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PRODUCTIVITY OF PV FACADES IN CHARACTERISTIC PERIODS WITH DIFFERENT ENERGY DEMAND FOR LIGHTING

Abstract
This paper presents an analysis of the possibilities of using energy generated by an experimental photovoltaic façade located on the building of the Technical University of Lodz, on the eastern elevation. The energy produced by the façade was designed to cover the demand for lighting in an office room. Research was carried out during the years 2015 - 2017 in selected periods of the year. The analysis showed that the winter and transitional periods generated much less electricity compared to the summer period, which is inversely proportional to the energy demand for artificial lighting in the office room.

Key words
built-in lighting, electricity, office room, photovoltaic façade

Introduction

More and more frequently, at the design stage of construction works, it is assumed that renewable energy sources are used in a given facility, which are intended to help cover energy needs as much as possible. This is mainly due to the growing interest in alternative energy sources that have a better impact on the environment than the conventional sources used up until now, based mainly on the consumption of fossil fuels. Political and social pressures focused on environmental protection and the broadly understood sustainable development have a great impact on this [1]. In this respect, photovoltaic installations (PV) are very popular. They are characterized by the possibility of using solar energy to produce electricity as a result of photoelectric conversion [2]. New technologies allow not only for the installation of photovoltaic systems in the form of additional construction on existing building elements, the so-called BAPV (Building Applied Photovoltaic). The creation of systems directly integrated with the façade of the building is also becoming more and more popular, the so-called BIPV (Building Integrated Photovoltaic). In this case, photovoltaic elements are used as components of traditional building components - they can act as a roof, façade, balustrade or shading. This solution is advantageous both for residential and commercial buildings, for example in the case of high office buildings. In addition, it is also worth bearing in mind that in favour of photovoltaic cells it is supported by the fact that they can be mounted not only on the building level, but also at an angle as a shading overhang and on flat and sloping roofs. An additional advantage is also the fact that PV panels mounted at an angle on the wall of the building will generate higher energy gains than in the case of horizontal or vertical installations, which results from a better angle of incidence of solar radiation [3].

In order to achieve the most profits, it is necessary, at the design stage, to determine the best location for panels on a given building, taking into account the most favourable orientation as well as the inclination angle, thanks to which the sun will be at the best possible level [4]. Another important factor, especially in the case of commercial facilities, is the inclusion of working hours in such a facility, because it is during their time that the largest consumption of electricity for various needs takes place [5].

The article refers specifically to the office building, because such buildings are characterized by high-intensity artificial lighting systems. Electricity is used for various types of installations – from lighting, to ventilation, air conditioning and heating. It is therefore justified to use renewable energy technologies in the form of photovoltaic façades in office buildings, which enable even a partial coverage of the electricity demand [4-5]. Thanks to this, when there are surpluses in energy production by PV façades, it is possible to sell it, which also generates financial benefits [6].

Installation of such systems and checking the efficiency of their operation also provides an opportunity to conduct research in terms of self-sufficiency of construction works. In other words, whether it is possible to build and operate a facility that is fully self-sufficient and therefore consumes only as much electricity as it is able to produce [7]. Of course, the largest energy gains are generated in a warm climate, where the exposure to the sun is much greater, even in countries located in Europe, for example, in Poland. As it is stated [8] in such countries as, for example, Brazil, where electricity costs are rising, and the costs of investing in photovoltaic panels are getting lower and lower, it is highly beneficial to invest in buildings already fitted with a photovoltaic installation. Very often well-designed buildings become so-called electricity generators, because they produce more energy than is needed for a given object. Thus, such an investment is not only a modern approach in the field of energy, but also constitutes an economic advantage [8]. It should also be added that technology based on the use of photovoltaic installations in buildings is not only an advantage resulting from the production of electricity. Combined solar photovoltaic and thermal systems (PVT) are also very popular, thanks to which it is possible to convert solar radiation into electricity and heat at the same time [9].

Among the many benefits of investments in renewable energy sources, such as PV panels, it should also be remembered that electricity in this type of system is produced only during the day, when the sun is present in the sky, so energy production does not take place 24 hours a day. Of course, photovoltaic technology is constantly evolving and it shows a lot of potential We can be sure that every year more and more innovative solutions will appear [1, 10]. It is influenced, among other factors, by the growing emphasis on the increasing use of alternative sources for electricity production. People attach more and more importance to how the negative impact of human activity on our planet can be reduced. It is assumed that each year the amount of energy produced by environmentally friendly technologies will increase [11]. Ecological solutions are becoming more popular in Poland. It can be observed, that, for example, photovoltaic installations are not used only by entrepreneurs, but also by individual clients.

The direct objective of the research in this work was to determine during which periods of the year and to what extent a photovoltaic façade mounted on the eastern face of the building is able to cover the energy needs of a research office room.

Description of the installation and research room

The subject of the research presented in this article was an experimental photovoltaic installation, located on the fourth floor of the Lodz University of Technology building, on the eastern elevation. CIS panels (Cooper Indium Diselenide) made of selenium, cooper and indium, which are thin-film panels with an efficiency not exceeding 12 % on average, were used for the construction of the installation. They are light, flame-resistant, made of 3 mm glass cover (white glass) and a 3 mm thick glass substrate mounted in an anodic aluminium frame [12]. They are characterized by their aesthetic appearance - a characteristic dark and indiscreet surface, much more homogeneous than the crystalline materials also used for the construction of photovoltaic panels, high flexibility in terms of shapes and dimensions, and most importantly - the ability to convert a significant amount of scattered radiation. These features are the great advantages of CIS panels, which makes them so popularly mounted on the facade of the building and are particularly attractive for architectural applications [13-14]. These panels are very effective and reliable even in the case of unfavorable lighting conditions, for example on cloudy days, and also are not very sensitive to high temperatures. The use of panels based on thin-film technology is not only economical, but also provides ecological benefits, because panels of this type also characterize low-energy production processes.

The view of the research wall is shown in Figure 1. The layout of the panels has been adapted to the existing building. A photovoltaic installation consists of eight PV panels that are arranged side by side to avoid free spaces. They are located around a window opening with an area of 1.44 m^2 (the surface area of the glass is 1 m^2). The window area was optimized at the design stage, so that the amount of daylight entering to room was adequate, consistent with the requirements. At the bottom, under the PV panels, there are six openings that are ventilation ducts [15-16]. Each of the PV panels at maximum efficiency has a maximum power of 80 Wp, 35 V voltage, 2.3 A current. According to the technical instructions specified by the manufacturer of the photovoltaics panels [12], the maximum system voltage for this model can be as high as 1000 V, while the permissible temperature of use has been set between -40 and +80 °C. The thickness of each panel is 35 mm (with a tolerance of: + 0 mm, -2 mm) and weighs approximately 13 kg/m^2.

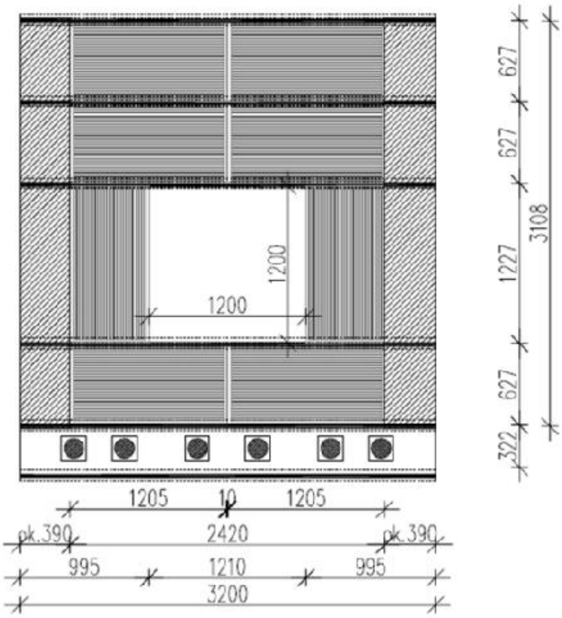

Fig. 1. Visualisation of the experimental façade
Source: [17]

The energy produced by the façade before it is used by the receivers passes through a system of devices such as DC meters, charge controllers, batteries and an inverter. When a direct current is converted into alternating current, it can be used to supply the receivers in the research room [5, 16].

The receivers of the produced energy are three LED luminaires mounted at a height of 2.6 m. They are a source of artificial lighting in an experimental office room, whose dimensions are 4.4 m in length, 2.6 m in width and 2.6 m in height. The power of a single luminaire is equal to 36 W, whereas the luminous flux is at a level of 3400 lm [16].

Materials and methods

The work uses data showing the amount of electricity produced by photovoltaic panels. These measurements are collected in the laboratory in which the research room is located. They come from sensors located in the built installation and are saved in a computer program developed for this purpose. Data storage takes place every 5 minutes, 24 hours a day.

The research was carried out in three periods over the years 2015-2017: in the period of the highest demand for lighting, i.e. during the winter period (October-February), in the period of average demand for lighting, the so-called transition period (March-April and September) and during the summer period, when the demand for lighting in the room is relatively small (May-August). An exact division into two analyzed years and periods is presented in Table 1.

Table 1. Characteristics of the analysed years and periods

	Year 1	**Year 2**
1 - Winter period	10.2015 - 02.2016	10.2016 - 02.2017
2 - Transition period	03 - 04.2016, 09.2016	03 - 04.2017, 09.2017
3 - Summer period	05 - 08.2016	05 - 08.2017

Source: Author's

The work also analyzed the possibilities of using the energy produced by the PV façade, taking into account the different sizes of electricity demand by the lighting installation. Due to the fact that there are three luminaires in the research office, and the power of each of them is 36 W, it was assumed that the power demand would be 36 W, 72 W and 108 W, with regard to whether one, two or three luminaires were working at a given time, which depends to a large extent on weather conditions and the personal preferences of the room user.

Results and discussion

An analysis of the experimental efficiency of the east oriented photovoltaic façade consisted in comparing the amount of energy generated by the installation during the selected characteristic three periods of two consecutive years. This comparison is shown in Figure 2. This analysis shows that year 2 was less favorable in terms of electricity production by the PV façade in each of the analysed periods. However, when comparing the periods distinguished between them, it can easily be seen that the most productive was the summer period, when electricity was produced much more than in the other two periods. Unfortunately, it does not translate into the need for artificial lighting in a room inside the building, which is the smallest in this period, unlike in the winter period, when the least energy is produced, and the use of artificial lighting is greatest, due to the overwhelming number of cloudy days in these months.

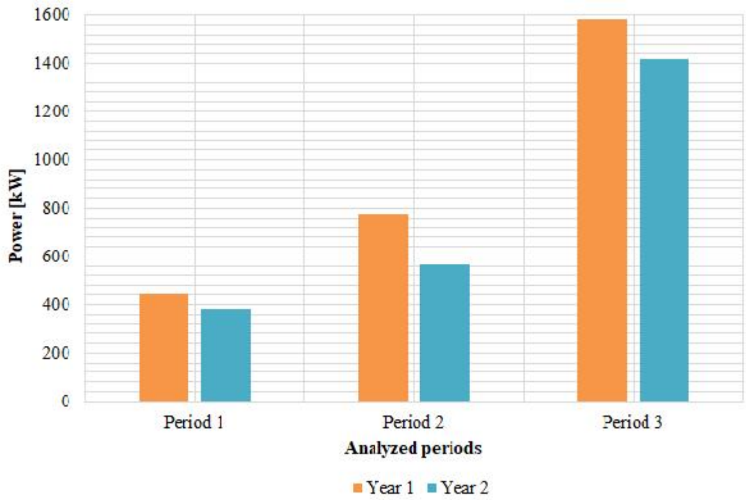

Fig. 2. Energy power generated by the PV façade
Source: Author's

The next analysis was to check the possibility of using the energy produced by the PV façade for the needs to power the lighting installation in the research room, taking into account the different demand for electric power through the LED luminaires. An analysis was carried out for each of the three periods, both analysed years, having regard to the three different luminaire power (36 W, 72 W, 108 W).

The first analysis was made for the power of LED luminaires equal to 108 W. It turned out that if all luminaires were 100% power, only in the summer period, in year 1, from May to August 2016, would the photovoltaic façade be able to cover the energy demand electricity in the morning hours, as illustrated in Figure 3.

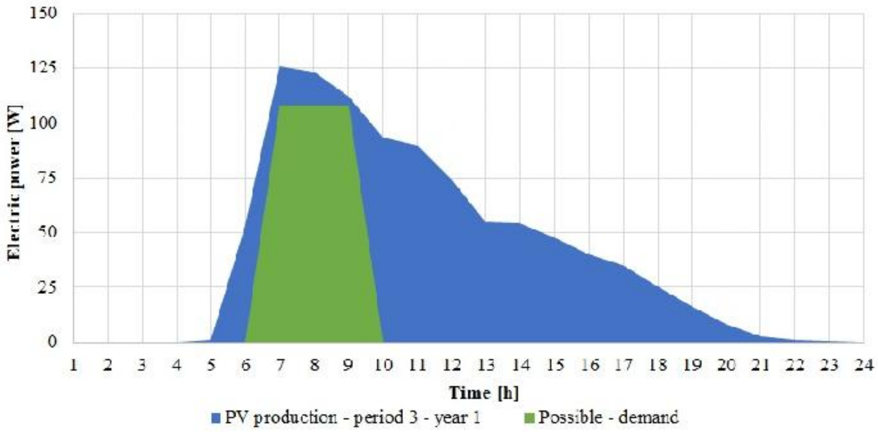

Fig. 3. Monthly averaged electric power generated in year 1, period 3 and possible demand for lighting of 108 W
Source: Author's

In the case when the installed luminaire power was 72 W, the period during which it was impossible to cover any electricity demand for lighting was the period 1 of year 1, while in the case of year 2, there were two periods – 1 and 2. In other periods it could have been achieved, but the periods 3 of year 1 and year 2 were the most favourable in this respect. In order to visualize the differences in the daily distribution of the possible power demand, Figure 4 presents the results as in Figure 3, for the period 3 of year 1.

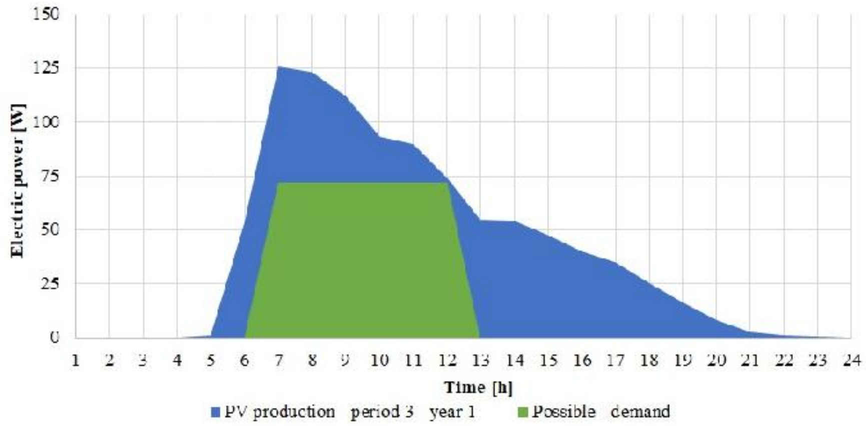

Fig. 4. Monthly averaged electric power generated in year 1, period 3 and possible demand for lighting of 72 W
Source: Author's

The last of the analyzed cases was the establishment of the power of electricity receivers at the level of 36 W. In this case, in the summer, in year 1 and year 2, the façade was able to cover the energy demand for LED luminaires to the greatest extent. The results for the summer period of year 1 are shown in Figure 5. In the transitional periods of both analyzed years, assuming that work in an office, and thus the need for artificial lighting would take place between 07.00 and 15.00, the façade would also work effectively and cover the demand for the given electrical power at this time.

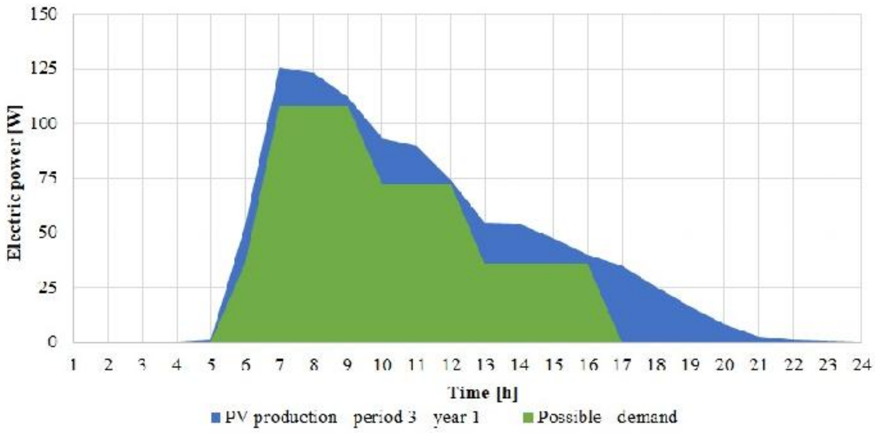

Fig. 5. Monthly averaged electric power generated in year 1, period 3 and possible demand for lighting of 36 W
Source: Author's

However, the only period in which not even the power demand could be met to a small extent, despite the fact that it was as low as possible, was the winter period in year 1, as shown in Figure 6 (therefore, demand energy was not determined in this figure). This means that from all analysed periods of both years it was the only least productive period.

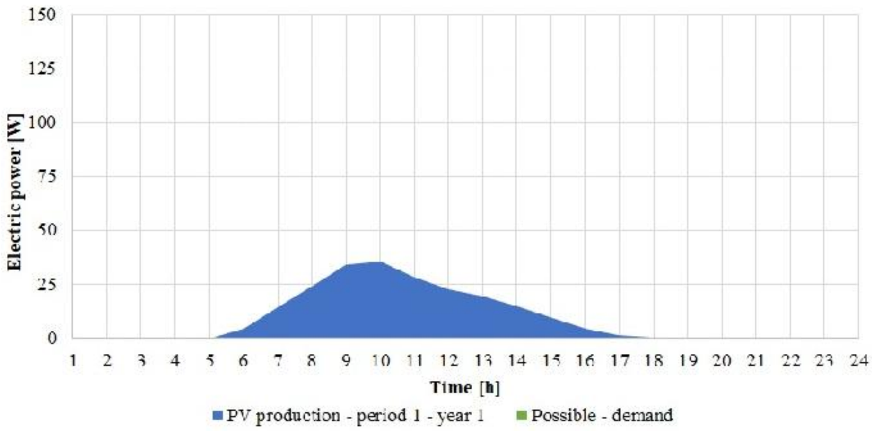

Fig. 6. Monthly averaged electric power generated in year 1, period 1 and possible demand for lighting of 36 W or 72 W or 108 W
Source: Author's

The results shown in Figures 3-6, thanks to the display of data during the day, also enable checking in which hours the façade generates the highest power. Therefore, it seems correct that the largest power gains are generated by the PV façade located on the eastern wall of the building in the morning hours, in other words in the first half of the day.

Summary and conclusions

Based on the research and data analysis, it can be concluded that in the two analysed years, year 2 was less sunny, compared to year 1. The energy gains generated by the PV façade in this period were smaller in each of these periods than in year 1. When comparing all the periods of the analysed years, taking into account the power demand for artificial lighting in an office room, it can be observed that during the summer period the amount of energy generated by the façade is the highest, while the smallest is during the winter period. Unfortunately, this does not translate into the expectations of potential users of the room, whose greatest demand for lighting from artificial sources is in the period when solar radiation reaching the room is the smallest, in other words during the winter period.

In the case of summer periods, surplus electricity produced can be expected, because the need to use artificial lighting can be low or negligible at this time, due to the possibility of using daylight. Here, it is also important to design the room in such a way that the number of window surfaces is adequate and not less than required. On the other hand, the excess energy, which would not be used for the needs of lighting receivers in this period, could be stored or used, for example, by other receivers, in accordance with the assumptions of the given facility.

Taking into account the needs of the office user throughout the day and examining the possibilities of a photovoltaic installation in terms of electricity production, it is possible to check under which conditions and whether the installation could operate autonomously. Work in this direction will be the next stage of the research. It is also important to take into account, in our research, measurements of incident radiation and to provide more detailed information on PV electrical power during the day to better understand the reason for the decline in photovoltaic power during certain periods. It should also be remembered that in our latitude, the location of the PV facades on the eastern walls is not an ideal location for this type of equipment.

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