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Potential of PV façade for supplementary lighting in winter

Dominika Knera[a]*, Eliza Szczepańska-Rosiak[a], Dariusz Heim[a]

[a]*Department of Environmental Engineering, Lodz University of Technology, ul. Wólczańska 213, 90-924 Łódź, Poland*

Abstract

Modern office and public buildings have to meet the requirement of zero-emission buildings through high insulation and integration of renewable energy sources on the own premises. The presented paper is devoted to exploring a BIPV facade potential as a source of electricity for supplementary lighting in an office room during winter. Analysis was carried out, for a typical office room with window centrally located in the facade, using simulation tool ESP-r for energy performance and Daysim for daylight luminance distribution calculation. Results indicate that electrical energy generated by BIPV cover supplementary lighting only in the room with south oriented façade.

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Keywords: Building Integrated Photovoltaic (BIPV); Artificial lighting; Visual comfort; Energy performance; Building envelope

1. Introduction

Nowadays, design strategies of new buildings include energy efficiency and sustainable development. More and more popular way to decrease energy demand is the application of Building Integrated Photovoltaic (BIPV) to produce electricity from solar radiation incident on photovoltaic cells. However, photovoltaic panels work only during the day and need expensive electrical equipment to store and transform electric energy for the twenty-four-hour utilization. Therefore, BIPV is a perfect solution for office and public buildings which are occupied during the day. Additionally, contemporary tendency is to cover office buildings facades with glass panels, which can be easily replaced by photovoltaic elements. Nevertheless, the designing process of any modern building must take into account an indoor

* Corresponding author. Tel.: +48-42-6313920; fax: +48-42-6364923.
E-mail address: dominika.knera@p.lodz.pl

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environment quality, including visual comfort. Lighting conditions at work space has a significant impact on the efficiency of the office employees. Daylight is regarded as the healthiest and most comfortable light for people. However, during winter natural illuminance is often insufficient and consequently application of artificial lighting is required. Photovoltaic facade can be considered as one of the energy sources to provide electricity for supplementary lighting.

The main aim of the presented research is to analyse the BIPV façade potential to cover energy demand for artificial lighting in the office room during winter when daylight is insufficient. Performed research was used for assessing whether the proposed solution provides the required visual comfort level.

2. Visual comfort

Visual comfort in an office space is very important and has an influence on the speed and accuracy of the work performed. Furthermore, visually comfortable life space affects health, well-being and life quality. Hence, creation of appropriate interior lighting conditions is crucial both for an employer and office workers.

Visual comfort depends on subjective evaluation, nevertheless, it can be described by the following values: lighting intensity, luminance distribution and glare [1]. In the presented research, the assessment of interior lighting conditions will be performed on the basis of illuminance level. Providing adequate level of illuminance and its spatial distribution has an influence on quality and efficiency of work. Insufficient lighting conditions result in sleepiness, tiredness and may cause accidents. The required average illuminance in the field of work and in the immediate surroundings of workspace is given in the standard [2]. Minimum level of the illuminance on the work plane in the office should be 500 lux and not higher than 2 000 lux to avoid visual discomfort. Subsequent significant parameter of visual comfort is the uniformity of illuminance which is a ratio of the smallest measured illuminance on a given surface to the average illuminance on the plane. For continuous operations such as office work, the uniformity of illuminance should be at least 0.7 on the work plane and 0.5 in the immediate surroundings.

3. Building Integrated Photovoltaic

Main idea of the Building Integrated Photovoltaic is to replace traditional elements of building envelope with active components equipped with photovoltaic cells [3]. Photovoltaic modules can be integrated into roof, facades or shading systems. Location has a significant influence on the performance of all systems. Efficiency of photovoltaic cell is sensitive to the many environmental factors like air temperature, solar radiation incident on the panel or spectral distribution. Furthermore, appropriate installation of the PV, considering orientation, position angle or temperature stabilization has an influence on the energy generation. Therefore, designing process of BIPV should take into account a number of parameters from a selection of cell technology to the effect of surrounding environments. Furthermore, using energy generated by photovoltaic panels requires professional electrical equipment containing charge controllers, accumulators and inverters.

The presented research is devoted to the analysis of BIPV ventilated façade. Most modern office buildings are designed as highly glazed skyscrapers. Photovoltaic panels can replace glazed elements of building envelope. Therefore, can be achieved electrical energy production by slight increase in construction costs. Additionally, PV panels integrated as a ventilated façade can be cooled by natural ventilation [4], or as a photovoltaic/thermal system can preheat air provided to the offices [5].

Photovoltaic technology is still a growing and developing branch of industry. There are many emerging technologies with huge potential of high efficiency together with low production costs. BIPV is a very good solution of renewable energy source usage, especially in highly glazed buildings in urban areas .

4. Case study

Analysis was carried out for the office building located in central Europe, the city of Lodz (51°46’N and 19°27’E), Poland. Climate data were used according to Typical Meteorological Year (TMY), developed on the basis of real weather data recorded on meteorological weather station since 1970 to 2000 and officially approved as a weather file for building performance simulation. Only winter period, between autumn and spring equinoxes (22.09-21.03) was selected, as availability of daylight is smaller than for the rest of the year and supplementary lighting is necessary. Simulations were performed for four cardinal directions of facade orientation (N, E, S, W). Studies were made for the selected part of the building consisting of a typical office room and adjacent ventilated BIPV façade. Office room was 4.4 m length, 2.6 m width and 2.6 m high. Occupation profile was assumed as for typical office with two employees from 8.00 to 16.00 equipped with individual computer set. Office room had one centrally positioned window whose surface area was previously optimized based on UDI index [6]. Window was defined as triple glazing with argon in space between glasses and visual transmittance equal to 0.7. BIPV facade consists of 8 CIS panels with efficiency declared by the manufacturer at the level of 12%. Electrical system consisting of charge controllers, accumulators and inverters is required to convert direct current from PV panels into alternating current that can be fed into an electrical network.

Analysis was performed using two software individual for assessment of energy from photovoltaic façade and visual comfort. Photovoltaic power output was calculated using simulation tool ESP-r [7]. Watsun-PV model implemented into ESP-r provided a certain amount of photovoltaic energy on the basis of simple one-diode equivalent model with consideration to temperature-dependency of basic electrical characteristic parameters (short circuit current and open circuit voltage) [8,9]. Mottillo et. al. validated the Watsun-PV model and compared the obtained results with one-diod model in 2006 [9]. Lighting conditions were estimated using "Daysim" software based on RADIANCE, with 1 hour timestep, taking into account geometry, materials, and sky conditions [10]. The RADIANCE model was validated many times for selected specific cases, since first publication in 1989 [11]. For calculations, the colour of internal partitions was assumed as follows: light gray walls, gray floor and white ceiling. Measurements of interior illuminance were made on two work planes at a distance of 1.5 m (A) and 2.5 m (B) in a straight line from the window and height of 0.85 m under floor (Fig. 4b). The annual amount of daylight in the office room was modelled in Daysim. Subsequently, the required supplementary lighting was calculated and compared with photovoltaic power. Assumed artificial lighting consisted of three LED lamps characterised by luminous flux at the level of 3 400 lm for each of them and power consumption equal to 36 W. System developed for supplementary lighting consisted of two stages. Firstly, when illuminance on B work plane was lower than 500 lux, two nearest lamps were switched on which resulted in power demand for lighting at the level of 72 W. Subsequently, in the case of insufficient illuminance on A surface, the third lamp next to the window was turned on causing an increase in power demand up to 108 W.

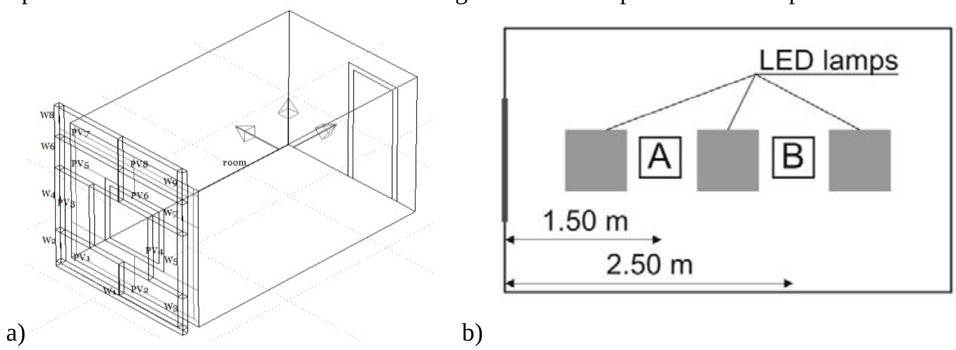

Fig. 1. (a) Scheme of the analysed office room with adjacent BIPV façade; (b) position of work planes.

5. Results

Calculations of illuminance were made with one hour time step for four orientations of the façade. Fig. 2 presents medium values of missing illuminance to the required 500 lux on A and B work planes and for east and south oriented façades. The highest missing illuminance for all cases can be noticed in December, which is caused by the shortest length of daylight occurrence. Furthermore, during the day, the lowest illuminance, near 0 lux, occurs at the beginning and the end of working time (8.00, 15.00, and 16.00). Missing lighting on the A work plane during midday is very low, less than 100 lux, for all analysed months and orientations of the facade. Lighting conditions are worse on the B work plane located further away from the window and missing illuminance for east oriented façade reaches more than

300 lux at 12.00. Consequently, both LED lamps located near the B work plane have to be turned on almost all the time in the office room with north, east, and west oriented façade.

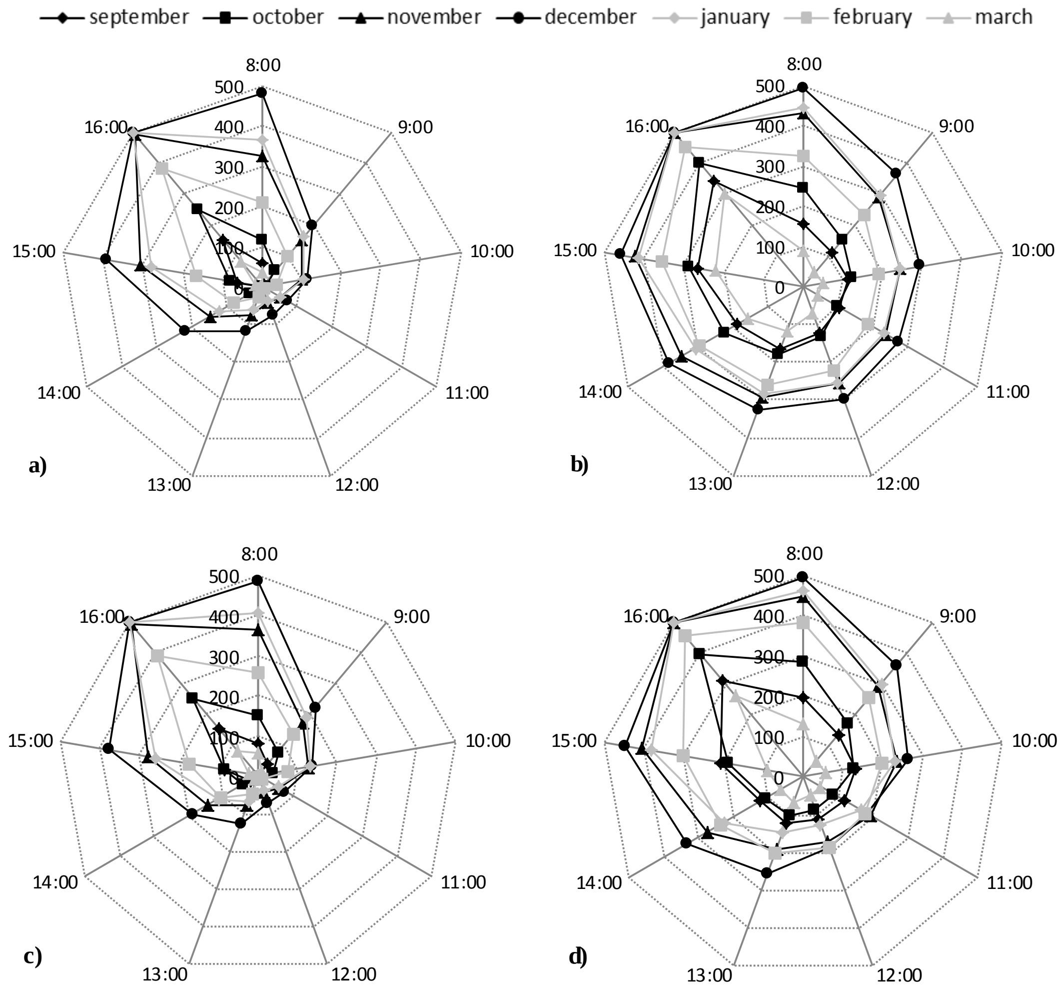

Fig. 2. Medium value of missing illuminance to the required level of 500 lux on A ((a); (c)) and B ((b); (d)) work plane and for east ((a), (b)) and south ((c), (d)) oriented façade in particular months.

Subsequent graphs presented in Fig. 3 and Fig. 4 show energy generated by photovoltaic façades during the whole day and energy required for supplementary lighting during working hours for all considered cases. It can be noticed that only south oriented BIPV façade generates enough electricity to cover energy demand for supplementary lighting during the whole analysed period (Fig. 3 (c)). However, because of impermanent work of photovoltaic panels, application of the battery bank is required to accumulate the excess of energy produced by PV during sunny days for the purpose of later usage in the case of insufficient electricity generation. Electricity generated by south and west oriented BIPV façades is deficient in November, December, January and the first half of February (Fig. 3 (b), (d)). Therefore, these office rooms need additional electrical source during the above mentioned months. Energy generated by north oriented façade is too low to cover energy demand for artificial lighting during the whole analysed period (Fig. 3 (a)).

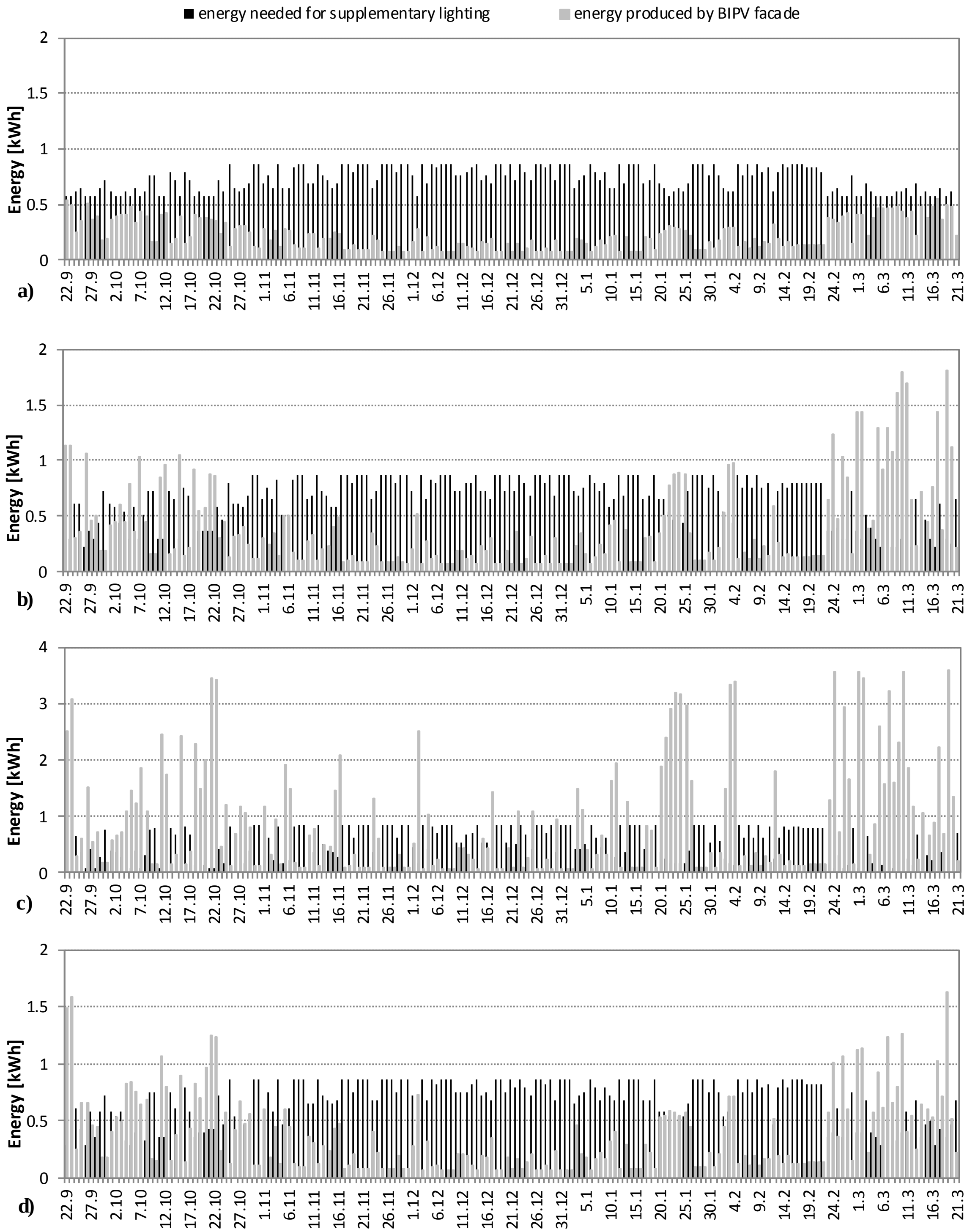

Fig. 3. Energy required for supplementary lighting during working hours and generated by photovoltaic façade during the whole day for (a) north, (b) east, (c) south, (d) west oriented façade.

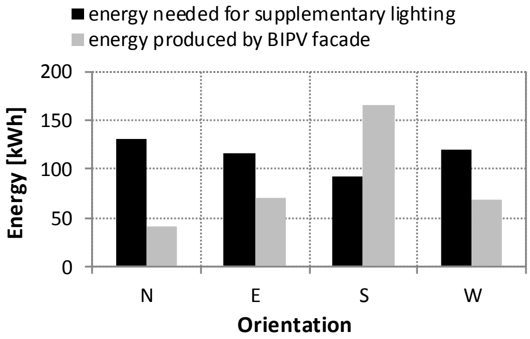

Fig. 4. Total energy required for supplementary lighting during working hours and generated by photovoltaic façade during the whole day.

6. Conclusions

The presented paper is devoted to the analysis of BIPV façade potential to cover energy demand for supplementary lighting in an office room during winter. Based on the obtained results, it can be concluded that requirement for artificial lighting is the highest in November, December and January, especially at the beginning and at the end of the working time. Furthermore, illuminance on work plane located at a distance of 2.5 m from the window is lower than assumed minimum of 500 lux during almost the whole analysed time period. Therefore, two LED lamps have to be permanently turned on during the working time, causing high demand for electricity. Any dimming control was not considered in this analysis. Summary results for the particular day show that only south oriented BIPV façade can completely cover demand for supplementary lighting in the adjacent office room. East and west orientation facades generate enough energy for artificial lighting during September, October, the second half of February and March. Electricity generated by north oriented BIPV façade is insufficient to cover energy demand for lighting during the whole analysed period.

Acknowledgements

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