Integration of PV modules into the building envelope in aim to achieve energy and environmental benefits

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Abstract: The main concern of this paper is research of possibilities to achieve energy savings and reduction of CO_2 emissions through integration of Photovoltaic (PV) modules into the building envelope of the existing office building located in Belgrade, Serbia. The paper shows different hypothetical models of energy efficiency improvement of the office building, by application of active solar system to the building envelope, more exactly by integration of PV modules into the facade structure. Methodological approach entails estimation of electric energy consumption of the existing building, design of hypothetical models – architectural integration of PV modules and comparative analyses of obtained results regarding electric energy necessary for cooling and lighting, as well as environmental benefits. Models of PV modules integration into the facade structure are discussed in terms of energy efficiency and reduction of CO_2 emissions. According to analyses presented in the paper it is concluded that facades with tilted PV modules have the best performance in terms of the contribution to energy savings and also offer new aesthetic potentials in the refurbishment of existing office building.

Key Words: Building integrated photovoltaics, Office buildings, Building appearance, Energy efficiency, CO_2 emissions.

1. Introduction

Energy consumption in buildings has increased in recent years due to growing demands for energy used for heating, cooling, lighting and equipment. Office buildings have one of the highest levels of energy consumption when compared with energy consumption in other buildings sectors (Burton, 2001). In Belgrade, as well as in Serbia, existing office buildings consume a lot of energy because construction of energy efficient buildings is still not strictly in practice. Existing buildings present a great potential to reduce energy demand by applying measures for energy improvement without changing installed electromechanical systems. There are a number of opportunities to minimize energy requirements. When it comes to office buildings, each reduction of energy consumption in buildings would result in a significant impact on the electrical power consumption. Considering this fact, the main target of this paper is research of possibilities in achieving energy savings through building refurbishment; more exactly possibilities for reduction of electric power consumption by integration of photovoltaic (PV) modules in the existing building envelope, namely in the envelope of an office building in New Belgrade. The analysis in this paper is hypothetical and it aims to show benefits of active solar systems integration in facades of office buildings in Belgrade climate conditions. For this analysis, data on Belgrade climate conditions are important and the most relevant once for this research are mentioned.

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Methodological approach includes analyses of electric energy consumption for cooling and lightning of the existing building; design of different variants of PV modules integration into the facades and creation of hypothetical improved building models; calculations of energy consumption and percentage of electricity substitution using PV modules and reduction of CO_2 emissions, as well as comparative analyses of obtained results.

1.1 Belgrade climate conditions

There is a great possibility in use of solar energy in Belgrade climate conditions. The energy potential of solar radiation in Serbia is about 30% higher than in Central Europe and the intensity of solar radiation is among the highest ones in Europe (Republic Hydrometeorological Service of Serbia). According to the same source, there is a potential for the production of electricity using solar energy considering that the average intensity of solar radiation ranges between 1.1 kWh/m^2/day in the north and 1.7 kWh/m^2/day in the south in January, and from 5.9 to 6.6 kWh/m^2/day in July; there is an average of 2096 hours of sunshine per year (which makes 45.48 percent of the potential/possible insolation); the highest insolation of about 10 hours per day is in July and August, while December and January are the cloudiest, with insolation of 2 to 2.3 hours per day.

2. Structural characteristics and electric energy consumption of the existing building

The existing office building, which is the subject of analysis, is located in a business complex in Block 26, New Belgrade, Serbia. The building is set up as a free-standing building on flat terrain on the corner of the city block (Fig. 1). The building is a compact rectangular shape, with shorter side of the southwest orientation, and the longer side of the southeast orientation. The facade is light structure, suspended facade (curtain wall), leaned against the building structure and hanged in front of it. Different solutions of PV modules integration into the suspended facade are proposed as hypothetical models of building facade improvement. PV modules can be integrated into the most of the contemporary suspended facade systems (Krstic-Furundzic, 2007).

Fig. 1. Location and appearance of existing office building in Block 26, New Belgrade

For discussion and calculations 8-storey corner lamella of existing building has been selected as part of the building that has the best orientation to the Sun, with two street facades facing southeast and southwest (Fig. 2). The southeast facade is sunny during all seasons throughout the insulation period, in winter from 8.50 to 14.20, in summer from 5.00 to 13.00, in the spring and autumn from 7.50 to 13.35. The southwest facade of the building is sunny in the summer after 10 am to 18 pm.

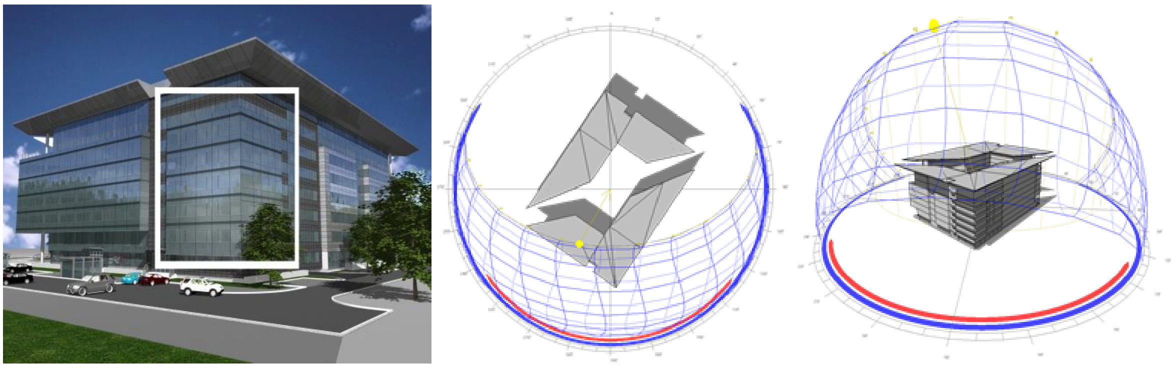


Fig. 2. Sunpath for a given position of the corner lamella of existing building

Surrounding objects, due to less height and adequate distance, do not cast a shadow on the subject property. Significant roof extension to the plane of the facade causes partial overshading of the last two floors. Therefore, facade areas from the second to fourth floor are considered as favorable for PV modules application.

2.1 Electric energy consumption of existing building

Lamella in office building in Block 26 in New Belgrade was analyzed from the standpoint of energy performance, and the impact of different interventions on energy efficiency. For the subject property numerical simulations were carried out by the company BDSP in a specialized software package TAS. A mathematical 3D model of the building was created and used for the analyses of energy performance of the existing situation and improved models. Based on the results of simulations in terms of annual energy consumption for heating, cooling, lighting and operation of the equipment, it has been concluded that the highest energy consumption has been for cooling, while the least for lighting. Comparative analysis of monthly and annual electric energy consumption for cooling and lighting of the existing building is shown in Table 1 and Fig. 3.

Table 1. Monthly and annual electric energy consumption of the existing building and CO_2 emissions

Month	Consumption of electric energy (kWh)		Primary energy consumption (kWh)		CO_2 emissions (kg)	
	Cooling (kWh)	Lighting (kWh)	Cooling (kWh)	Lighting (kWh)	From Cooling	From Lighting
1	0.00	11296.00	0.00	28240.00	0.00	14967.20
2	467.61	11349.60	1169.03	28374.00	619.58	15038.22
3	5910.22	11637.60	14775.55	29094.00	7831.04	15419.82
4	18154.92	11835.20	45387.30	29588.00	24055.27	15681.64
5	39804.01	9433.62	99510.03	23584.05	52740.31	12499.55
6	57178.67	9051.21	142946.68	22628.03	75761.74	11992.85
7	64834.14	9702.63	162085.35	24256.58	85905.24	12855.98
8	67256.77	9164.61	168141.93	22911.53	89115.22	12143.11
9	42256.25	9320.22	105640.63	23300.55	55989.53	12349.29
10	22450.75	12320.80	56126.88	30802.00	29747.24	16325.06
11	4376.78	11152.00	10941.95	27880.00	5799.23	14776.40
12	365.34	12320.80	913.35	30802.00	484.08	16325.06
Total	323055.46	128584.29	807638.65	321460.73	428048.48	170374.18

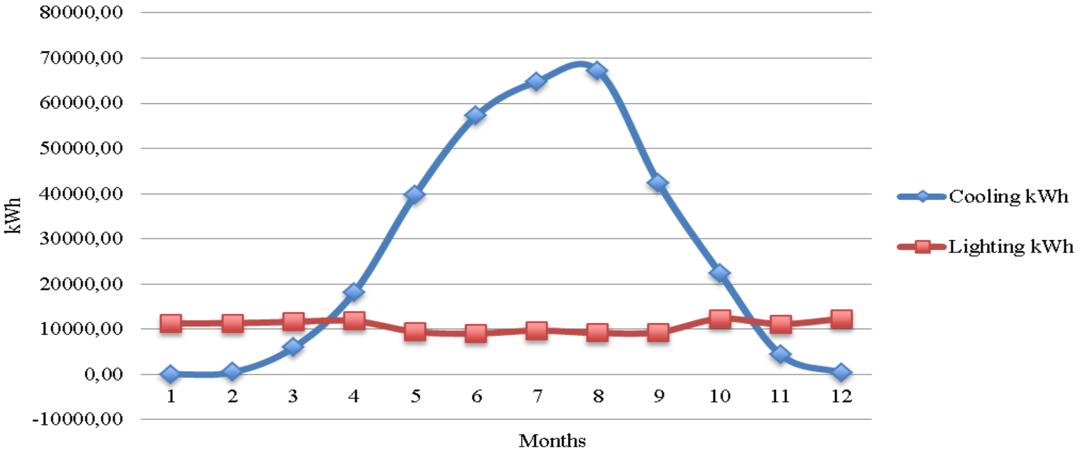
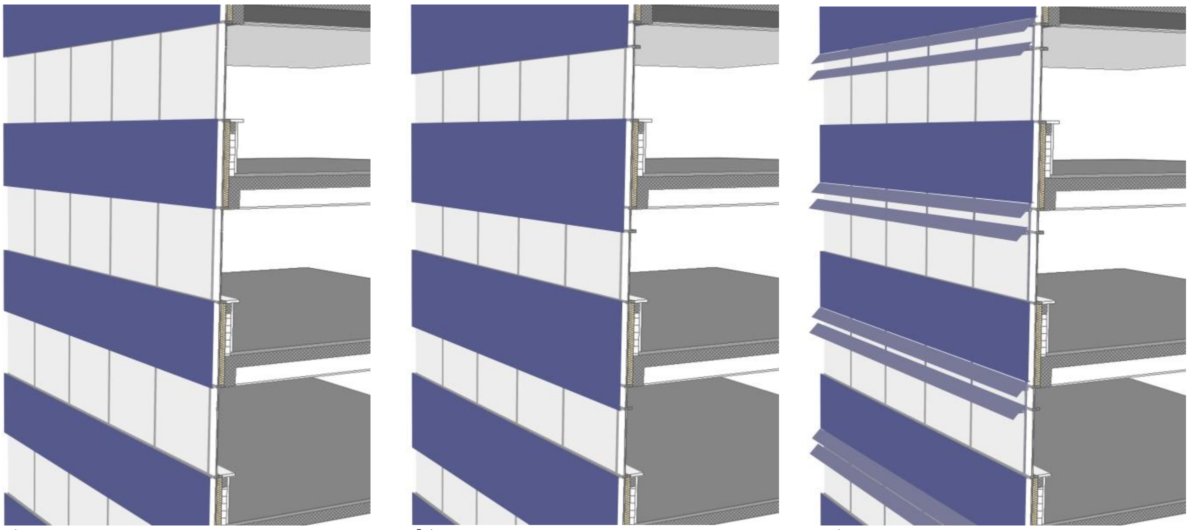


Fig. 3. Monthly and annual electric energy consumption of the existing building

3. Architectural integration of PV modules

The case study shows different models of energy efficiency improvement of the office building in Block 26, New Belgrade, by integration of PV modules into the envelope. The design of integration of solar systems was defined consequently according to the actual characteristics of: the building location – the context (considering urban planning, social, climatic and geographical aspect); the building (considering the compatibility in respect to the building construction type, building materials, the shape, the function, the style and design of the building); the facade and roof (considering the building physics characteristics, mounting, physical and appearance characteristics of solar systems), (Krstic-Furundzic and Kosoric, 2009).

Different models of integration of PV modules into the facade of corner lamella are proposed and their energy efficiency has been estimated, as well as the contribution to the reduction of CO_2 emissions. Design variants of integration of PV modules into the envelope of the office building in Block 26, Novi Beograd, are presented in Fig. 4. Position of PV modules and their areas on the facade are explained in Table 2.



a) b) c)

Fig. 4. Design variants of integration of PV modules into the office building facade
a) Design Varian 1- vertical position 90˚ in parapets, b) Variant 2 - two lines - 90˚ in parapet - and upper part of windows, c) Variant 3 – in parapet 90˚ and 2 lines of sun shadings 45˚

4. Results

Proposed design variants, as hypothetical models, are analyzed and discussed from aspects of energy efficiency and reduction of CO_2 emissions. Models are defined from the standpoint of energy efficiency levels achieved in accordance with applicable domestic and foreign regulations. The energy efficiency of building is defined according to the energy demand for cooling and lighting. Calculations and simulations of PV systems for all design variants were done in PV*sol 2.6 (Krstic-Furundzic and Sudimac, 2010). The standard modules with polycrystalline cells were used for calculations. Based on the results of numerical simulations for different positions of PV modules on the facade (Fig. 4), annual production of electric energy has been calculated, as shown in Table 2.

Table 2. Annual production of electric energy related to PV modules location and area

	PV modules location	PV modules area [m^2]	Energy from inverter (kWh)	Energy from PV modules (kWh)
Variant 1	Parapet (90˚), non-transparent PV modules	238.00	24,627.00	25,578.00
Variant 2	Two lines in parapet	308.00	29,164.00	30,605.00
	parapet 1 (90˚), non-transparent PV modules	238.00	24,627.00	25,578.00
	upper part of windows (90˚), transparent (50%) PV modules	70.00	4,537.00	5,026.00
Variant 3	Parapet and 2 lines of sun shadings, non-transparent PV modules	336.00	40,694.00	43,680.00
	parapet (90˚)	238.00	24,627.00	25,578.00
	sun shadings 1 (45°)	49.00	9,153.00	10,377.00
	sun shadings 2 (45°)	49.00	6,914.00	7,724.00

Annual electric energy consumption of the existing building for cooling is 323055.46 kWh and 128584.29 kWh for lighting (Table 1). The amount of electric energy production for Variant 1 – 24,627.00 kWh, Variant 2 – 29,164.00 kWh, Variant 3 – 40,694.00 kWh (Table 2). Electric energy production is subordinate to PV modules location, as well as to available area. Comparative analyses of obtained results regarding monthly and annual amount of electric energy consumption and production by PV modules are carried out and presented in Table 3 and Fig. 5.

Table 3. Comparative review of monthly and annual production of electric energy in kWh from different variants

Month	**Variant 1 (kWh)**	**Variant 2 (kWh)**	**Variant 3 (kWh)**
1	2005.00	2380.00	2792.00
2	2080.00	2464.00	3065.00
3	2320.00	3022.00	3840.00
4	2113.00	2580.00	3775.00
5	2069.00	2183.00	3775.00
6	1820.00	1950.00	3420.00
7	1930.00	2185.00	3665.00
8	2150.00	2460.00	3782.00
9	2310.00	2790.00	3810.00
10	2510.00	3210.00	4010.00
11	2040.00	2355.00	2850.00
12	1280.00	1585.00	1910.00
Total	24627.00	29164.00	40694.00

It is evident that different locations of PV modules give different results regarding electric energy production: Variant 1 - PV modules integrated in the parapets (90˚) can produce monthly electrical energy from min 1,280.0 kWh in December to max 2,510.0 kWh in October; Varian 2 - PV modules integrated in the parapets and upper part of window (90˚) can produce monthly electrical energy from min 1,585.0 kWh in December to max 3,210.0 kWh in October; Variant 3 - PV modules integrated in the parapets (90˚) and two lines of sun shadings (45˚) can produce monthly electrical energy from min 1,910.0 kWh in December to max 4,010.0 kWh in October.

Significant differences in the amounts of electric energy production related to variants of PV modules location are noticeable. In relation to total annual electric energy production it has been concluded that the Variant 3, with PV modules integrated in the parapets (90˚) and two lines of sun shadings (45˚), is the most efficient, as shown in Fig. 5.

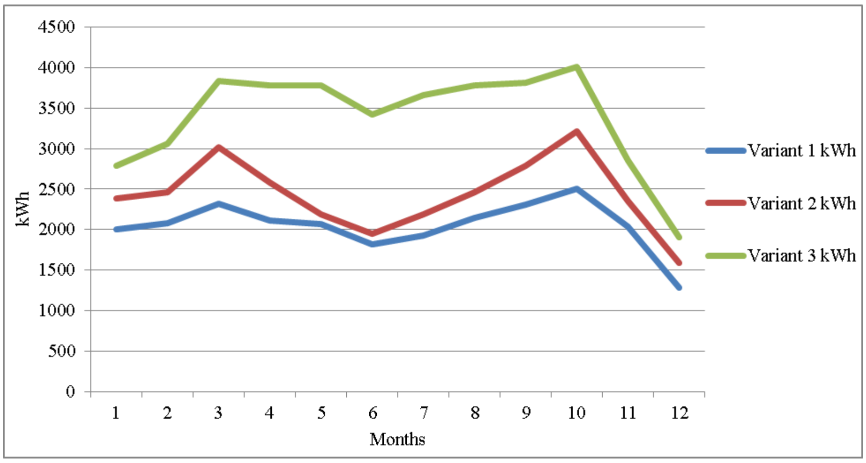


Fig. 5. Comparative review of monthly production of electric energy for different variants

In case of Variant 3 integration of PV modules into the facade, monthly and annual CO_2 emissions for cooling and lighting are calculated and shown in Table 4 and compared to existing building in Fig. 6.

Table 4. Monthly and annual consumption of electric energy and CO_2 emissions in case of Variant 3 integration of PV modules

Month	Consumption of electric energy (kWh)		Primary energy consumption (kWh)		CO_2 emissions (kg)	
	Cooling (kWh)	Lighting (kWh)	Cooling (kWh)	Lighting (kWh)	Cooling (kWh)	Lighting (kWh)
1	-2792.00	8504.00	-6980.00	21260.00	/	11267.80
2	-2597.39	8284.60	-6493.48	20711.50	/	10977.10
3	2070.22	7797.60	5175.55	19494.00	2743.04	10331.82
4	14379.92	8060.20	35949.80	20150.50	19053.39	10679.77
5	36029.01	5658.62	90072.53	14146.55	47738.44	7497.67
6	53758.67	5631.21	134396.68	14078.03	71230.24	7461.35
7	61169.14	6037.63	152922.85	15094.08	81049.11	7999.86
8	63474.77	5382.61	158686.93	13456.53	84104.07	7131.96
9	38446.25	5510.22	96115.63	13775.55	50941.28	7301.04
10	18440.75	8310.80	46101.88	20777.00	24433.99	11011.81
11	1526.78	8302.00	3816.95	20755.00	2022.98	11000.15
12	-1544.66	10410.80	-3861.65	26027.00	/	13794.31
Total	282361.46	87890.29	705903.65	219725.73	374128.93	116454.63

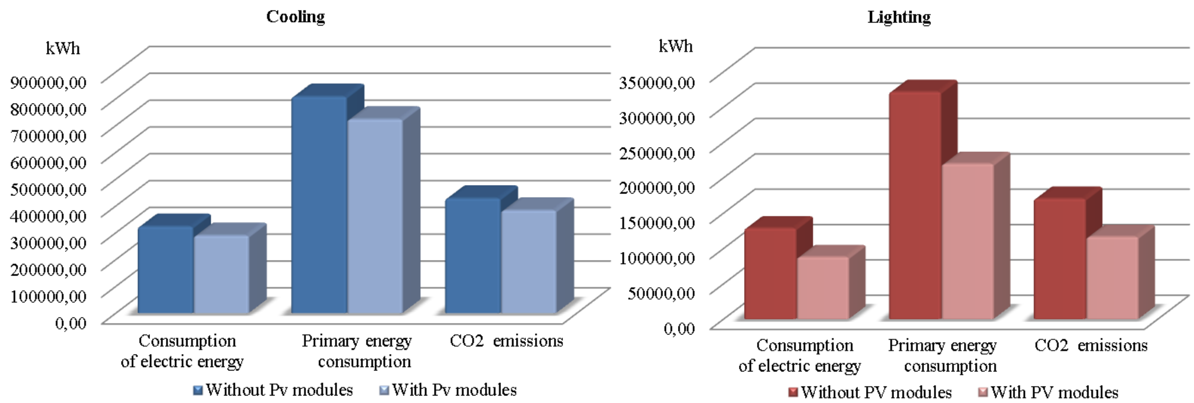


Fig. 6. Comparison of annual consumption of electric energy for cooling and lighting and CO_2 emissions before and after Variant 3 integration of PV modules

Electric energy produced by integrated PV modules in case of Variant 3 can meet demands for 10.45% of annual energy consumption for cooling and 31.65% of annual energy consumption for lighting (Fig. 7).

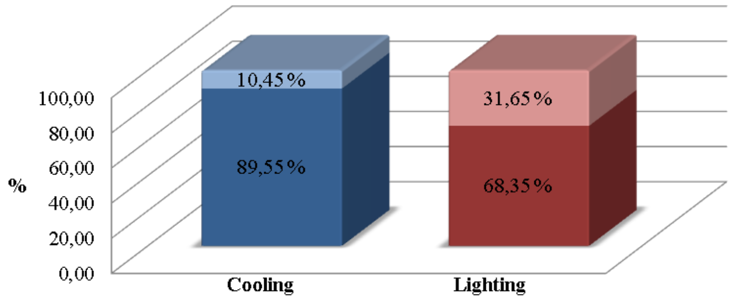


Fig. 7. Annual participation of PV modules in substitution of electric energy demands

In case of Variant 3 integration of PV modules into the facade it is concluded that more electric energy is produced than is necessary for cooling in January, February and December. During the year PV modules produce electric energy that can meet cooling demands from 5-6% in June, July and August to 65% in March and November. In terms of electric energy needs for lighting PV modules cover up to 40% of energy demands (Fig. 8).

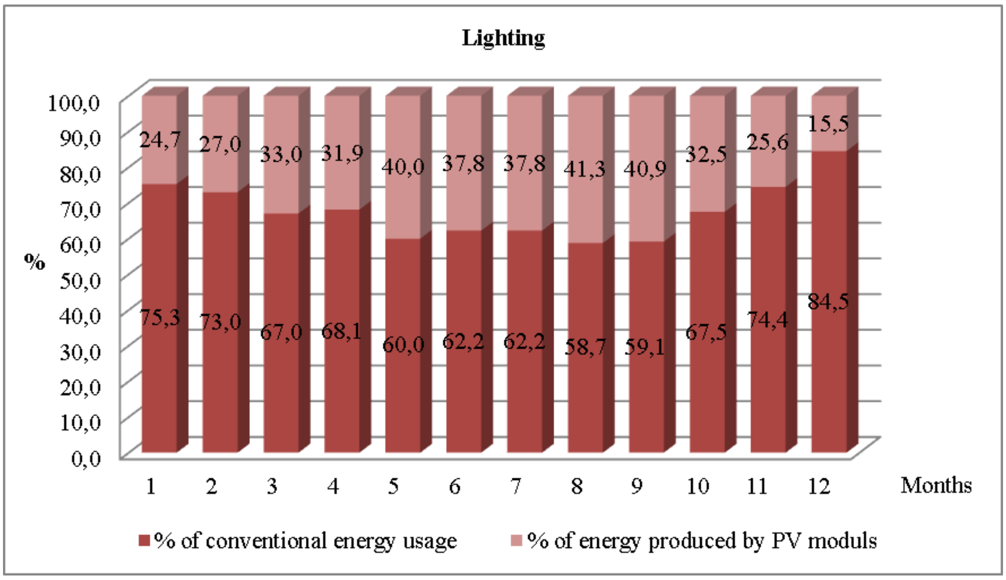


Fig. 8. Monthly participation of PV modules in substitution of electric energy demands for lighting

5. Discussion and conclusions

It can be concluded that for cooling and lighting existing office building spends significant amounts of electric energy. Analyses presented in the paper show that tilted PV modules integrated into the facade are more favorable in sense of energy efficiency comparing to vertical ones. Tilted PV modules can also be used as shading devices that give new aesthetic potentials and can significantly contribute to existing office building appearance.

Percentage of satisfaction of annual energy demands for cooling by PV models integration is too small. However, significant energy savings can be obtained for annual energy demands for lighting as well as reduction of CO_2 emissions. This is indicated by the results of the analysis of Variant 3 of integration of PV modules in the facade, which is shown in Fig. 9.

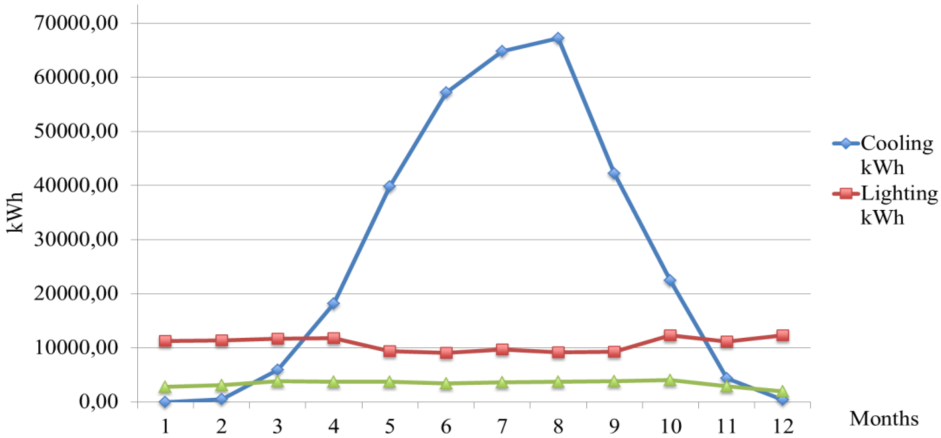


Fig. 9. Comparison of electric energy production of Variant 3 integration of PV modules and energy demands for cooling and lighting

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