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# Determining the photovoltaic generated electricity necessary to provide for the household consumption of single-family homes

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# Determining the photovoltaic generated electricity necessary to provide for the household consumption of single-family homes


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**Abstract.** This report reviews the possibility of estimating the required quantity of electricity to be generated to meet the needs of single-family homes. The results of the implementation of two estimation variants are compared, based on the hourly percentage distribution of the average daily consumption for household loads and specific rates of electricity consumption, deduced to 1 urban inhabitant. The efficiency of the methodologies is evaluated, as well as the possibilities for their use for determining the power of storage systems.


## INTRODUCTION

Preliminary estimation of the size of the power generation units is crucial for the financial costs associated with their construction and for meeting the needs of electricity consumers. When designing roof photovoltaic systems for single-family houses, in addition to the regulatory restrictions on installed capacity, we are faced with several other types of requirements and restrictions. Some of them are a consequence of the available roof space, the geographical orientation of the roofs, the angle to the direction at which the solar radiation falls on them, the options for the types of structures that can be used. Other types of requirements and restrictions are related to the nature of household consumption in single-family buildings, the connection of buildings to the electricity grid, the possibility of building storage systems.

If we look at the nature of household consumption, it is usually such that in the time range of the day, when we have the maximum generation of electricity from photovoltaic systems, household consumption is relatively low, especially in spring and autumn. In order to be able to predict what capacities should be installed, it is necessary to take into account the hourly consumption and generation of electricity, possibly with the inclusion of storage systems or in combination with hybrid power from the photovoltaic system (PVP) and the electricity supply grid, with or without selling the excess amount of energy with a corresponding economic balance of costs and revenues.

The main problem in this case is on what basis to determine the nature of consumers and how to compare it with the nature of electricity generation by PVP.

Regarding the forecast of electricity generated by photovoltaic systems, there are lots of software programmes (which on the basis of previous statistics on weather conditions, the length of daylight, the geographical location of the PVP, the intensity of solar radiation and the angle at which the sun's rays fall to the earth's surface on a certain day and hour, as well as on the basis of computational models that take into account the aging of photovoltaic cells) can make a sufficiently accurate average forecast for the electricity produced hourly for each day of the year. This means


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that it is relatively easy to predict the average statistical amount of electricity produced. However, in order to determine how much electricity will be needed to produce and what capacity will be needed, we should determine the basis on which to compare it in terms of electricity consumed by household consumers - hourly, daily, monthly and/or year-round. In addition, the comparison may be based on "satisfying maximum consumption in minimum production conditions" for a specific day or days or hours, or be based on the total amount of electricity consumed and generated per year. It may also be necessary to determine the capacity of possible energy storage systems.

## METHOD OF BALANCE COMPARISON

One of the variants is to assume the power of photovoltaic systems (disregarding the limit of up to 5kWp in the Republic of Bulgaria) to be equal to the power of the household consumer depending on the group in which he falls in terms of home heating [1][2], (assuming that the roof area of the single-family house allows this). In this case, practically, there should be electricity production exceeding its consumption, as in a very small range of the day, the consumer would consume to the maximum of its capacity and such an investment would be economically unprofitable, especially with contrasting differences in quantity and the price of the sold electricity, and the quantity and the price of the purchased one.

Another option is to compare the electricity generated by photovoltaic systems with that used by the household consumer, and the quantities will be adjusted again to the group in which he falls in terms of the method of heating the home. In this case we will have a better balance of generated and consumed electricity.

In the present study the second option is reviewed, using two variants to determine the basis on which to assess the consumption of household consumers in our country (Republic of Bulgaria). The presented material for both variants is based on the same amount of annual specific consumption of electricity for lighting and household needs per capita, for buildings that use electricity entirely for heating. The value of this specific rate, according to existing methods for determining household loads in the design of electricity supply in settlements "village" with a population of up to 2000 inhabitants is $W_{p(person)} = 900kWhp^{-1}/year$ [1][3].

The first variant, designated “M1”, uses the hourly distribution of electricity consumption for one day, obtained on the basis of the average daily electricity consumption for the months of January and July, using average hourly coefficients showing how much of the

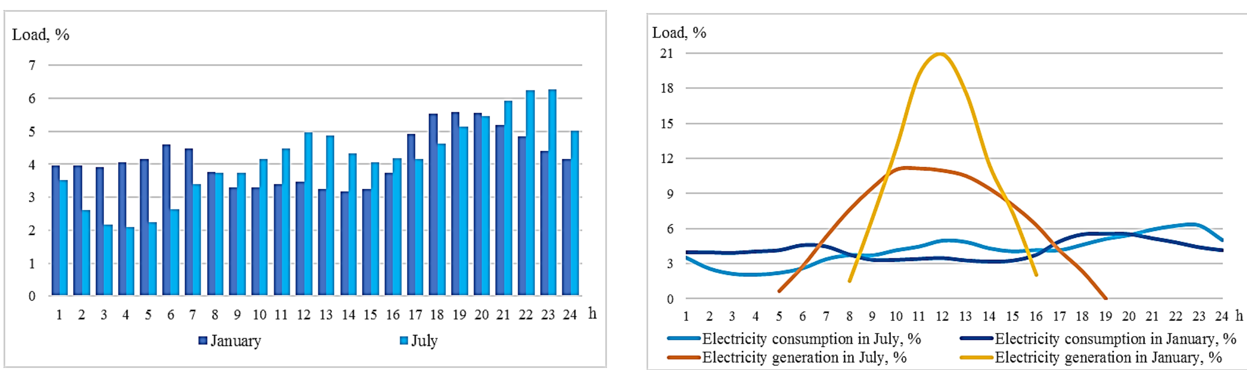


**FIGURE 1.** Hourly percentage distribution of average daily consumption (M1) and electricity generation (M1, M2)

total daily electricity consumption is used at a specific hour [3] – fig, 1. According to this methodology [3] it is introduced that the monthly consumption for January and July is respectively 10.7% and 7.75% of the annual specific quantity of $900kWhp^{-1}/y$. The graph of fig. 1 shows in percentage terms the hourly distribution of electricity consumption in January and July (in blue colour), and the right graph also shows the hourly percentage distribution of electricity generated by a photovoltaic system (PVP) (for the region of Plovdiv, Bulgaria) determined on the basis of the average daily generation for the months of January and July (in yellow colour), simulated with [4].

The next two graphs of fig. 2 present a percentage hourly comparison between the average daily consumption and electricity generation for the two months.

The figures show that in January we have a narrower time range in which electricity is generated by photovoltaic systems. Comparing the percentage of monthly consumption for January and July, we see that in January more electricity is consumed.

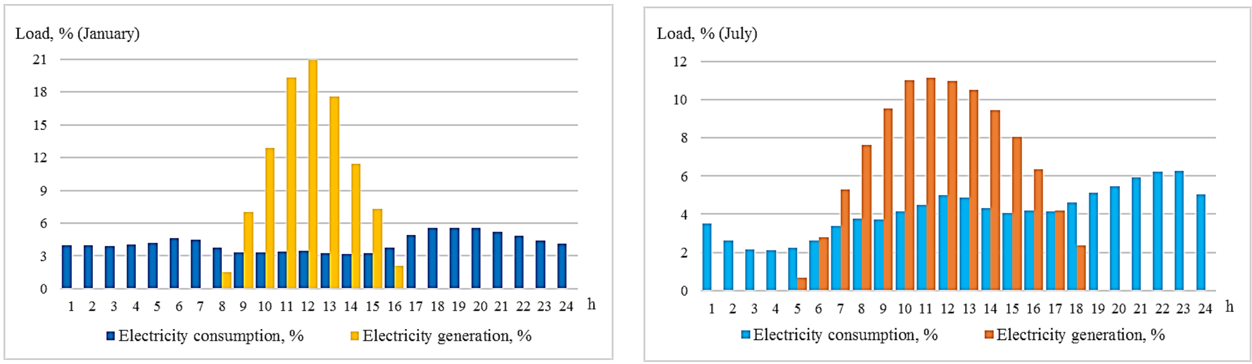


**FIGURE 2.** Comparison of the percentage hourly distribution of the average daily consumption and generation of electricity for the months of January and July for M1

Therefore, if it is decided to meet the electricity needs in January entirely with such generated by a PVP, this system will have to be able to produce the required amount of electricity, for example on the basis of the average daily consumption for January. It is appropriate to increase it, for example by 20%, to cover technical losses and the availability of stock. Thus, the total average daily quantity that a PVP should produce under these conditions per capita is 1.2x (900kWh/31day)x10.7% = 3.73kWh/p. Fig. 3 shows the hourly distribution of consumption and generation of electricity in kWh per 1 inhabitant.

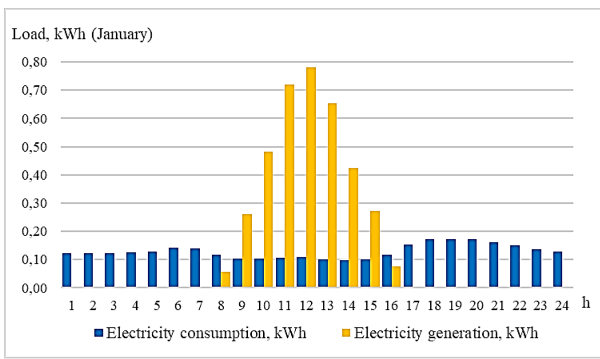


**FIGURE 3.** Hourly distribution of consumption and generation of electricity in kWh per 1 inhabitant (M1)

From the analysis of the data related to fig. 3, the following is established:

- the total daily average for the month quantity of electricity consumed is 3.11 kWh/p;
- the electricity consumed during its generation is 0.84kWh/p;
- the electricity to be supplied to storage batteries (taking into account the reserve) or sold to the electricity grid is 3.25 kWh/p (the purchased should be at least 2.27 kWh/p).

Taking into account the presence of four residents in a single-family house, there would be an increase of 4 times. Accordingly, the PVP for a single-family house should be such as to provide an average daily production of 3.73x4 = 14.92kWh.

The second variant, designated as "M2", uses the hourly distribution of electricity consumption, obtained by coefficients for hourly distribution of consumption on an annual basis, used by an electricity distribution company to profile consumers in the regulated market in our country. The base used in this study is [5] for 2020y. "Standardized load profile H1" - consumers using only electricity for heating.

Fig. 4 shows a comparison between the percentage distribution of electricity consumption for the months of January and July using the data from options M1 and M2.

The graphs show that there is a discrepancy between the hourly distributions of loads by the two methods. In addition, the H1 profile used for M2 sets the share of the annual loading schedule at 11.8% for January and 5.91% for July. If this data is compared with the share distribution in [3], variant M1, they are 10.7% and 7.75% respectively.

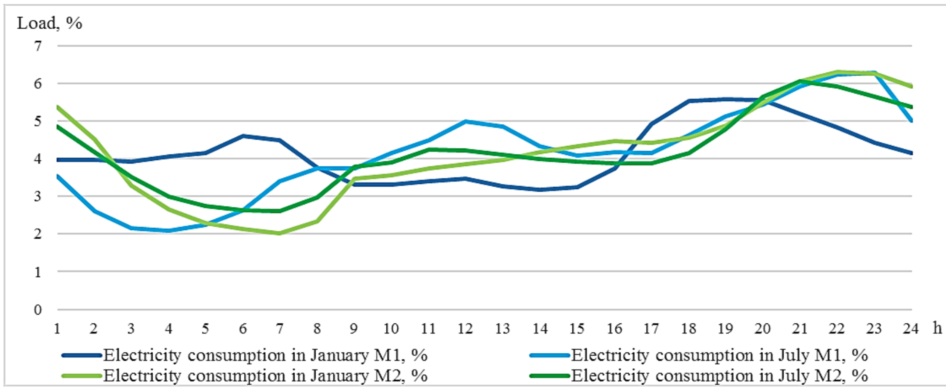


**FIGURE 4.** Percentage hourly distribution of the average daily consumption for January and July for M1 and M2 variants

The following graphs, on fig. 5, show hourly comparisons in percentage of the average daily consumption and generation of electricity for M2.

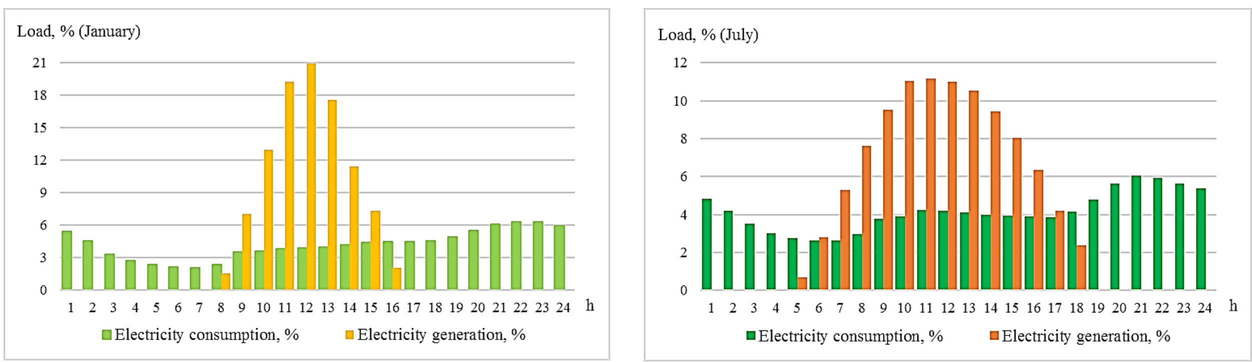


**FIGURE 5.** Comparison of the percentage hourly distribution of the average daily consumption and generation of electricity for the months of January and July (M2)

As with the M1 variant, in this case it can be seen that in January we have a more significant reduction in the hours in which we have electricity generation from photovoltaic systems.

Thus, following the same considerations as for M1, the total quantity that a PVP should produce on average per capita per day is 1.2x(900kWh/31day)x11.8% = 4,11kWh/p.

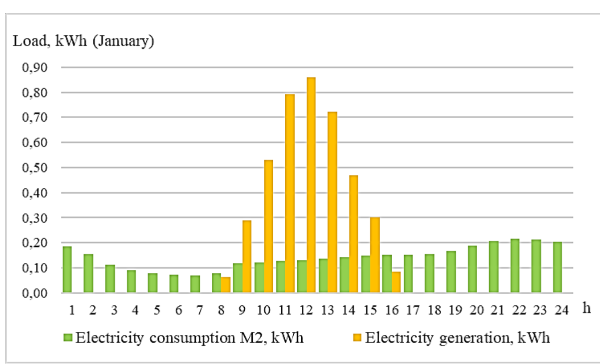


**FIGURE 6.** Hourly distribution of consumption and generation of electricity in kWh per 1 inhabitant (M2)

From the analysis of the data related to fig. 6 the following is established:

- the total daily average quantity of electricity consumed for the month is 3.43 kWh/p;
- the electricity consumed during its generation is 1.16kWh/p;

- the electricity to be supplied to storage batteries (taking into account the reserve) or sold to the electricity grid is 2.95 kWh/p (the amount purchased back should be 2.27kWh/p).

As in variant M1, taking into account the presence of four residents in a single-family house, the corresponding PVP should be such as to ensure an average daily production of 4.11x4 = 16.44kWh.

Fig. 7 shows the hourly average daily percentage distribution of electricity consumption for January, for variants M1 and M2 (per 1 inhabitant) against the background of the hourly distribution of electricity generated by a PVP, in quantity equal to consumption plus a stock of 20% per 1 inhabitant.

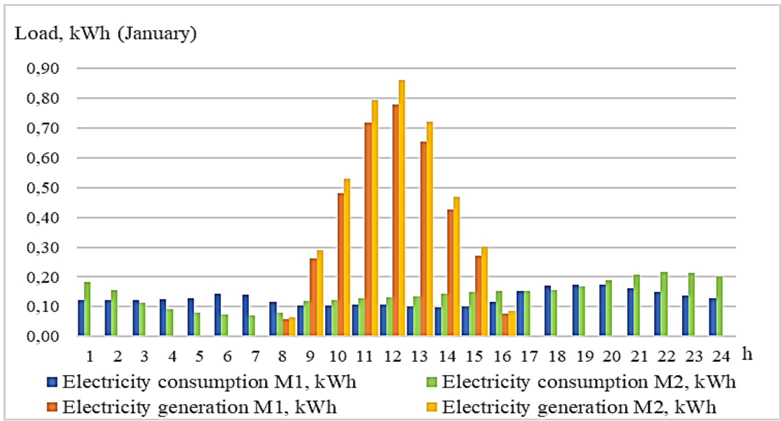


**FIGURE 7.** Hourly distribution of the average daily consumption and generation of electricity for the month of January, for variant M1 and M2, per 1 inhabitant

**TABLE 1.** Electricity for 4 residents of a single-family house

| **Option M1** | | **Option M2** | |
|---|---|---|---|
| 900kWhp$^{-1}$/year | 2710kWhp$^{-1}$/year | 900kWhp$^{-1}$/year | 2710kWhp$^{-1}$/year |
| Average daily quantity of electricity consumed, kWh | | | |
| 12.44 | 37.46 | 13.72 | 41.32 |
| Electricity consumed during its photovoltaic generation, kWh | | | |
| 3.56 | 10.72 | 4.64 | 13,97 |
| Electricity supplied to storage batteries or to the electricity supply network, kWh | | | |
| 13.00 | 39.14 | 11.80 | 35.52 |
| Electricity consumed outside the photovoltaic generation period, kWh | | | |
| 9.08 | 27.34 | 9.08 | 27.34 |
| Required average daily amount of electricity produced by the photovoltaic system, kWh | | | |
| 14.92 | 44.92 | 16.44 | 49.50 |

Comparing the results of the two methodologies presented in Table 1, it can be seen that we have about 10% difference in the average daily amount of electricity consumed during the analysed month, with a larger difference in the share of electricity consumed during photovoltaic generation, which difference, in terms of percentage is about 30%, and in terms of quantity is 1.08kWh for the entire building. However, analysing the last row of the table, it can be seen that the quantity of electricity consumed, determined at a specific rate of 900kWhp$^{-1}$/year, seems to be significantly lower than the actual quantity of electricity consumed this month by a single-family building. This fact means that it is necessary to determine more precisely the values of the specific consumption rate per 1 inhabitant, related to single buildings, as well as their energy efficiency class and the level of furniture. However, if we set a rate of 1800 kWhp$^{-1}$/year, which is the rate of 1 person for cities up to 10,000 inhabitants [2] or the rate 2710kWhp$^{-1}$/year for cities with a population between 10,000 and 30,000 inhabitants [2], the final results start to seem more logical.

It is interesting that despite the different values of the percentage distribution of consumption in M1 and M2 - fig. 4, the energy consumed outside the time period 08.00 - 16.00 is the same in value for both variants. The difference between the average daily quantity that needs to be produced under the two variants is within about 10%. The energy supplied to storage batteries or to the grid varies between 9-11%.

## CONCLUSION

In conclusion, the following can be said on the subject:

- the coefficients used in both variants, describing the hourly distribution of the loads, lead to about 10% difference by variants in the total loads, as well as in the possible capacities of the storage systems;

- with a well-assessed specific rate of electricity consumption per 1 habitant, a relatively good estimation can be expected for the required capacities of photovoltaic systems of single-family houses, depending on the requirements set in both variants;

- when determining the installed capacity of photovoltaic systems that produce the minimum calculated quantities of required average daily electricity, the degradation of the coefficient of efficiency of these systems over time should also be taken into account;

- it is obvious that while satisfying the most difficult conditions in terms of generation and consumption of electricity, i.e. those in January, in other months with better weather conditions, there will be a significant surplus of production capacity. For this reason, the concept of photovoltaic power being such that it produces the same amount of electricity as is consumed on average in January is not very appropriate. It would be more appropriate for the design to be based on a year-round quantity of electricity, with the shortage/lack of production to be compensated by a power supply grid from other types of electricity sources and/or by a combination of appropriate energy storage systems;

- the variants shown can also be used to predict the required daily capacity of storage systems.

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