there is a weather station, it is recommended to use the measured meteorological data for the design of the photovoltaic system.

III. Simulation of a grid-connected PV system Prepare Your Paper Before Styling

To emphasize the importance of using the measured meteorological data in designing solar photovoltaic systems, the paper proposes calculating the energy produced by a photovoltaic grid-connected system for a building located in the Brasov area. For this, the transient analysis software (Trnsys) will be used; Trnsys software uses the data generated by METEONORM as the default database for weather data [6]. The simulation of the performances of the grid-connected photovoltaic system will be done using the weather data generated by the METEONORM software for the closest location to Brașov and the weather data measured for the urban and extra-urban area of Brașov. The measured weather data will be implemented in the Trnsys subroutines.

In addition, the same analysis of the performance parameters of photovoltaic systems will be performed for their simulation using PVSOL and PVGIS software.

A. System description

After finding out the solar energy potential of the solar panel installation location, it is possible to proceed to the calculations regarding the justification of the investment in such a system.

Photovoltaic systems can be designed for a number of applications, among the main advantages of their use being the energy independence, modularity, low installation costs, operational safety, reliability, but not least that the fact that electricity is free. However, the main limiting factors of this technology are its still high price compared to traditional systems, low return and long payback time.

However, the use of photovoltaic systems in various applications is a cost-effective option.

The building subject to energy simulations is a residential building for which a system (fixed stand type) with an installed power of 4kWp mounted on the roof was chosen. For the load profile of the building was considered a profile with constant load (annual consumption of 1460kWh); it has been considered that the proposed system is sufficient to supply a small family household (for example, two person's household with one or two children).

The grid-connected photovoltaic panel system proposed for analysis is composed of the following basic components: the photovoltaic panel, the charge controller, the inverter, the utility meter and the electrical network.

The photovoltaic panel system produces energy during the day and the other components are needed for the correct conversion, distribution and storage of the energy produced by them.

The photovoltaic panel system consists of 16 solar PV modules (eight in series and two in parallel, the maximum power (Pmax) for each solar panel is 250Wp,) which are electrically connected to each other. For the photovoltaic panels, a variant sold in Romania was chosen (AE Solar, type AE250P6-60, Polycrystalline). The cell type is polycrystalline with a panel efficiency of 15.27%.

The photovoltaic matrix generates direct current, feeding on sunlight.

The charge controllers regulate the direct current coming from the photovoltaic panels; these controllers can be of two types: PWM (Pulse Width Modulation) controllers or with pulse width modulation and MPPT controllers or with tracking the maximum power point. For the proposed simulations was chosen the second variant, respectively the solar PV modules ensures the generation DC power at the best output power at a time during daylight hours, [9]. In addition, for the case considered, being a photovoltaic system with a voltage of up to 160 volts, it is justified to choose maximum power point tracking controllers.

One of the key components of any photovoltaic panel system is the inverter. It converts the generated direct current into alternating current, taking into account the fact that most household and electronic equipment is supplied with alternating current.

Regardless of the photovoltaic panel system used, it has a utility meter. This counter is connected to the system and measures how much electricity the house on which the panels are installed uses.

B. Simulation tool – Trnsys modelling

In order to analyse the performance of the photovoltaic system - as mentioned before - the Trnsys software will be used, the scheme of the model being presented in Fig. 11.

For building the Trnsys model of the grid connected photovoltaic system with a capacity of 4kW, the following types of components were used:

- to implement meteorological data characteristic both to urban and extra-urban area of Brasov, the Weather Data Processor, Type 99, was used (see Fig. 11), that allows the use of a customized weather data file and reads the data provided at regular time intervals; for the simulations with the meteorological data of the METEONORM database, a Weather Data Processor, Type 15, was used (the simulation will be made for the closest location to Brașov, site contained in the METEONORM database);

- for modelling of the electrical performance of a photovoltaic array, Type 94 was used; the parameters defined for this component are characteristic of the type and number of chosen photovoltaic panels, respectively, module voltage at max power point and reference conditions: 29.16V; module current at max power point and reference conditions: 8.57A; module area: 1.6368m^2; number of modules in series: 8; number of modules in parallel: 2; array slope: 35^o;

- power conditioning devices, Type 48a, that operates in Mode 0, peak-power tracking collector, no battery, power is feedback to an utility;

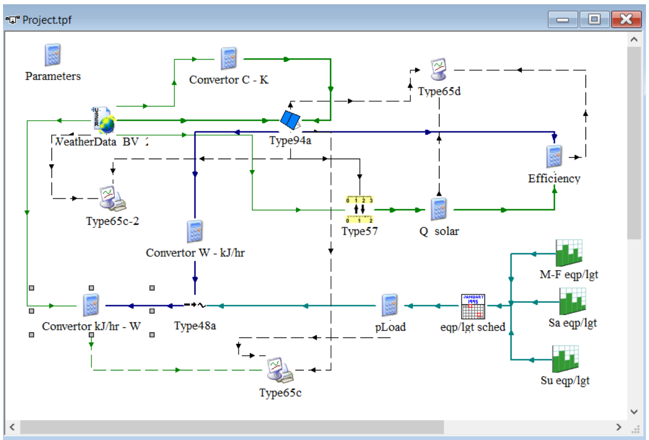
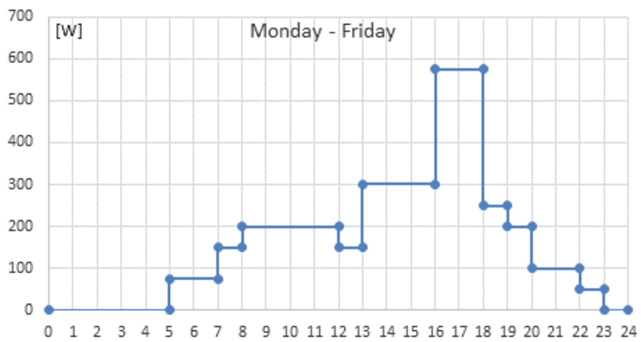


Fig. 11. *Trnsys model of the 4kW PV grid-connected system*



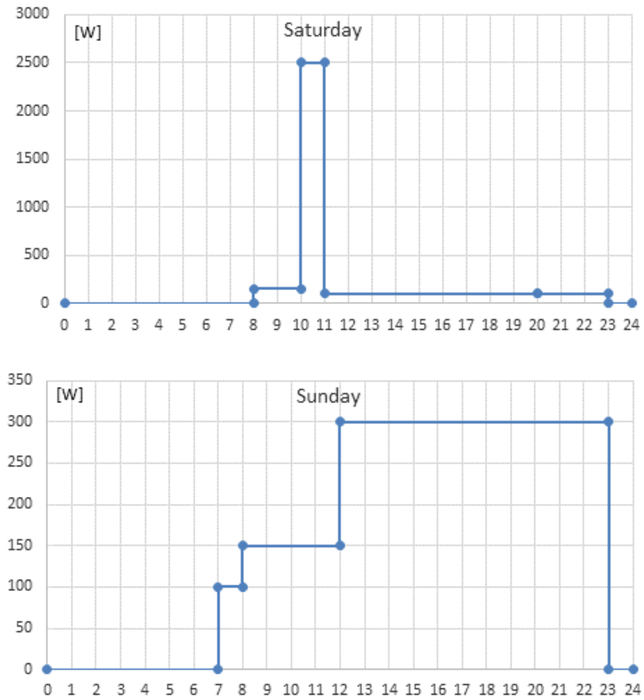


Fig. 12. *Load profile for all days of the week*

- by means of Type 41, there were specified three forcing functions, one for each working day of the week (Monday to Friday), one for Saturday and one for Sunday; for the description of time-dependent forcing functions, for the three types of loading, Type 14 was used; the three daily loading schedules used are shown in Fig. 12; because this version of the component uses dimensionless units, so that it can be used in a very generic way, each unit on the ordinate corresponds to 500W, this correction being made with the help of the pLoad component;

- for the necessary conversions of the units of measurement were used unit conversion routines provided by Type 57 and equation tools: Convertor C-K, Convertor kJ/hr-W, Convertor W-kJ/hr;

- for the display of desired variables, there was used Online Graphical Plotter, Type 65d and Type 65c, the last one allowing in addition to automatic graphical display of data also, their sending them to an external file for further processing.

IV. Results and Discussions

The performance parameters discussed in this section refer to:

- monthly variation of PV generated energy;

- monthly energy consumption and monthly energy consumption covered by PV and by grid;

- the annual PV energy, the annual own consumption, the annual grid feed-in energy, the annual covered by grid energy;

- the solar fraction defined as the ratio between the own consumption energy and the consumption (monthly or annual values).

It must say that considering the load profile considered (4kWh/day), the annual value of consumption is 1460kWh.

The analysis of the performance parameters for the simulations corresponding to the urban area Brașov (using the measured weather data) leads to the following conclusions, Fig. 13 and Fig. 14:

- The maximum monthly energy production is of 595kWh and was obtained for August and the minimum one for January, respectively of 191kWh;
- The value of the solar fraction falls between the limits of 37.3% for December and 71.5% for July;
- PV annual energy value obtained is 4822kWh; of this amount about 17% is used for own consumption and about 83% is energy feed in grid;
- From the total annual consumption of 1460kWh, about 44% represents energy covered by PV and 56% energy covered by grid;
- The annual value of energy covered by grid is 818kWh (energy required to cover the entire consumption) the energy feed in grid being about 4004kWh;

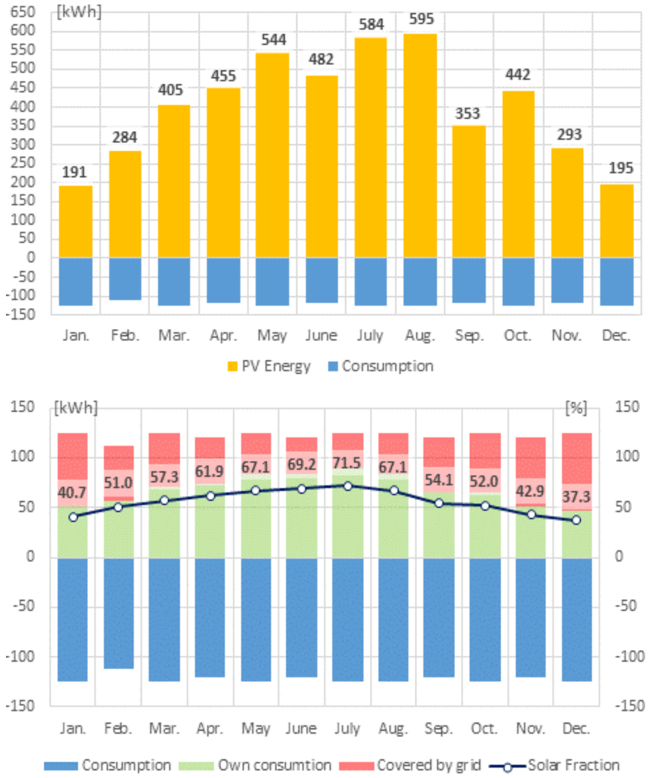


Fig. 13. *Monthly PV energy and monthly consumption – urban area of Brașov*

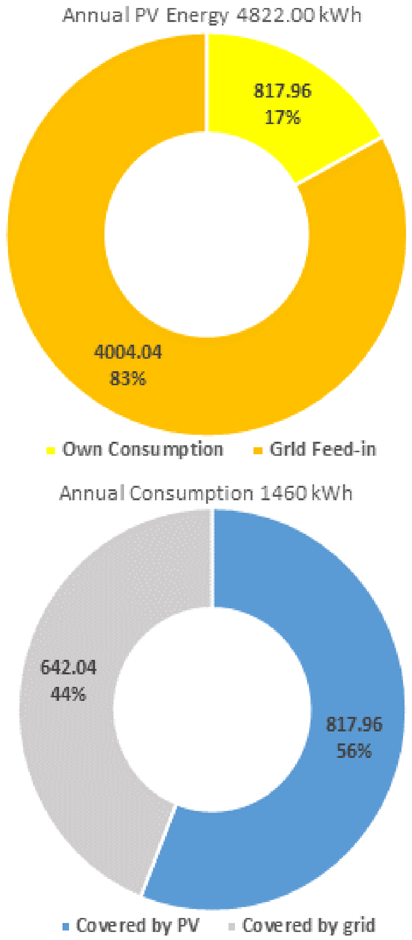


Fig. 14. *PV Energy, consumption, own consumption, grid feed in energy, energy covered by PV and covered by grid – urban area of Brașov*

- The annual value of the solar fraction is about 56% and the annual value of the own power consumption (the ratio between the own consumption and the PV energy) is about 17%.

For the extra-urban area of Brașov, the simulations highlighted the following aspects (Fig. 15 and Fig. 16):

- The maximum values of energy production are obtained for the months of July and August (584kWh);
- The minimum monthly value of energy production is 178kWh and is recorded for January;
- The values of the solar fraction fall within the limits of 38% (December) and 70.2% (July); notes the qualitative variation similar to the solar fraction curve to that of the solar energy curve, confirming that the main factors influencing the values of the solar fraction are climatic conditions;
- The annual value of PV energy obtained is 4769kWh; from this about 17% represents the own consumption and about 83% represents energy feed in grid;
- From the total annual consumption of 1460kWh about 45% represents energy covered by grid and 55% represents energy covered by PV;

- The annual energy covered by grid is about 803kWh and the annual energy feed in grid is about 3965kWh;

- For the annual value of the solar fraction was obtained a value of 55% and for the annual value of the own power consumption a value of 16.8% (values close to those calculated for the urban area);

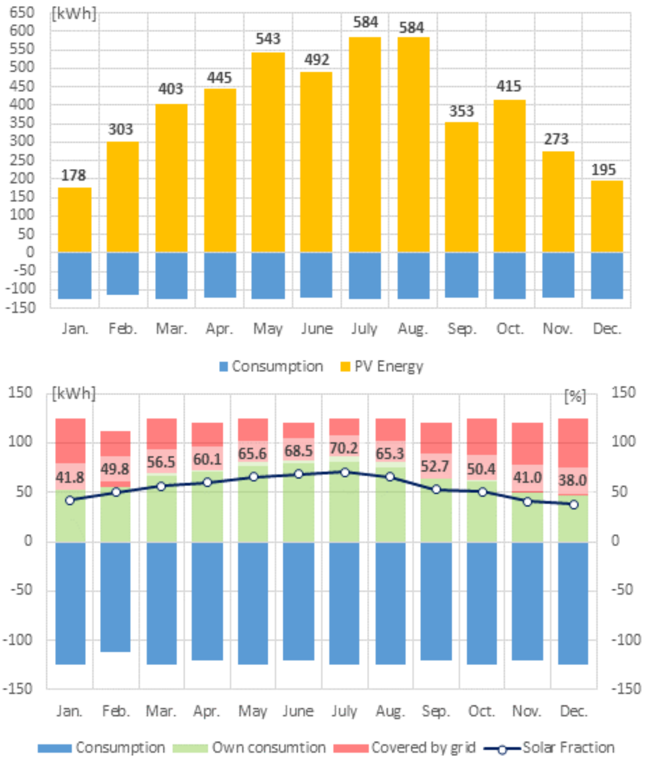
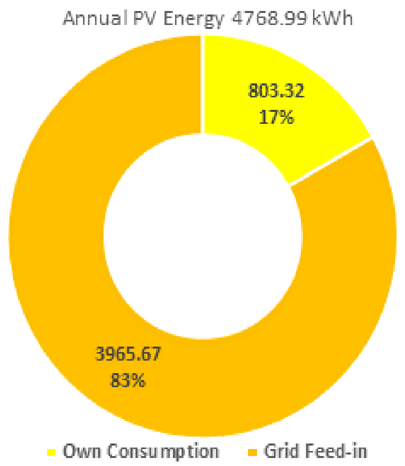


Fig. 15. *Monthly PV energy and monthly consumption – extra urban area of Brașov*



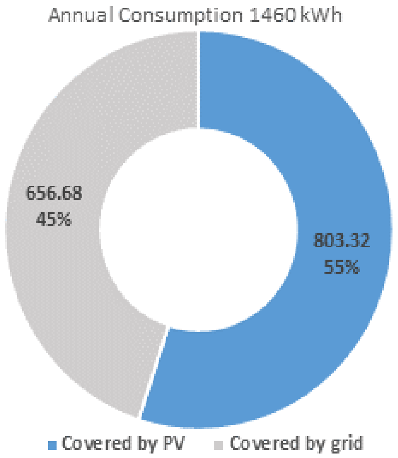


Fig. 16. *PV Energy, consumption, own consumption, grid feed in energy, energy covered by PV and covered by grid – extra-urban area of Brașov*

- The annual value of PV energy for the extra-urban area (4769kWh) is slightly lower compared to that for the urban area (4822kWh), as well as the annual value of solar energy is slightly lower for extra-urban area (1268kWh) compared to that recorded for the urban area (1276kWh).

If the closest city to Brașov, the existing city in the METEONORM database, is used, the simulations of the PV on grid system led to the following results (Fig. 17 and Fig. 18):

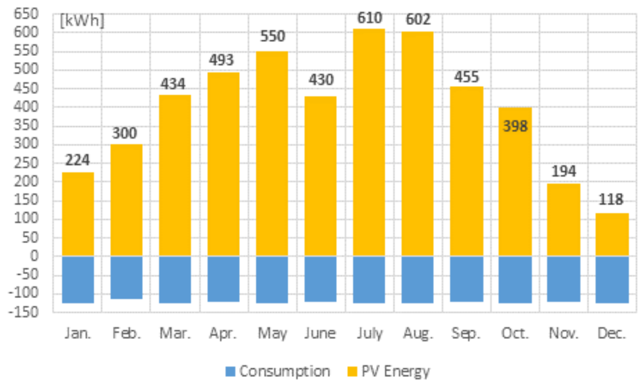
- The monthly value for PV energy production varies between 118kWh (December) and 610kWh (July);

- The monthly values of solar fraction varies between 29.4% for December and 73.3% for July;

- The annual PV energy production is about 4808kWh; of this value, about 17% represents own consumption and 83% represents energy feed in grid;

- Regarding the annual energy covered by grid, this represents about 44% from the total annual consumption of 1460kWh; the energy covered by PV represents about 56%;

- The annual energy covered by PV is about 825kWh and the annual energy feed in grid is about 3983kWh;



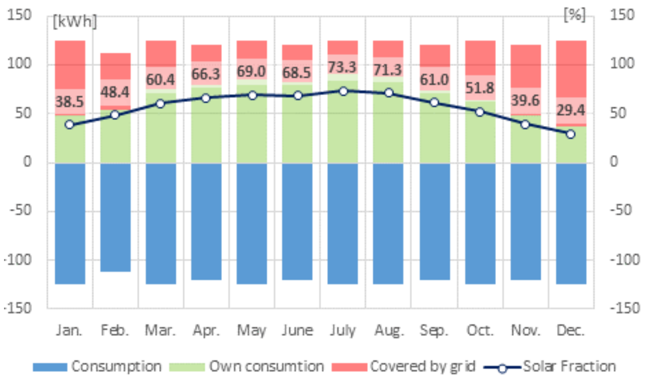


Fig. 17. *Monthly PV energy and monthly consumption – the closest city to Brasov, city from METEONORM database*

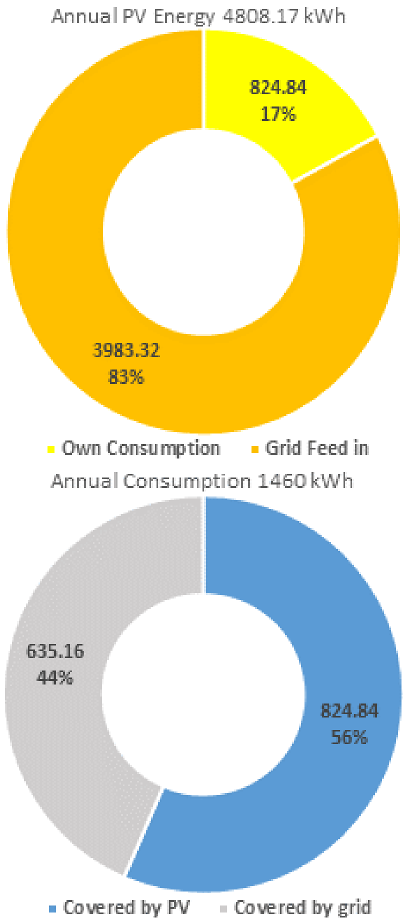


Fig. 18. *PV Energy, consumption, own consumption, grid feed in energy, energy covered by PV and covered by grid – the closest site to Brașov*

- The annual value of the solar fraction is 56.5% and the annual value of the own power consumption is 17.5%;

- Comparing the annual values of PV energy obtained from simulations using METEONORM database (4808kWh) and the measured weather data for Brașov area (4822kWh), it is obtained a difference of 22kWh. Even if the annual difference is not large, however, the analysis of the monthly variation of photovoltaic energy highlights that there are months where these differences are important. In addition, it cannot be stated that there is an even overestimation of PV energy values for all months. For instance for January the PV energy is overestimated with about 33kWh (and this value is relatively high considering that is a winter month with low solar potential) and for December, an underestimation about 77kWh is noticed (and again a high value considering the winter month).

As mentioned above, when choosing the loading profile, a situation of Profile with constant load was chosen and for the type of photovoltaic panels, a variant of panels was chosen that are sold in Romania but, that can also be found in the software PVSOL database (AE Solar panels, type AE P6-60_250-275W). These simulation preconditions have been established so that the simulation to be performed for the same conditions for all software and the comparative analysis of the data to be as accurate as possible.

Therefore, an analysis of the performance parameters when using the PVSOL software leads to the wording of the following conclusions (Fig. 19 and Fig. 20):

- Monthly PV energy production takes values between 555kWh for July and 307kWh for November;

- The annual value of PV energy production is about 5341kWh; of this value approximately 12% represents the own consumption energy end 88% represents energy feed in grid;

- From the annual consumption of 1460kWh, 43% represents energy covered by PV and 57% represents energy covered by grid;

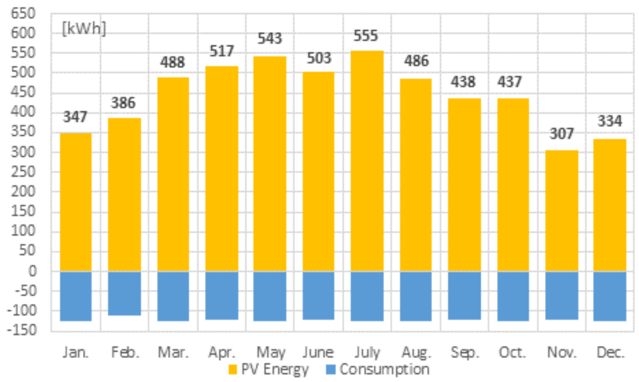


Fig. 19. *Monthly PV energy and monthly consumption – PVSOL simulation for Brașov*

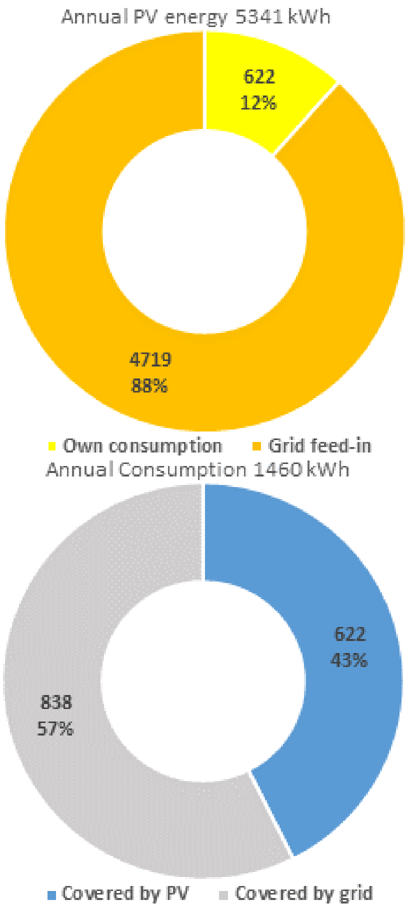


Fig. 20. *PV Energy, consumption, own consumption, grid feed in energy, energy covered by PV and covered by grid – PVSOL Brașov*

- Calculating the annual solar fraction it resulted the value of 42.6% and for the own power consumption a value of 11.6%; there is an important difference between these values and those calculated with the measured data for Brașov;

- It is noticed that similar to the monthly solar energy variation compared to the measured solar energy for Brașov urban area (fig. 2), for the winter period (January, February, December) and the months of March and April, the PVSOL software overestimates in a great extend the PV energy calculated with the measured weather data.

Regarding the simulations performed with the PVGIS software, the following conclusions can be worded, Fig. 21:

- The monthly values of the PV energy production are between the limits of 165kWh for December and 516kWh for July;

- Except for September, all the monthly values of PV energy production simulated with PVGIS software are underestimated comparing the values obtained with measured weather data;

- the greatest differences between the monthly values of the PV energy simulated with PVGIS and those obtained with the measured data for the Brasov urban area (differences greater than 80kWh) were registered for the months: May, August and September.

- The annual value of PV energy production is of 4277kWh, value that is underestimated largely compared to the value of photovoltaic energy obtained with the data measured for the urban area.

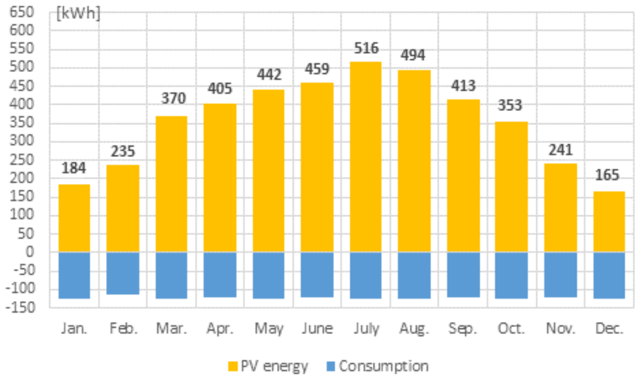


Fig. 21. *Monthly PV energy and monthly consumption – PVGIS simulation for Brașov*

The analysis of the annual values of produced photovoltaic energy leads to the conclusion that the simulation using Trnsys software leads to the smallest percentage difference compared to the value calculated using weather data recorded for the urban area of Brașov, respectively about 0.3% (Fig. 22).

The percentage difference between the annual values of photovoltaic energy calculated using the PVSOL database and that obtained using the weather data recorded for the Brașov urban area is approximately 10.8%. Therefore the use of simulations with data generated by the PVSOL software could lead to an under-dimensioning of the PV system (the annual PV energy production is estimated to be higher with approximately 520 kWh).

What is interesting is that although the annual value of photovoltaic energy obtained from simulations with PVSOL software is overestimated, still the annual value of own consumption energy is 622kWh compared to 818kWh, value calculated with measured weather data (percentage represents 17% of PV energy).

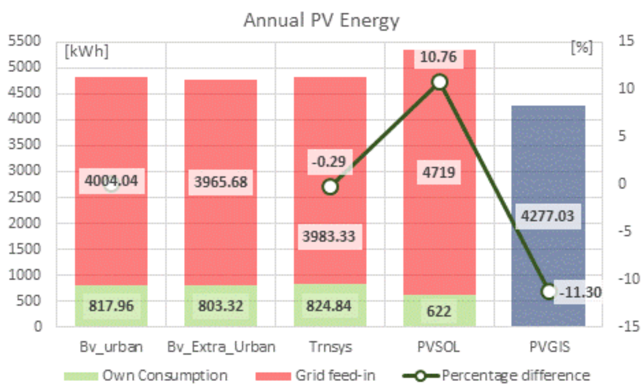


Fig. 22. *Annual PV energy*

The percentage difference between the annual values of photovoltaic energy calculated with the PVGIS software and that obtained using the data measured for the urban area of Brașov is approximately -11.3% PV (the annual PV energy production is estimated to be lower with approximately 545 kWh).

In terms of both the values of the solar potential and the values of photovoltaic energy, between the two areas of Brasov (urban area and extra-urban area) there are relatively small differences.

Although between the annual values of photovoltaic energy calculated using the weather data provided by METEONORM, respectively using the measured weather data, there are no significant differences, an analysis of monthly values, emphasises that there are months for which the differences are significant, Fig. 23.

Thus, the overestimation of photovoltaic energy is about 100kWh for September, and for the months of January, March, April and July this overestimation is between 25kWh and 38kWh. The most important underestimation of photovoltaic energy is for November, this having a value of 98kWh; for October and December the underestimation is between 44kWh and 77kWh.

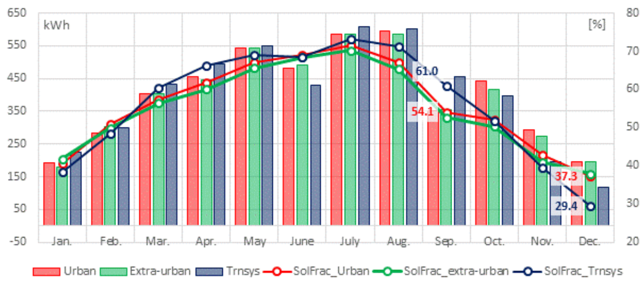


Fig. 23. *PV Energy and Solar Fraction*

Also, the analysis of the monthly values of the solar fraction shows that the percentage differences are between -8% and 7%, values recorded for the months for that there were significant differences of overestimation and underestimation of photovoltaic energy (December and September).

To highlight better the above differences, Figs. 24-26 present the monthly variation of energy generation and energy consumption for the months of September and December, months at the maximum and minimum in terms of photovoltaic energy production. The diagrams represents the simulations achieved with Trnsys using the meteorological databases for Brașov urban and extra-urban areas and the METEONORM database for the nearest town to Brașov.

Given the results of simulations with Trnsys software and the PVSOL and PVGIS software, it can worded the following conclusion: sizing of the grid-connected photovoltaic systems is recommended to be performed using meteorological data from weather stations located in the area of implementation theirs.

The weather data generated with the specialized software cannot take into account the geographical and climatic characteristics specific to each area of implementation of the PV systems. The city of Brașov is located in a depression area, in the internal curvature of the Carpathians, its climate being characterized by the transition note between the temperate climate of oceanic type and the temperate climate of continental type [10].

In these circumstances, the development of some methods for generating weather data that take into account all these specific conditions of such an urban area (where the urban pollution leads to a decrease in solar radiation), is extremely difficult.

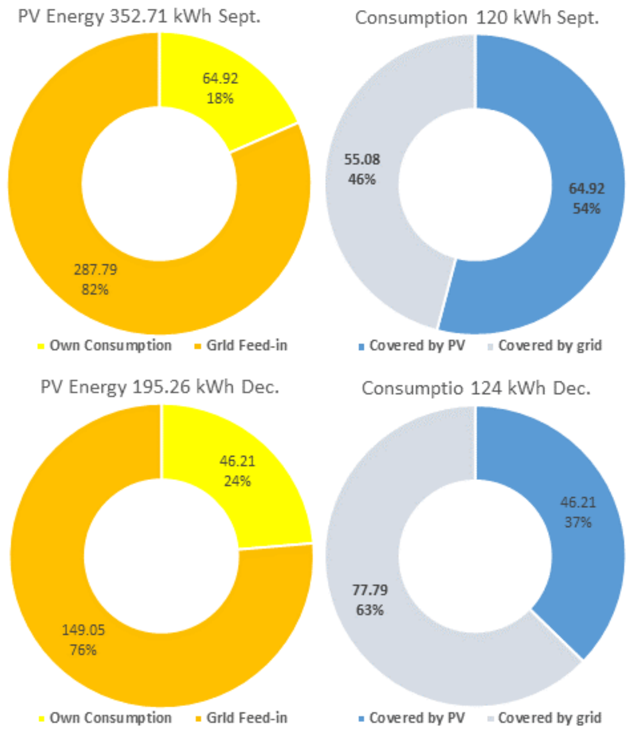


Fig. 24. *Monthly variation of energy generation and energy consumption for the months of September and December – urban area of Brașov*

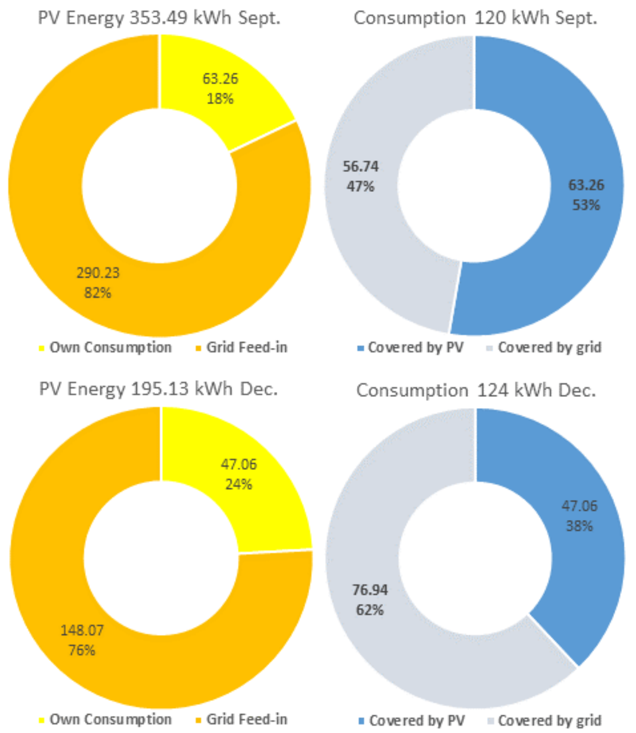


Fig. 25. *Monthly variation of energy generation and energy consumption for the months of September and December –extra-urban area of Brașov*

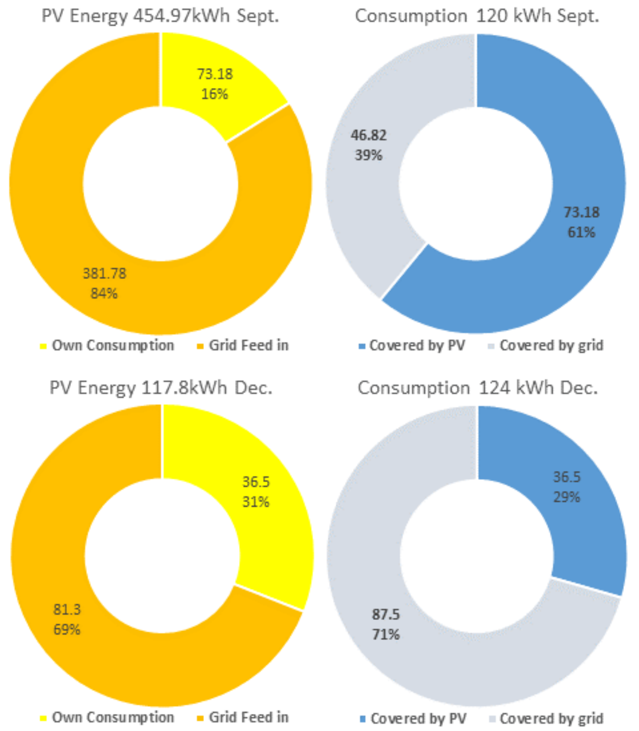


Fig. 26. *Monthly variation of energy generation and energy consumption for the months of September and December –the closest town to Brașov (Cluj-Napoca)*

One last aspect to mention concerns the avoided CO_2 emissions. Thus, if we take into account the fact that in 2017 at national level, the average specific values of CO2 emissions and radioactive waste resulted from electricity production, were 314.52kg/kWh [11], then for the considered PV system, the value of avoided CO2 emissions is about 1516kg/year for the urban area and 1500kg/year for extra-urban area.

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