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Professional paper

IMPROVEMENT OF FACADE STRUCTURES BY APPLYING INTEGRATED ACTIVE SOLAR SYSTEMS

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Abstract

Solar energy presents an energy source that can be used in different segments of our daily life. For the optimal use, it is necessary to know the basic features of solar radiation. There are many reasons for the exploitation of solar energy that can be found in the functioning of the facilities. By applying it, is possible to achieve energy efficient buildings while improving the use of the space comfort. Photovoltaic systems that are used as integrated systems within the sheath of a building can be fixed elements placed on constructive facade which simultaneously serve as elements for sun protection. The most important issues while projecting photovoltaic systems are the optimum orientation of the buildings and tilting angle of the photovoltaic modules as well as level of transparency. In this study an analysis is made about the optimal photovoltaic system which can be installed over constructive facade of offices /public administration building of city Gostivar. The analysis was conducted by using the software PVSYST. The most appropriate, i.e. the most optimal photovoltaic system is the system which consists of accordion profiled curtain wall with integrated transparent and semitransparent photovoltaic modules. The results of this study showed a maximum contribution of photovoltaic conversion, which also fits with the aesthetic characteristics of a facility. The active solar systems that integrate energy efficient facade structures, contribute to preserving the environment through the use of discretionary (green) energy resources.

Keywords: Solar energy, integrated photovoltaic modules, energy efficiency, educational buildings, double glass structure

1 Introduction

The greatest potential for operating energy efficiency is the redevelopment of buildings in the 1950s and 1980s. It is necessary to have a strategic analysis of how to find the realities that the European Union and other organizations have established (*Francesco, et al* 2017).

One of the most obvious criteria in relation to the application of solar energy for building renovation is the need to improve the building envelope from a thermal point of view, a durability point of view and from an architectural point of view (Dalenbiick, 1996). Applying glazing as a double facade can also be an interesting alternative that can enhance the building envelope. The installation of photovoltaic systems in a double envelope becomes part of the overall design of the structure (Hestnes, 1999).

In principle, photovoltaic systems integrated into a building can be used on all parts of the building envelope. Although roof surfaces are the part where photovoltaic elements are most often placed due to their favorable radiation values, facades also have great potential. The ratio of the facade area to the roof area increases with the height of the building. In addition, the available roof area is often reduced due to various installations and upgrades, which mean that photovoltaic systems integrated into facades, are particularly interesting in densely built urban centers. And thanks to the availability of thin photovoltaic modules, integration into facades has become even more relevant (Odersun, 2011).

2 Common methods of energy renovation of buildings

A general approach to renovation, such as a integrating a photovoltaic system on double-envelope, means that it must improve the thermal performance of public buildings in northwestern Macedonia by reducing the need for non-renewable energy sources. The public buildings to be analyzed in this paper must undergo a major renovation that must include solar concepts for electricity generation.

The conditions for significant renovation of old buildings with an emphasis on energy efficiency are defined in the Republic of Macedonia by the Energy Law.

2.1 Architectural integration requirements: The envelope of the building defines its architectural appearance and its relationship with the urban and natural environment. This paper investigates photovoltaic systems that are integrated into the facade surface where the existing wall and openings are retained, and the integration of photovoltaic systems is performed on the new double facade during renovation. The obtained new double façade has an aesthetic impression that can be defined according to (Kosorić, 2008):

- criteria for evaluating aesthetic quality with the use of active solar systems,
- visualization concepts,
- Parameters that determine the formal / functional characteristics of photovoltaic systems.

2.2 Concepts of solar renovation: This paper will explore integrated systems as part of a double facade. Facade implementation usually includes a vertical wall, sawtooth wall across vertical axle, accordion profiled curtain wall and sawtooth wall across horizontal axle with integrated transparent and semitransparent photovoltaic modules. In Table 1 are shown a standard, economical, and accepted construction as a good example of the sequence of non-transparent, semi-transparent and the glass in the newly designed double facade during reconstruction of buildings (Farrington, 1993).

Table 1. Four systems of non-transparent, semi-transparent and the glass

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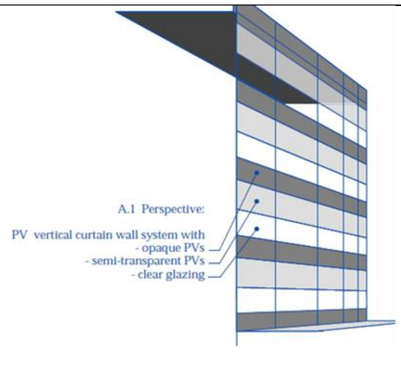
<td>
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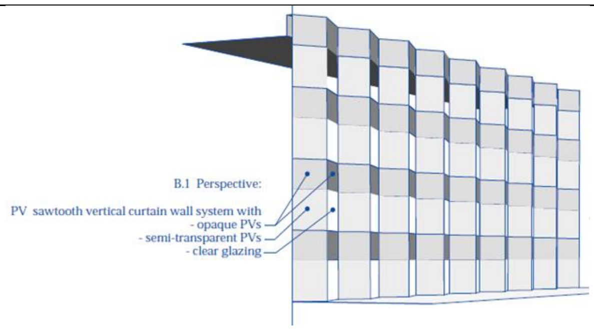
<td>
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<tr>
<td>A vertical wall with integrated transparent and semitransparent photovoltaic modules</td>
<td>Saw tooth wall across vertical axle with integrated transparent and semitransparent photovoltaic modules</td>
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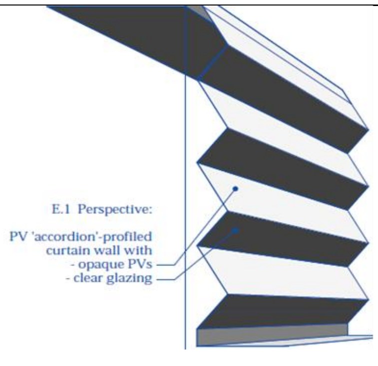
<td>
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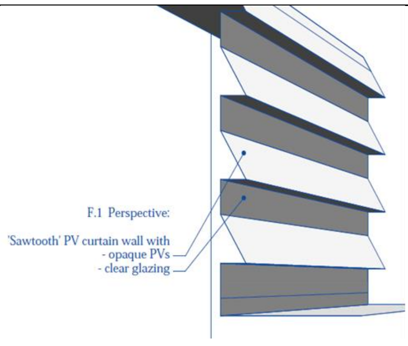
<td>
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Accordion profiled curtain wall with integrated transparent and semitransparent photovoltaic modules	Sawtooth wall across horizontal axle with integrated transparent and semitransparent photovoltaic modules

According to Atmaja (Atmaja, 2013), the direction and inclination angle of the façade installation will determine the amount of solar energy collected. In the northern parts of the country, photovoltaic modules will produce more electricity when facing southeast or southwest than if they face northeast or northwest, and vice versa. The tilt angle will help to achieve optimal isolation if the horizontal slope is 60 ° or the vertical slope is less than 15 °. The higher the distance from length ratio, the higher is the isolation on the panels.

3 Analysis of case study

The building defined as case study is located in the town of Gostivar, at Braća Ginovski no. 61, and belongs to an earlier historical period of construction. It was built in 1975, the architect of the building is Kiril Muratovski and so far, there is no concrete project to restore the building envelope. The Gostivar Conservation Center did not protect the Gostivar Regional and Local Government building, which means that there are no restrictions in terms of changing the design concept of the existing building.

In order for the renovation of the envelope in terms of installing a double facade with integrated photovoltaic modules to be successful, the existing envelope of Gostivar Regional and Local Government building must be repaired in accordance with report D3.3, D3.4 (Magyar et al, 2015), and energy efficiency measures that are suitable for the renovation of public buildings towards buildings with zero net energy consumption and their application which are listed in Table 2.

Table 2. Local Government building envelope renewal levels, (Magyar, 2015)

Building envelope	Before renovation		Renewal - level 1.			Renewal - level 2.			Renewal - level 3			Renewal - level 4		
	Technical data	U-value [W/m²K]	Technical data	U-value [W/m²K]	Specified cost [EUR/m²]	Technical data	U-value [W/m²K]	Specified cost [EUR/m²]	Technical data	U-value [W/m²K]	Specified cost [EUR/m²]	Technical data	U-value [W/m²K]	Specified cost [EUR/m²]
Wall		1,61	+20cm EPS	0,16	55	+20cm EPS	0,16	55	+20cm EPS	0,16	55	+15cm EPS	0,20	50
Roof / last floor		2,84	+20cm EPS	0,16	35	+20cm EPS	0,16	35	+20cm EPS	0,16	35	+15cm EPS	0,22	30
Window	Aluminum frame	3,30	PVC frame	1,10	220	PVC frame	1,40	200	PVC frame	1,80	120	PVC frame	1,80	120

Figure 1. View of the position of the Gostivar Regional and Local Government Building, source: Google Earth (photo edited)

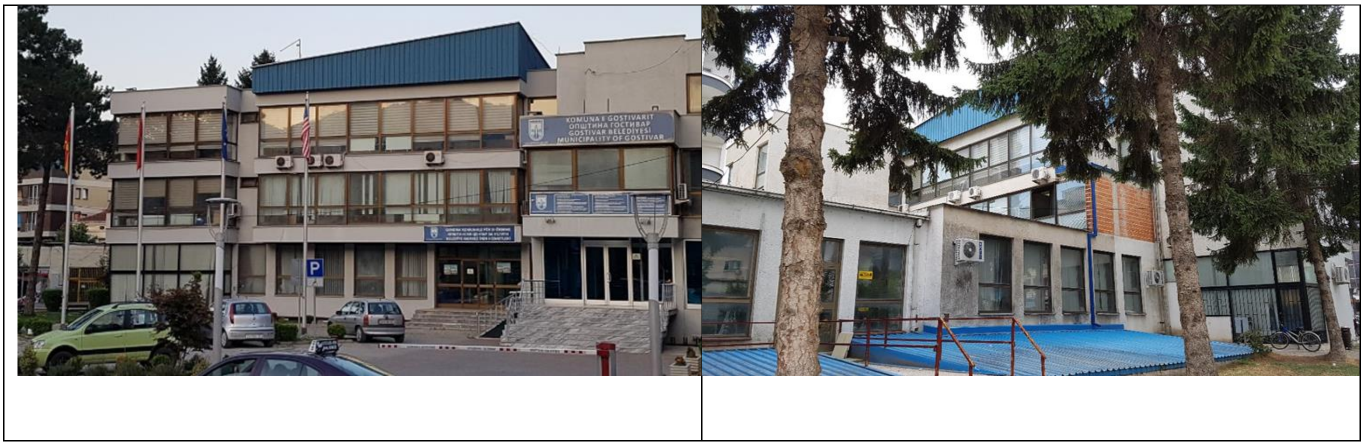


Figure 2. Gostivar Regional and Local Government Building: west façade (left), north façade (right) (photo taken: 18.07.2017.)

The building consists of three floors - ground floor and two floors. Photo and project documentation, which consists of old substrates, shows the condition of the building envelope. The construction of the building is a reinforced concrete skeleton with a fine-ribbed reinforced concrete mezzanine structure. The walls are made of hollow brick 25/25/20 cm, Windows are galvanized metal profiles glazed with thermal insulation glass. The building has a metal roof structure covered with blue aluminum sheet, aluform 150/55 mm.

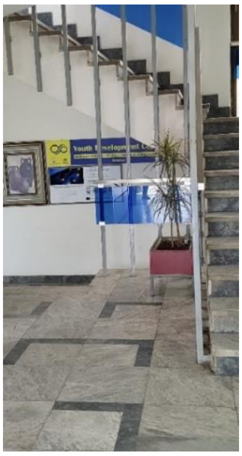
a)  b)  c) 

Figure 3. Gostivar RLG Building, internal appearance: a) entrance door, b) external openings, c) central hall (photo taken: 17.8.2017)

In Table 3 there are given basic information about geographical conditions, building geometry and properties as well as Internal Savings and their schedule.

Table 3. Basic information about Gostivar RLG Building

Category - Offices / Public administration		Subcategory - Regional and local government	
Northern latitude	41º47`29``	Floors	Po+P+2
Eastern longitude	20º54`28``	Average number of users	60
Elevation	531 m	Usable A_k (m²)	1200
An architect	K. Muratovski	Volume of the heated part of the building V_e (m³)	3768
Part 1. Building geometry			
walls, north (m²)	310	windows, north (m²)	35,00
walls, east (m²)	276,64	windows, south	112.50
walls, south (m²)	173,55	windows, west	167,56
walls, west (m²)	334.00	roof (m²)	367.00
windows, east (m²)	88,00	floor (m²)	449,34

Part 2. Building properties					
	Before investing	Request until 2020.		Before investing	Request until 2020
U-walls (W/m²K)	1,61	0,35	*U*-roof (W/m²K)	2,84	0,25
U-window(W/m²K)	3,30	1,30	*U*-the floor (W/m²K)	0,76	0,40

Part 3. Internal Savings and their schedule			
Space lighting		Appliances	
Working days (h/day)	5	Working days (h/day)	5
Saturdays (h/day)	0	Saturdays (h/day)	0
Sundays (h/day)	0	Sundays (h/day)	0

Part 4. Holidays												
	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Okt.	Nov.	Dec
Holydays	4	0	0	2	3	0	1	2	1	2	0	1

Part 5. Heating mode					
	Set temperature (° C)	Duration (h/day)		Set temp. (° C)	Duration (h/day)
W. days (h/day)	20	10	Non working hours	14	14
Saturdays (h/day)	14	24	Holidays	14	24
Sundays (h/day)	14	22			

Part 6. Heating system			
Emission efficiency (%)	100	Production efficiency (%)	100
Distribution efficiency (%)	95	Energy source / fuel (%)	Fuel oil

3.1 *Determination of the system - description of the experiment:*

Four different double glazed façade systems were explored differ from each other according to the position of the photovoltaic modules relative to the building envelope. The systems of photovoltaic modules explained in detail previously in the text are:

- System A: Vertical wall with integrated transparent and semitransparent photovoltaic modules (Figure 4);
- System B: Sawtooth wall across vertical axle with integrated transparent and semitransparent photovoltaic modules (Figure 5);

- System C: Accordion profiled curtain walls with integrated transparent and semitransparent photovoltaic modules (Figure 6);
- System D: Sawtooth wall across horizontal axle with integrated transparent and semitransparent photovoltaic modules (Figure 7).

Figure 4. Appearance of the western façade of the Gostivar Regional and Local Government building: a) existing appearance, b) partially clad façade with integrated photovoltaic panels of the system

Figure 5. Appearance of the western façade of the Gostivar Regional and Local Government Building: partially clad double façade with integrated photovoltaic panels of system B

Figure 6. Appearance of the western façade of the Gostivar Regional and Local Government Building: partially clad double façade with integrated photovoltaic panels of system C

Figure 7. Appearance of the western façade of the Gostivar Regional and Local Government Building: partially clad double façade with integrated photovoltaic panels of system D

4 Data analysis and results

4.1 *Daily energy consumption:*

The method of interviewing the users of the building made it possible to calculate the overall need of the users for electricity. Table 4 shows the largest electricity consumers in selected building. Values were calculated for a usage period of five days per week.

Table 4. Daily electricity consumption during the year in RLG Building in Gostivar

Device type	Device number	Power required (W/device)	Period of use (h/day)	Daily consumption (Wh)	Annual energy consumption (MWh /year)
LED light	40	18	3	2160	0,5184
Personal computer	20	250	8	40.000	9,60
Printers	10	426	1	4260	1,0224
Fax	10	65	0,50	325	0,078
LCD projector	5	260	0,20	260	0,0624
Air conditioners	6	3200	8	153.600	36,864
Other devices (DVD)	5	20	2	200	0,048
Other devices (receivers)	5	50	2	500	0,12
Stand-by devices	10	5	24	1200	0,288
Pumps	4	385	10	15.400	3,696
Total annual energy consumption(MWh / year)					52,2972

4.2 *Total energy production with system A, B, C, D:*

The total annual electricity production when installing the integrated photovoltaic system in the structural facade was achieved by summing the results of individual orientations.

Table 5. The total annual electricity production with the ABCD system

Orientation	System A[MWh]	System B [MWh]	System C [MWh]	System D[MWh]
west	17,70	23,70	23,70	16,60
East	19,50	17,60	24,20	17,10
north	8,30	17,50	12,80	7,00
south	10,10	15,00	18,70	12,70
In total:	55,60	73,80	79,40	53,40

4.3 *Comparison of values for systems A, B, C and D:*

By designing new types of structural facade, the area of the facade of buildings increases. The newly designed double façade consists of integrated photovoltaic panels located in different places for different types, such as transparent and semi-transparent modules, which were discussed. The values of produced electricity for each of the applied systems are shown in Table 6.

Table 4: Data on the area and total energy produced with newly designed types at the RLG building in Gostivar

System	Projected area (m^2)	Electricity required for users (MWh)	Total energy produced (MWh)
A	940,22	52,30	55,6
B	1249,5		73,8
C	924,9		79,4
D	834,15		53,4

Figure 8 shows the values of electricity produced in accordance with the needs of the RLU building in the town of Gostivar. For each type, a quantity that meets the needs of the user is specified.

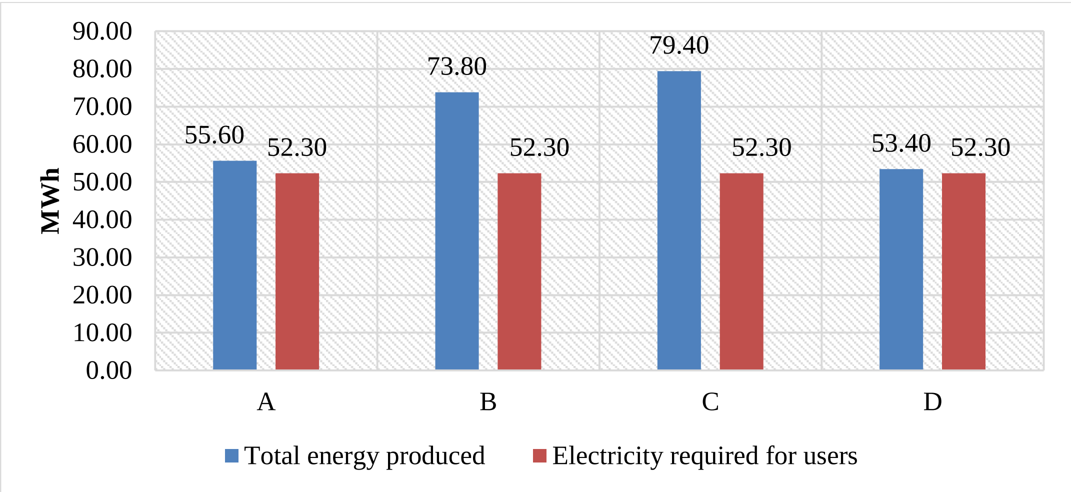


Figure 8. Comparison of the value of produced and consumed energy at the RLU building in Gostivar

4.4 *Selection of the most suitable solution for the RLU building in the city of Gostivar:*

According to the obtained results, the amount of electricity produced by all types meets the requirements of users. According to figure 8, the most favorable solution should be sought for system C because the total amount of electricity produced is higher, if compared to other systems, depending on the aesthetic characteristics.

5 Conclusion

The model of low-energy buildings with the application of optimal solutions using photovoltaic systems integrated into newly designed double facades, which can be applied to other existing public buildings in Macedonia in energy renovation of the building envelope, is a double facade in the form of a suspended facade profiled as an accordion with integrated opaque and semi-transparent photo modules (type C).

The model of the optimal solution for a plus energy building consists of:

- Semi-transparent systems that are integrated into the newly designed double facades in the window area or under the roof beams 90 cm high, tilted at an angle of 120 ° (-60 °) in 50% transparency, which gives the impression of solar glazing. The use of solar glazing produces electricity, and at the same time transmits a certain amount of light inside the building and provides the possibility of shading. Visibility through semi-transparent modules reaches about 50%;

- The glazed part, 120 cm high under the semi-transparent part, which is designed without photovoltaic modules, because the categories of the building, such as working, require constant daylight;
- Non-transparent integrated photovoltaic modules tilted at an angle of 60 °, placed at opaque parts of the facade wall, represent an opaque cladding of the facade wall.

References

[1.] Atmaja, T. D. (2013.), Façade and rooftop PV installation strategy for building integrated photo voltaic application, Energy Procedia 32 [2013], str.105. - 114.

[2.] Dalenbiick, J. O. (1996.), Solar energy in building renovation, Energy and Buildings, 24 [1996] Giiteborg, Sweden, str. 39. - 40.

[3.] Farrington, R. (1993.), (Kiss Cathcart Anders Architects, P.C.), Building-Integrated Photovoltaics, National Renewable Energy Laboratory, 1993.

[4.] Francesco P., Malighettia, L.E., Iannacconea, G., Maseraa, G. (2017.), Prefabrication as large - scale efficient strategy for the energy retrofit of the housing stock: an Italian case study, Procedia Engineering 180 [2017], str. 1160. - 1169.

[5.] Hestnes, A. G. (1999.), Building Integration Of Solar Energy Systems, Solar Energy, 67 [1999], str. 181. - 187.

[6.] Kosorić, V. (2008.), Aktivnisolarnisistemi, primena u materijalizacijiomotačaenergetskiefikasnihzgrada, Građevinskaknjiga, Beograd, ISBN: 978-86-395-0534-9

[7.] Law on Energy, Official Magazine of the Republic of Macedonia, no. 16/2011. i 136/2011.

[8.] Magyar, Z., Nemeth, G., Kontra, J. (2015.), D3.3 Report on best practices and lists of technologies useful for the refurbishment of buildings with detailed national sections, D3.4 Report on proposed packages of measures, Contract N°: IEE/13/886/SI2,674899 Refurbishment of the public building stock towards NZEB acronym of the project Republic ZEB

[9.] Odersun. 2011. Manual for BIPV Projects. www.odersun.com/uploads/pdf/Odersun-BiPV%20Manual-110902-EN (05.04.2016.)