

PAPER • OPEN ACCESS

Influence of User Electricity Load Profile and Calculation Time Step on the Photovoltaic System Balance

To cite this article: J Novotny and T Matuska 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **290** 012082

View the [article online](#) for updates and enhancements.

You may also like

- [Modeling and analysis of the solar photovoltaic levelized cost of electricity \(LCoE\) - case study in Kupang](#)
Rusman Sinaga, Nonce F. Tuati, Marthen D.E. Beily et al.
- [The outflow characteristics of PV water lifting systems based on multiple tracking strategies](#)
Wei Hu, Shiwen Hou, Junfeng Zhu et al.
- [An Investigation of the Recovery of Silicon Photovoltaic Cells By Application of an Organic Solvent Method](#)
Vaidyanathan Subramanian, Prichard Tembo and Milan Heninger



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Influence of User Electricity Load Profile and Calculation Time Step on the Photovoltaic System Balance

J Novotny^{1,2} and T Matuska²

¹ Faculty of Mechanical Engineering, Czech Technical University in Prague

² University Centre for Energy Efficient Buildings of Technical University in Prague

jiri.novotny@fs.cvut.cz

Abstract. Realistic energy balance of photovoltaic system has a direct impact on realistic economic evaluation of operation costs for given building. To estimate the realistic electricity power profile with a short-time step, a generator based on appliances power, occupancy and external daylight presence has been developed and used for simulations. Generator allows to create different power profiles for the whole year (all days identical, workdays-weekends, 365 different days) with given time-step resolution (from 1 minute to 1 day). Paper presents and analyses the results from parametric simulations of PV production and building electricity loads balance with different times-steps. Monthly calculation approach used as a standard methodology for building performance evaluation significantly overestimates the solar fraction of PV systems. Only calculations with time steps shorter than 1 hour lead to results close to reality. A methodology for monthly balance correction to realistic results based on yearly PV production to building consumption ratio will be presented.

1. Introduction

At present, emphasis is placed on increasing the use of renewable energy sources in buildings. It results in increased attention to the reliability of computational practices in the assessment of the of the renewable energy utilization. The paper focuses on photovoltaic (PV) systems generating electricity without storage in batteries. Calculation of electricity production from photovoltaic systems can be reliably calculated using climatic data and suitable computer models, more or less complex. On the other hand, for the design and assessment of the PV system, it is necessary to know the electricity consumption of the building for which the PV system has been designed. In most cases of existing buildings, electricity consumption is known (energy bills, measurements), but only in the form of monthly or yearly data. For new buildings, power consumption can only be estimated based on statistics and considered equipment.

When assessed the PV systems in buildings without electrical heating system or electrical preparation of domestic hot water, the user electricity consumption plays a crucial role in PV system design and benefits of PV system application. User energy consumption includes electricity consumption for household appliances and lighting. On the other hand, due rather different behaviour of household occupants, the total consumption of user energy cannot be standardized. Moreover, variability of the load profile, not only during the year but also throughout the day, has a significant effect on the assessment of the utilization of the PV system production. The reliability of the energy balance is heavily influenced by the time step applied in the the calculation. For the purposes of the



analysis of the PV system balance, a generator of a probable load profile for the household has been developed based on the computational core of I. Richardson and M. Thomson [1]. The original tool was modified with permission of the authors and used for the following analysis. Different types of annual load profiles (1-day, 7-days or 365-days) with various time steps (from 5 minute to 1 hour) has been obtained. Finally, an extensive parametric analysis has been performed to create a simplification function to estimate the percentage of solar fraction based only on the ratio of annual PV production to annual user energy consumption.

2. Common calculation procedures

In the common Energy Performance of Buildings (EPB) assessment, the monthly calculation step is used to evaluate the PV system. However, when using a monthly calculation step for EPB, there is a significant difference in results from realistic solar fraction values for PV systems application without electricity storage, especially due to large calculation time step. Moreover, the influence of the user energy load profile is not a part of EPB assessment because considered as too detailed and simply not available. Currently, the most commonly used software tools for EPB assessment already offer a more detailed hourly calculation with more or less standardized load profiles, but the use of even shorter time step is not usual in the EPB assessment. **Figure 1** shows an example of electric power generation by a PV system with 5 min time step and household electricity load with time step 60 min. The graph also illustrates the case of considering the constant load (daily average power). It can be seen that considering the detailed load profile can lead to different results of the solar fraction than in the case of a simplified assessment with constant load. This has an impact on the assessment of operation cost savings, because the energy directly saved by the PV system can apply a significantly different price than the surplus energy exported to the grid. When balancing PV systems at a monthly or annual time step, one may come to conclusion that the PV system production could cover most or all of the electricity consumption, which is practically not true. The impact of the calculation time step and the specific load profile on the solar fraction assessment is shown in the following analysis.

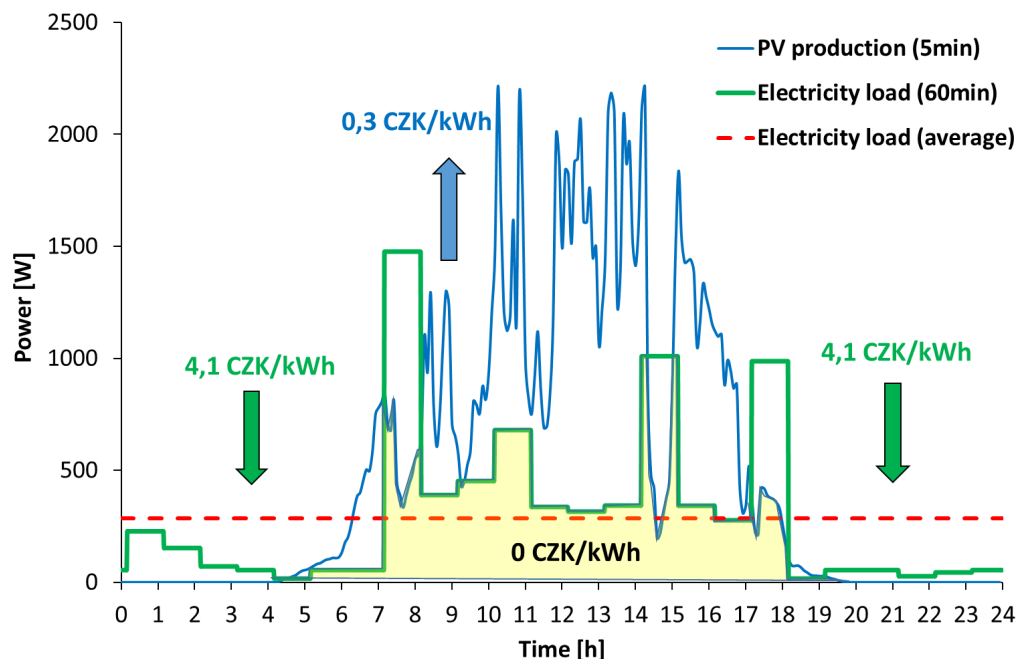


Figure 1. Daily energy balance of PV system

3. Load profile

Only household appliances and lighting electricity has been regarded as user electricity load to be covered by PV production. For the analysis of the influence of the time step on calculated solar fraction of PV system different types of load profiles have been considered.

- **constant (permanent profile)** – The profile represents the continuous user electricity load with a constant power, based on the annual consumption in kWh divided by the number of hours (8760).
- **1-day (daily profile)** – The profile is generated by a computer generator as a one day profile repeating throughout the year, considering the average solar irradiance for the calculation of lighting demand.
- **7-days (weekly profile)** – The profile considers different behaviour of users during weekdays and weekends and one typical week (5 + 2) is generated, which is repeated throughout the year. Electricity demand for lighting is based on average solar irradiance.
- **365-days (annual profile)** – The profile considers every day in a year with unique user electricity load profile, considering the hourly solar irradiance data and respecting weekday and weekend days.

Load profiles are generated with a detailed 1-minute time step including a specific profile of active occupancy and solar irradiance to calculate the electricity need for lighting. Household appliances available to include for profile generation are refrigeration devices, kitchen appliances, washing appliances, TV, computers, lighting type and other common electronics.

The concept of active occupancy means the active presence of persons in the household. Therefore, the activity of a sleeping and absent person is considered as zero. The profile of active occupancy in **Figure 2** was defined for 3 people. The first person gets up at 6:00 and the other persons get up later. At 8.00, all occupants leave their homes and return at 14.30 at the earliest. Before midnight, they all go to sleep.

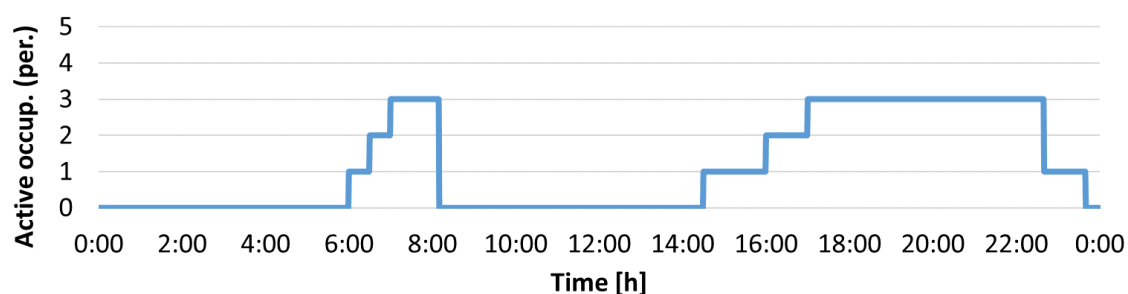
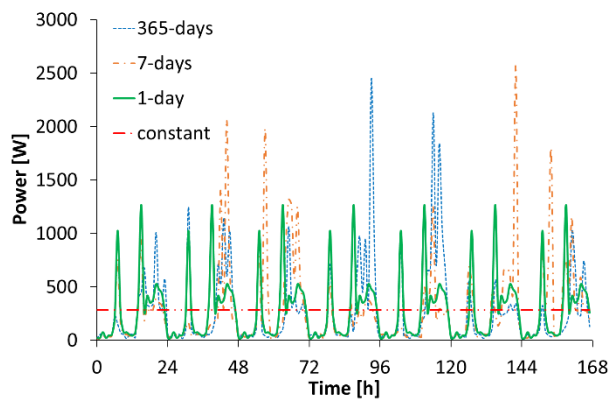
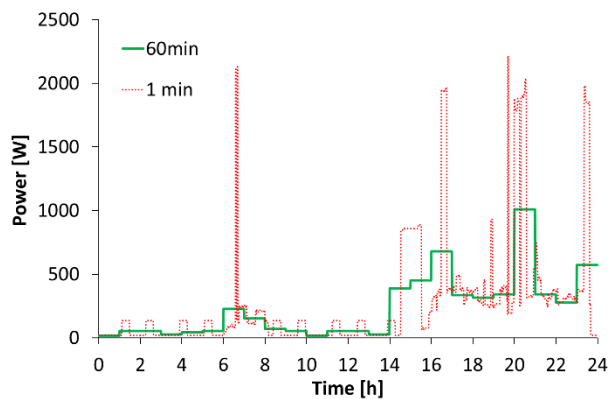


Figure 2. Active occupancy profile for 3 persons

Figure 3 shows the different types of user load profiles for the first week of January 2016. One-day profile can be seen visibly due to repeating course throughout the week. Load profiles for 7-days and 365-days show a different profile for each day of the week. The constant value of the electric load shows the permanent load profile.

**Figure 3.** Types of user load profiles**Figure 4.** Load profiles with different time steps

The generated load profile with 1-minute time step can be integrated into larger time steps as needed. **Figure 4** shows the load profile for a summer day (365-days detailed profile type) with different time steps of 1 minute and 1 hour, where a significant difference can be seen. The longer the time step is applied, the lower the peak power load due to integration results.

4. Analysis of the PV system balance for households

The balance of the PV system is given by the production of the electricity by the PV system and the electricity consumption of the household. The output of the PV system results from its size and parameters (installed power, module area, efficiency, temperature effect, module technology). Electricity consumption results from design of lighting, household appliances equipment (number, types) and occupancy. For the purpose of the analysis user electricity consumption of 2500 kWh has been considered. Different load profiles were provided for three persons in the household: constant, 1-day, 7-days and 365-days (see **Figure 3**) and different time steps (5 min, 15 min, 60 min, day, month and year) were also considered for the analysis.

Production of PV system was calculated by TRNSYS simulation software with respect to the time steps 5 min, 15 min, 60 min, day, month and year. Climate data for the calculation were obtained from the meteorological station of the University Centre for Energy Efficient Buildings CTU in Prague (UCEEB) in Buštěhrad with a one-minute time step for year 2016. The considered area of the PV modules is 20 m², the nominal efficiency is 16 %, the thermal coefficient 0.0045 1/K. The slope of the PV modules is considered 45° with orientation to the south. Electricity storage was not considered.

Balances of user energy consumption and PV production were performed at appropriate time steps. In **Figure 5** and **Figure 6** is a graphical representation of the PV system balance relative to a detailed 365-days profile using different time steps. The production of the PV system is shown only with a 5-minute time step. By comparing the graphs, different consumption profiles can be seen relative to the time period in which **Figure 5** shows the profile generated for the summer day 1st July 2016 and **Figure 6** profile for winter day 1st January 2016.

For the purpose of the analysis, occupants are mostly out of household during the day, which corresponds with **Figure 2** and represents a standard household. Therefore during the PV production in sunny day, there is almost no consumption of user electricity during the day due to the absence of occupancy. There is a slight increase in the morning hours, then a decrease in the load representing appliances independent of the presence of occupants (fridge, freezer, etc.) and consequently a considerable increase in the evening hours due to the use of common household appliances. The solar fraction is thus relatively low. However, when considering a constant consumption with a 1-day time step, the calculated solar fraction is significantly higher. **Table 1** and **Figure 7** show an assessment of the total solar fraction by the PV system for the household consumption.

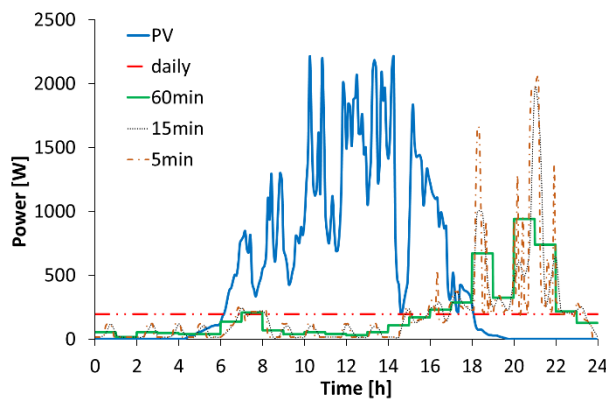


Figure 5. Balance of PV system, 365-days profile, summer

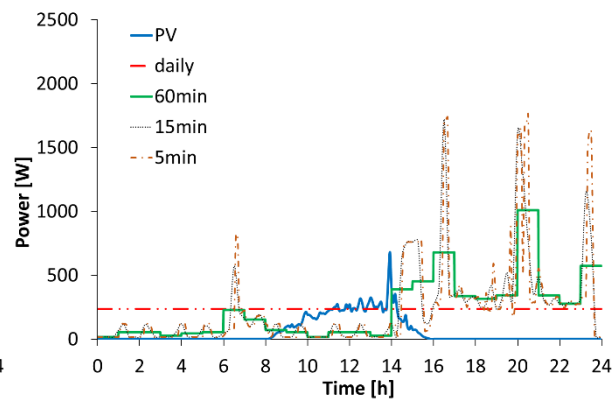


Figure 6. Balance of PV system, 365-days profile, winter

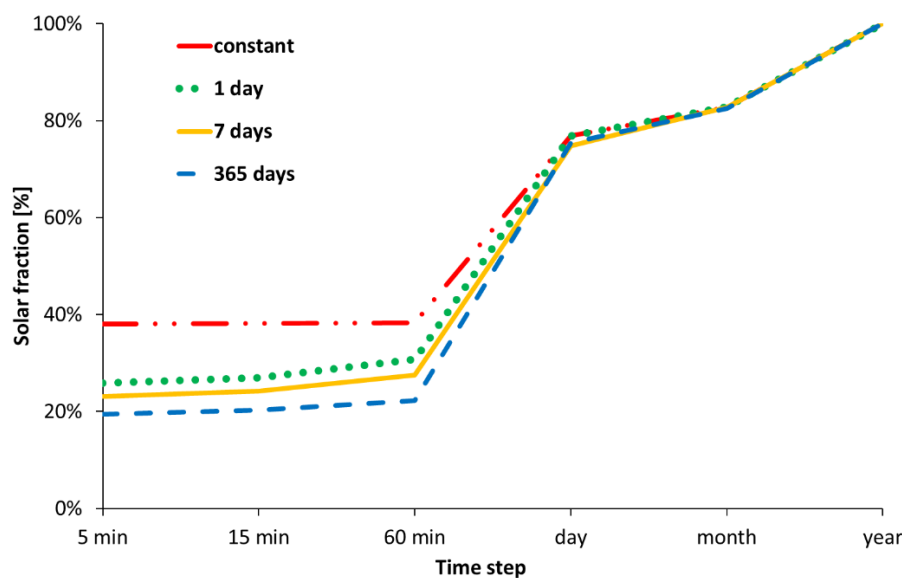


Figure 7. Influence of the time step on solar fraction

Table 1. Influence of the time step on solar fraction

Solar fraction		Time step					
		5 min	15 min	60 min	day	month	year
Type of profile	constant	38%	38%	38%	77%	83%	100%
	1-day	26%	27%	31%	77%	83%	100%
	7-days	23%	24%	27%	75%	83%	100%
	365-days	19%	20%	22%	75%	83%	100%

The analysis shows the significant influence of the calculation time step and the selected type of the load profile on the calculation of the solar fraction. For given time step, results for different types of load profiles differ from one another by single percents, except for the use of an unrealistic constant (permanent) profile with a continuous permanent load that shows clearly unrealistic values. Regardless of the load profile type, there is a significant difference in results based on short time steps up to 1 hour compared to results obtained with longer time steps (day, month, year). The shorter the time step

is, the lower the solar fraction results, the closer it gets to the real values. If the time step is sufficiently short – one hour and shorter, the results differ only in percents and relatively reliable results can be expected. In the case of a day, month and year time step that does not include the current production and consumption balance and night time, the results of the calculation are inconsistent with reality.

5. Simplified function for solar fraction estimates

To provide a simulation of PV system production to cover load profile with sufficiently short time step in conventional EPB assessment is not realistic in praxis due to the lack of available climate data and characteristic profile of variable user behaviour. Therefore, parametric simulations have been performed to obtain a function for simplified determination realistic solar fraction of PV system based only on ratio of annual PV production to annual user electricity consumption E_{PV}/E_U . To derive the function, about 500 combinations of different load profiles and PV system size have been considered. The load profiles have been based on detailed 365-days profiles with 5 minute time step but for different number of occupants (from 1 to 5), different active occupancy profile (10 profiles, see **Figure 8**), user behaviour (out of household during the day / in the household during the day) and different level of household equipment (higher standard / lower standard). Profiles represent different electricity consumption ranging from 1260 to 4340 kWh/year, depending on the boundary conditions. For each number of occupants, two profiles of active occupation were defined for the case of "conventional" households (during the day in work or at school) and case of being mostly in household during the day, but no more than two persons together (see **Figure 8**). Considered home appliances for a higher standard are a refrigerator with freezer, iron, vacuum cleaner, hair dryer, personal computer, home printer, television (55"), DVD blue-ray player, TV set-top box, hob, oven, microwave, kettle, toaster, dishwasher, washer / dryer and lighting. For a lower standard, following appliances are not considered: home printer, television (55" but 24" replacement), DVD blu-ray player, hob, microwave, toaster and dishwasher. The parameters of the appliances considered according to the current product portfolio for households.

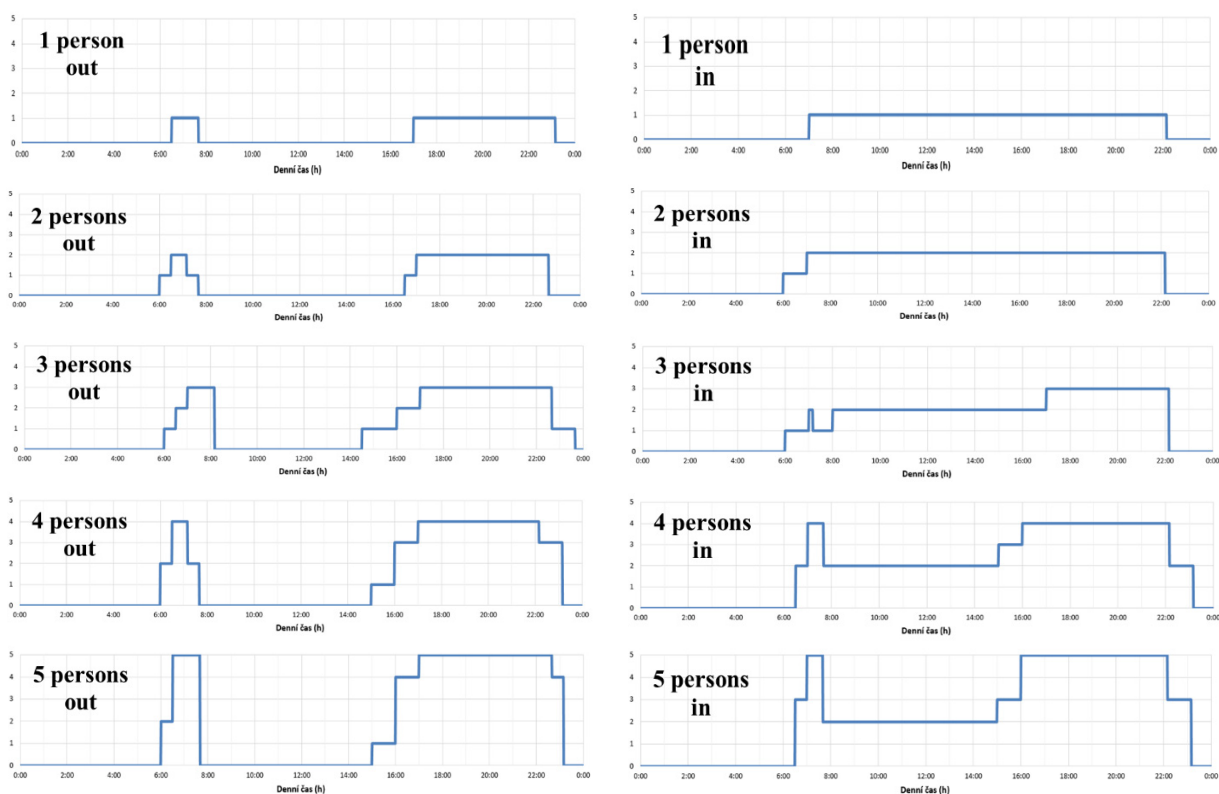


Figure 8. Active occupancy profiles used in parametric simulations

The calculation of the PV production was performed in the TRNSYS with 5-minute time step for the common size of PV systems used in family houses, i.e. with a peak power ranging from 1.6 to 5 kW_p, which corresponds approximately to photovoltaic modules area from 10 to 30 m². Detailed climate data mentioned in analysis above have been used. Subsequently, the annual solar fraction for PV system has been calculated for total 488 cases. Resulting chart is shown in **Figure 9**, where the knowledge of the balance ratio between annual production of the PV system (E_{PV}) and the annual consumption of the user energy (E_U) can be used for estimating of solar fraction. Two functions have been derived (bold line) to simplify the determination of solar fraction value close to reality, regardless of the knowledge of detailed user load profile. Cloud of points at lower part of the chart represents the households where occupants stay out during the day, i.e. at work or at school. Upper cloud is valid for households with persons who stay mostly at home during the day, but not more than 2 people together.

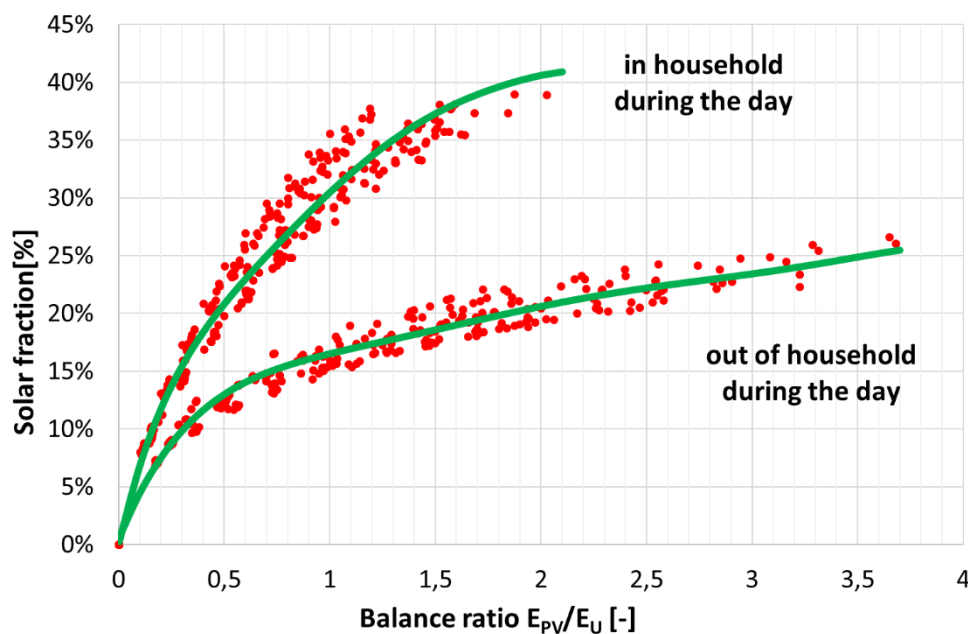


Figure 9. Simplifying chart for estimating solar fraction

Following example shows the use of the functions for household with 3 occupants staying out of the household during the day. The annual consumption of the electricity (E_U) obtained by the measurement is 2500 kWh/a. Calculated production of electricity by a potential PV system (E_{PV}) with a peak power of 3.2 kW_p is 3000 kWh/a, so the balance ratio of production of E_{PV} to E_U is equal to 1.2. Solar fraction resulted from function applied is 17,4 % with range between 16 to 19 % according to the chart in **Figure 9**. This is significantly lower value than a simple annual balance, which would make the user likely to be deceived by the fact that the PV system production (3000 kWh) will completely cover all consumption of the user energy (2500 kWh) resulting to unrealistic 100% solar fraction.

6. Conclusion

The correct assessment of the PV system solar fraction is based on the electricity consumption and production balance, while respecting the appropriate load profile with sufficient level of detail and time step of the calculation. It has been shown that considering a constant (permanent) load profile based on the year average of household electricity consumption results in inappropriate results even for calculations with short time steps used. Regardless to type of load profile, calculation time step shorter than 1 hour can be regarded as sufficient to obtain realistic values, contrary to time step in the range of days, month or a year. The hourly time step for assessing solar fraction for a household may still be too long when we recognize how some household appliances such as an electric oven, hair

dryer, or vacuum cleaner will be used, with a significant increase in power in just a few minutes. However, by further decreasing the time step, change of annual solar fraction is only at the absolute percent.

To provide a simplified approach how to get realistic results for practical calculations with limited inputs, a simulation analysis have been performed with almost 500 alternative combinations of load profile and PV system size. Detailed 365-days load profile with 5 minute time step and climate data with 5 minute time step have been used in analysis. Two functions have been derived to calculate solar fraction based only on balance ratio of annual production of the PV system to the annual user electricity consumption in the household.

Acknowledgments

This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I, project No. LO1605 – University Centre for Energy Efficient Buildings – The sustainability phase a project SGS16/212/OHK2/3T/12 – Modelling, controlling and designing of environmental technology equipment.

References

- [1] Richardson I, Thomson M, Infield D and Clifford C 2010 Domestic electricity use: A high-resolution energy demand model *Energy Build.* **42(10)** 1878-87