Photovoltaic Facade Performance Evaluation

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Abstract. A high-rise building façade with integrated photovoltaic panels, located in the Central European region with temperate climatic conditions was tested. The PV façade was monitored for three years. Results of the PV system monitoring show that the façade positively influence the energy efficiency and reduction of carbon dioxide emissions from the building operation.

1. Introduction

Energy efficiency and applications of renewable energy technologies represent major issues for sustainable building constructions [1,2]. The conversion of solar energy into electricity due to photovoltaic panels has found wide applications in building industry [3,4]. The PV systems are installed separately or integrated into building constructions. Building-Integrated Photovoltaic Systems – BIPS [5,6] are designed for new buildings as well as for building renovations [7,8]. They are installed for roof and façade applications [9].

The PV system efficiency for the electric energy conversion is influenced by many factors like availability of solar radiation in the climatic locality, topographical features, shading obstructions and neighbouring buildings, etc. [10-12]. The BIPS installation depends on the PV system type (materials, grid-tied system) dimensions and geometry, tilt and orientation to the cardinal points [13,14].

The photovoltaic systems are highly efficient for direct solar radiation but they also respond to diffuse sky radiation. The building integrated PV modules should be installed in positions of maximum insolation. They must be ventilated for their proper performance. Apart from the main design and installation demands, the facade aesthetic appearance plays also important role for the BIPV system integrations. Design optimisations and modelling of the BIPS have been topics of research projects [15,16].

A post-occupancy survey of a building with integrated photovoltaic façade was performed. The paper shows main results of the building PV façade monitoring. This monitoring was provided under a university research project focused on smart region technologies for sustainable development.

The studied building is located in city Brno in the Czech Republic. The multi-functional building was constructed in 2013 [17]. The building of over-ground height 111 m consists of 30 floors and two basements with parking places. There are commercial areas on the ground, first and second floor. The building main services are installed on the 3rd floor. Administrative offices between the 4th and 21st floor are followed by apartments up to the 26th floor. Three external installation floors are located on the top of the building.

2. Method

The post-occupancy evaluation of the studied building was focused on a monitoring of energy generated from the PV integrated façade. Photovoltaic panels are integrated into the south façade of the high-rise building, figure 1 [18]. That orientation gives potential of intensive solar irradiation in case of clear sky with direct solar radiation. For these conditions the façade is highly efficient. Lower efficiency is monitored for diffusive solar radiation during cloudy sky conditions.

The studied building is in the locality with temperate climatic conditions. Outdoor conditions like global horizontal irradiance (monitored by pyranometer CPM Kipp&Zonnen) and outdoor temperature (local meteo-station data) were monitored for the building evaluation.

Figure 1. High-rise building with the PV façade

Energy efficiency of the BIPS installation depends on the building location and the façade orientation. These are key factors for availability of solar radiation for energy conversion on the PV system. Simulations of sun-path diagrams were run for the evaluation of the high-rise building potentials of solar radiation availability in the urban area, figure 2. Simulations of sun-path diagrams in software DesignBuilder [19] were performed for day-time of the 21st March and 21st June, 8:00 and 12:00 and 16:00, at locality of city Brno, CZ - longitude 16° 36’ E, latitude 49° 11’ N, altitude 241 m.

a) b)

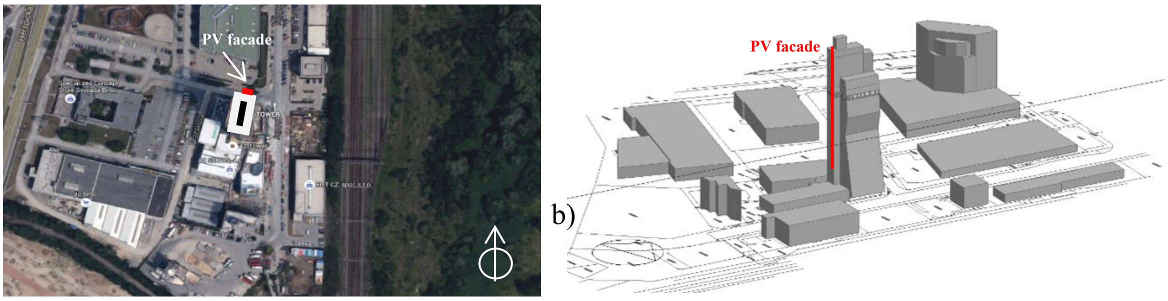

Figure 2. Location of the high-rise building and neighbouring buildings in the urban locality
a) Map of the locality (google map), b) 3-D scheme of the high-rise building and neighbouring shading obstructions (DesignBuilder).

A part of the building south facade in the position of the external lift is covered with PV panels, figures 1 and 2. The area of the BIPV façade installation is 685 m^2 with the total amount of 390 + 2 poly-crystalline PV panels. The panels consist of the EVA encapsulation photovoltaic system with triple-layer back sheets in an anodized aluminium frame (ET solar). The PV panel characteristics are shown in Figure 3 [20]. Three-phase inverter Sunny Tripower is used for the PV system of total power is 89.7 kW. The generated electricity is used as a complement for the building electric energy consumption [21].

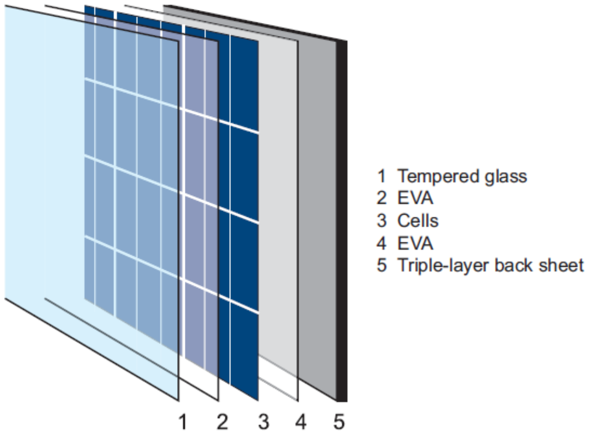

Figure 3. PV panel composition

3. Results and discussions

The sun-path diagrams of the building locality show potentials for the south PV façade insolation in March and June, figure 4. Neighbour buildings are low and they do not influence the PV façade shadings.

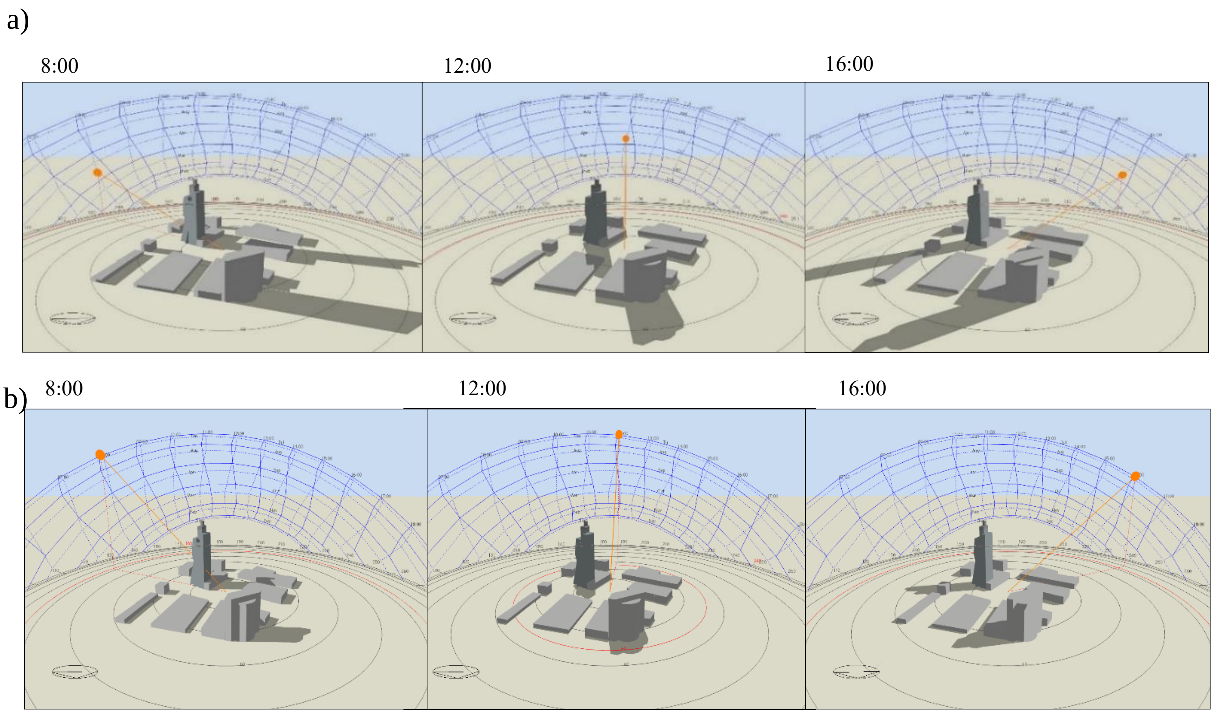

Figure 4. Sun-path diagrams of the high-rise building locality (DesignBuilder simulations) a) 21st March, time 8:00 and 12:00 and 16:00, b) 21st June, time 8:00 and 12:00 and 16:00.

Outdoor climatic conditions of the studied building locality were monitored. Examples of characteristic profiles of hourly values of solar irradiance affecting the building and the façade reflected solar energy as well as outdoor temperatures, monitored in June 2015 are shown in figure 5. The measured data show that the part of solar radiation affecting the façade is reflected into outdoor space (about 10 percent). The reflection represents lost in the PV façade solar energy conversion potentials.

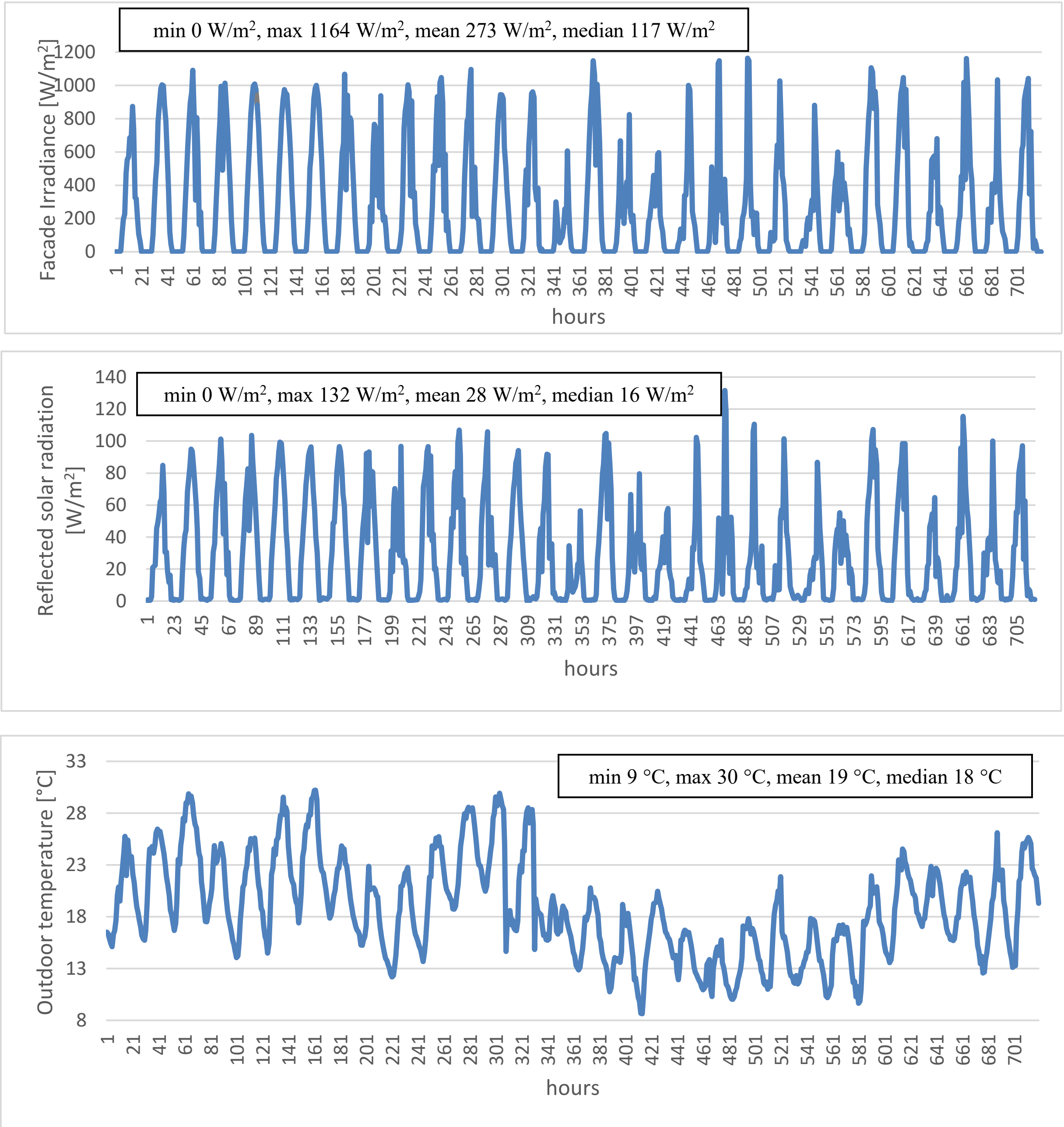

Figure 5. Characteristic hourly profiles of solar irradiance [W/m^2] and the façade reflected solar radiation [W/m^2] and outdoor temperature [°C], monitored in June 2015 (pyranometer CPM Kipp&Zonnen and local meteo-station data).

Annual profiles of the electric energy generated from the PV façade were tested for three years [21]. Results of the monitoring are summarized in figure 6 and Table 1. It is obvious that the façade efficiency varies in dependence on local climatic conditions. Minimum generation of electric energy is in winter seasons from November to February. Maximum energy production is between March and September. The PV system highest efficiency appears to be in March and April as well as in July and August. Solar radiation of higher altitudes in May and June is substantially reflected on the vertical façade compared to lower solar altitude situations. It means that the energy conversion is lower for these months.

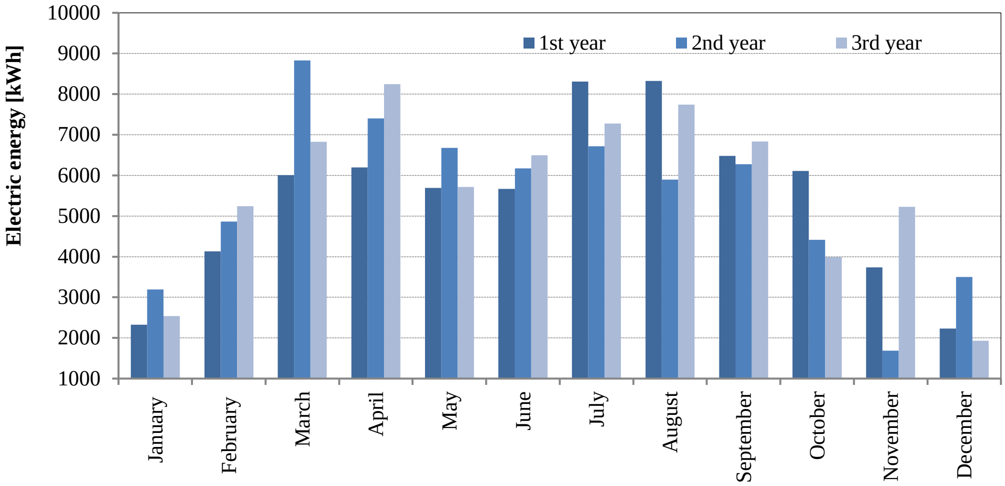

Figure 6. Annual profiles of the PV façade electric energy generation for three-year monitoring period

Table 1. PV Façade generated energy for the monitoring period

Year	1st year	2nd year	3rd year
Minimal value (month) [kWh]	2228 (December)	1689 (November)	1932 (December)
Maximal value (month) [kWh]	8321 (August)	8826 (March)	8246 (April)
Annual monthly average [kWh]	5433.7	5468.5	5672.5
Total energy per year [kWh]	65204	65622	68070
Electric energy generated by the PV façade the three year monitoring 199 MWh			

The PV generated energy has positive impacts on the building environmental classification. The clean technology of the PV solar panels represents potentials for reduction of emissions of CO_2 and SO_2 and NO_x compared to the electricity production from traditional sources [22], Table 2.

Table 2. Reduction of emissions compared to energy from traditional sources and PV collector

Energy source	Emissions		
	CO_2 [g/MJ]	SO_2 [g/MJ]	NOx [g/MJ]
Electric energy , mix CZ [22] Solar PV collector [22]	207.4 13.3	0.464 0.058	0.313 0.035
Reduction of emissions [g/MJ] Reduction percentage [%]	194.1 93.6	0,406 87.5	0.278 88.8

4. Conclusion

The post-occupancy evaluation of the photovoltaic façade prove its energy efficiency. Despite the climate conditions with prevailing overcast days, the façade energy conversion is more than 65 MWh per year. The total electric energy generated from the façade photovoltaic system during the three-year monitoring period was about 199 MWh. Maximum electricity production depends on the façade irradiation and solar altitude. The vertical south-oriented PV façade absorbs maximum of solar energy during months of transitional periods in the temperate climate locality.

The PV facade system is supportive to the building energy efficiency and positively influences the reduction of emissions from the building operation. The utilization of solar radiation for the building electricity substantially decreases CO_2 emissions compared to traditional energy sources.

Acknowledgment
This paper was worked out under the project no. LO1408 “AdMaS UP - Advanced Materials, Structures and Technologies”, supported by Ministry of Education, Youth and Sports under the „National Sustainability Programme I” and under the project Competence Centre TE02000077 supported by the Technological Agency of the Czech Republic. The project documentation of the AZ Tower building was provided by the SCF SERVICE Ltd.

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