Application of photovoltaic in renovation and modernization of school buildings and facilities

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***Abstract*—The article analyzes the proposed projects of installation of photovoltaic power source on school dormitory buildings. Photovoltaic sources are considered as a suitable tool to reduce the energy consumption of buildings and their installation is also supported by subsidies. However, their installed capacity must be properly designed, which is often not the case in practice.**

A model example of a PV installation with an installed capacity of 49 kW_p is used to compare the actual values of the electricity produced with the planned values. It is shown that the original design of the PV source will only be able to utilize about 55% of the generated power.

With such a result, the current common approach to designing the installed capacity of PV sources needs to be changed or further technical measures are needed to utilize the remaining electricity.

Keywords—photovoltaic sources, electrical installations, energy consumption of buildings, smart readiness indicator

I. Introduction

The energy consumption and energy intensity of public buildings is still an important issue in achieving the goals of improving energy efficiency and reducing greenhouse gas emissions. Statistically, buildings account for 40% of total energy consumption in the European Union, with almost 85% of these buildings built before 2000 [1].

In the conditions of the Slovak Republic, there is a significant investment debt in the sector of school buildings, their maintenance and comprehensive renovation. Although a number of programmes, support and subsidy schemes are currently underway to renovate and make their operation more energy efficient, often only partial measures are implemented and only a few projects can be said to have been fully and appropriately renovated.

At present, energy efficiency improvements are mainly focused on the following measures:

- thermal insulation of the building envelope;
- replacement of the building's windows and doors;
- replacement of the heat source (boiler);
- hydraulic regulation of heat distribution systems;
- installation of solar thermal systems for hot water heating;
- installation of photovoltaic systems for electricity generation;
- replacement of existing light fittings and light sources.

In most cases, the above measures are implemented individually and over a longer period of time, without achieving the expected results. The audit report on public buildings [2] also notes the following shortcomings and obstacles to the achievement of the set objectives:

- "Lack of data, fragmentation of support instruments among several ministries, insufficient public funding in past periods, and low commitment of public building owners to prepare for building renovation.
- Institutional funding consists of more than 15 entities and is chaotic and opaque.
- Public building managers, and by extension the state and its institutions, lack the professional capacity to provide adequate and well targeted financing, as well as to prepare and implement projects. Individual ministries renovate their buildings largely according to the current availability of resources, without analytical assessment."

In view of the above and the real lack of professional capacity in the preparation and implementation of school building renovation projects, it is appropriate to define procedures and key points for their proper preparation and implementation.

This article focuses on the issue of installing photovoltaic systems as one of the tools for achieving better energy efficiency in school dormitory buildings.

II. Typical condition of school dormitory buildings

Almost all school dormitory buildings in Slovakia were built before 1990. Many of them are already 50-60 years old. Previous renovations have mainly focused on insulation of the building envelope, replacement of windows and doors, necessary roof repairs and replacement of heating technology [3].

However, most of the internal wiring of these buildings has remained in its original state and is at the end of its useful life. This is particularly true of the electrical, water, waste and heating systems. Very often, therefore, the nice shell of renovated interior spaces covers what should have been

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replaced long ago and which causes considerable operational problems.

As already mentioned, renovation is not carried out comprehensively and in one go, but in stages. Often, the renovation of technical equipment in buildings is only undertaken after the breakdown of a technological unit or when funding is obtained from subsidy programmes for specific measures.

In the case of the installation of photovoltaic equipment on the roofs of school dormitory buildings, the motivation is the subsidies announced for the installation as well as the desire to reduce electricity consumption by the operators of these installations.

III. Photovoltaic projects

The installation of photovoltaic systems (PV) is considered a suitable tool for reducing the electricity consumption of public buildings. In Slovakia, photovoltaic sources are most often installed in two modes, as a small source (installed capacity up to 10.8 kW) or a local source (mainly installed capacity up to 100 kW). These frameworks are determined by the relevant law [5]. In the case of local sources, it is assumed that all the electricity generated will also be consumed at the point of consumption and will not be fed into the grid.

When determining the installed capacity of a PV source, the following parameters are commonly addressed:

- Location and area for the installation of the PV panels (orientation to the cardinal points, possible shading);
- The total annual or monthly electricity consumption determined on the basis of electricity bills;
- The reserved power capacity of the off-take point;

The proposed installed capacity of a PV source is most often determined by the available area for its installation, while the electricity consumption at a given point of use only indicates the limit of maximum production that should not be exceeded. As already mentioned, the electricity consumption is taken as a whole within a month or a year.

The PV contractor and installer are motivated to install equipment with the highest achievable output to increase their profit from the project.

This approach results in a number of implemented PV installations not delivering the expected benefits in terms of significant savings in electricity consumption and costs.

IV. Analysis of the actual operating conditions of the PV project

The above mentioned facts can be best illustrated by a real example of a planned photovoltaic source on the roof of a school dormitory in Bratislava.

TABLE I. Basic data about the proposed photovoltaic project

Installed capacity:	49 kW_p
Investment cost:	55 000 EUR
Annual electricity production (available energy):	57 650 kWh
Average annual electricity consumption of the dormitory:	150 000 kWh
Declared use of generated PV electricity to cover own consumption (energy used)	45 720 kWh (80%)
Calculated market price of electricity:	0.15 EUR/kWh
Investment payback period:	8 years
IRR:	12.5%
NPV:	51 700 EUR

Both the designer and the supplier of the technology declared that 80% of the generated electricity will cover their own consumption. It is not clear how they arrived at this result.

The school dormitory has its typical operating mode, which is uneven in terms of electricity consumption. In the case of this accommodation, approximately 40% of the accommodation area is used for long-term rentals. This fact should have an impact on the electricity consumption even during school holidays and was one of the arguments for setting such a high installed capacity of the PV source.

For a thorough analysis of the generation and coverage of current electricity consumption, the following model was chosen:

- analysed data of the consumption of the school dormitory for the whole year 2023 in 15 minute intervals and hourly intervals of electricity consumption [6];
- Calculated PV generation trajectory in hourly steps based on 2023 meteorological data [4];
- comparison of this data and calculation of the amount of electricity that could cover the current consumption of the point of consumption;

From the analysed waveforms, the following findings can be reported.

The potential electricity generation from the PV source in each month and week of 2023 was greater than the electricity consumption of the building. Since the excess electricity generation cannot be fed into the grid in this case, this energy remains unused.

This situation is best illustrated by the month of March 2023, when the school dormitory was in full operation and fully occupied.

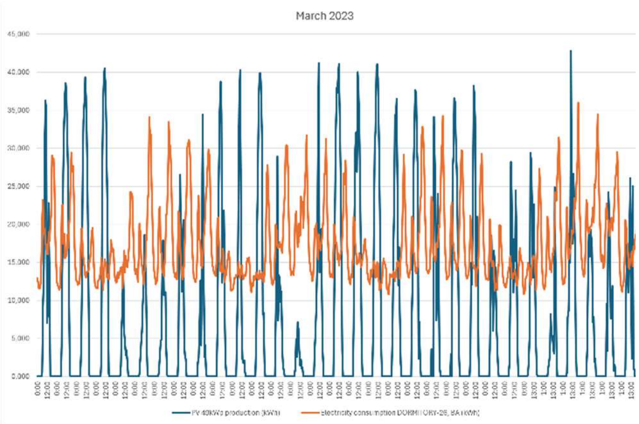

Fig. 1. Electricity generation and consumption in March 2023

During the summer, it was assumed that the production from the PV source may exceed the consumption. This has been confirmed, but from the displayed waveform it can be seen that the untapped potential of the generated electricity is too large.

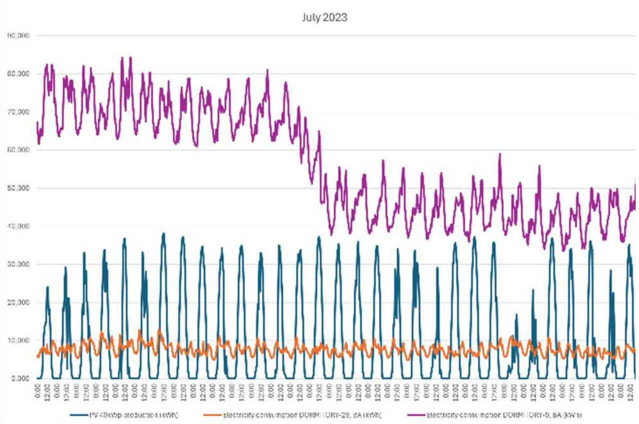

Fig. 2. Electricity generation and consumption trajectory for July 2023 (with the addition of the consumption trajectory of the larger school complex with dormitory, swimming pool and school)

In this case, the electricity consumption pattern of a larger school facility (dormitory, swimming pool and school) is also shown for comparison. For comparison, the total annual consumption of this facility is 690 000 kWh, almost 5 times more. From the consumption history (DORMITORY-9) it can be seen when the regular summer shutdown of the swimming pool started and yet all the electricity generated could be used to cover the consumption. So size matters in the energy industry!

Looking in more detail at the weekly pattern in the month of November 2023, it is evident that the school dormitory scheme has its peaks in electricity consumption in the morning and evening hours. Generation from PV inherently peaks at midday.

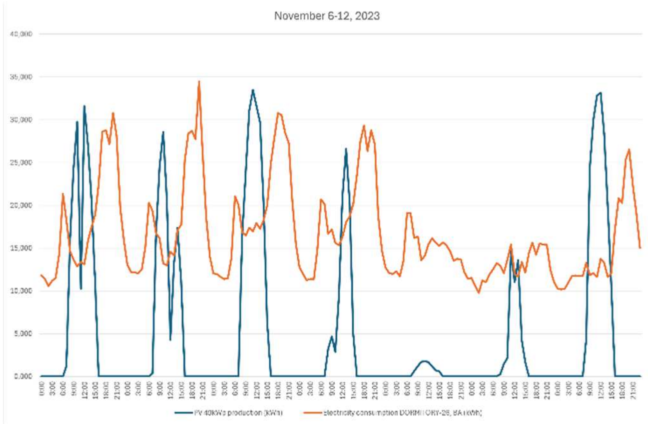

Fig. 3. Production and consumption trend in the week 6.11.2023-12.11.2023

After a comprehensive analysis of the year-long electricity production and consumption patterns, it is clear that we can realistically cover 31 980 kWh of the school dormitory's consumption with electricity from photovoltaics (only 55% of the total possible production of the photovoltaic resource). Approximately 25 600 kWh thus remain unused.

TABLE II. RECALCULATED ECONOMIC INDICATORS OF THE PROJECT IN RELATION TO THE REAL USE OF THE GENERATED ELECTRICITY

Installed capacity:	49 kW_p
Investment cost:	55 000 EUR
Annual electricity production (available energy):	57 650 kWh
Average annual electricity consumption of the dormitory:	150 000 kWh
Real use of generated PV electricity to cover own consumption	31 980 kWh (55%)
Calculated market price of electricity:	0.15 EUR/kWh
Investment payback period:	11.5 years
IRR:	8.7%
NPV:	28 870 EUR
Calculated market price of electricity:	0.21 EUR/kWh
Investment payback period:	8.2 years
IRR:	12.2%
NPV:	50 250 EUR

This will affect the overall economic indicators of the project as shown in the table above.

On the other hand, it should be mentioned that the evaluation of the economic return of the project was calculated at an electricity price of EUR 0.15/kWh. Currently, for several months in a row, the average electricity price on the market has been EUR 0.21/kWh. At this amount, the project again achieves the economic indicators at the originally planned level.

The fact that the investment costs of PV resources remain stable and increasing electricity prices are a reality changes the approach for determining the optimal performance of a PV power source.

V. Conclusion

Photovoltaic electricity sources are a very suitable tool for reducing the energy intensity of buildings and achieving climate goals. For their application, it is crucial that the maximum of the electricity they produce is also consumed at the point of use.

It is inappropriate to design the installed capacity of PV sources based only on the cumulative data of monthly and annual electricity consumption of a given customer site. It is necessary to use and analyse the year-round electricity consumption patterns that are available for most of the customer sites.

The current level of electricity prices, together with the possibility to draw subsidies for the construction of photovoltaic sources, changes the approach for the design of the installed capacity of the photovoltaic source. Under current conditions, it is most appropriate to install the maximum possible capacity (use all available area) and then look for possible uses for the electricity generated.

School dormitories have the space and energy potential to use all the electricity generated from photovoltaic sources. However, exploiting this potential requires technical modifications, especially to the energy distribution systems. A very useful tool in this process is the use of the Smart readiness indicator.

Acknowledgement

This work was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I04-03-V02-00033.

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Proceedings

2025 25th International Scientific Conference on

ELECTRIC POWER ENGINEERING (EPE)

CZECH TECHNICAL UNIVERSITY IN PRAGUE
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and

BRNO UNIVERSITY OF TECHNOLOGY
Faculty of Electrical Engineering and Communication
Department of Electrical Power Engineering

EPE 2025

Name: Proceedings of the 2025 25th International Scientific Conference on Electric Power Engineering (EPE)
Publisher: Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Electrical Power Engineering
Published: May 29, 2025, Prague, Czech Republic
Editors: Zdeněk Müller, Jan Rimbala
Edition: first
Volume: 1
Circulation: 100
Cover: Tomáš Prajs, Praha, © 2025

The authors are responsible for the contentual and lingual accuracy of their papers and the materials they present.

IEEE Catalog Number: CFP2573X-USB

ISBN: 979-8-3315-8636-2

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