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Professional paper

AESTHETICS AND ENERGY EFFICIENCY OF NONINTEGRATED SOLAR SYSTEMS AT FACADE STRUCTURES

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Abstract

Nowadays 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 its application, it is possible to achieve energy-efficient buildings. Nonintegrated photovoltaic systems can be used as fixed elements placed on the constructive facade which simultaneously serves as elements for sun protection. The most important issues while designing photovoltaic systems are the optimum orientation of the buildings and the tilting angle of the photovoltaic modules as well as the level of transparency. In this paper, an analysis is made about the optimal photovoltaic system which can be installed over the constructive facade of a building. The analysis was conducted by using the adequate software analyzing angle of 00, defining the most appropriate, i.e., the most optimal photovoltaic system, which consists of opaque modules placed horizontally or at an angle of 0º. The results of this study showed a maximum contribution of photovoltaic conversion, which also fits with the aesthetic characteristics of a facility. Solar systems, contribute to preserving the environment through the use of green energy resources.

Keywords: Aesthetic characteristics, solar energy, nonintegrated photovoltaic systems, energy efficiency

1 Introduction

The use of solar energy in architecture has been present since the earliest development of human civilization. To create suitable living conditions, man had to orient his habitat towards the Sun, as well as adapt it to the bioclimatic conditions of his environment. Starting from the caves as the original habitats and onwards, one notices the advantage of the home orientation to the south as well as the need for additional thermal insulation on the north side (for people in the northern hemisphere, for those in the south it is the opposite). Solar energy can be used in both newly designed and existing buildings. With its application, it is possible to achieve energy-efficient buildings while improving the comfort of space users.

2 Aesthetic aspects of the building envelope using solar systems

The use of solar energy affects the energy performance of the building, as well as the architecture of the building. The facade of the building defines the architectural expression of the building and its relation to the urban and physical environment. According to (Kosoric, 2008) the aesthetic expression while using active solar systems can be defined as:

- Criteria for evaluating the aesthetic quality in the application of active solar systems
- Concepts of visualization
- Parameters that determine the formal and functional characteristics of active solar systems

The criteria for evaluating the aesthetic quality are the following (IEA Task 7):

- Naturalness in the installation (the active solar system must be a visual and logical part of the building)
- Architectural impression (the building should be attractive while solar systems should contribute to and improve the design of the building)
- Composition of color and material (color and material should blend in with the other materials used as well as with the environment)

- Harmony in the solution (dimensional fit depends on the size of the solar systems, as well as the spans in which they are placed in relation to the dimensions of the building)
- Integration with the environment
- Design innovation, (Waldau, 2010)

According to architectural design, the following concepts of visualization can be defined as (Kosoric, 2008):

- Active solar systems should not affect the aesthetic-formal expression of the building, to be unobtrusive or "invisible" (with high roofs or when placed in renovated buildings of historical importance)
- Active solar systems to have a direct impact on the architectural image of the building

Parameters that determine the form-functional characteristics of active solar systems are:

- The shape of the roof or facade wall where the solar systems are installed
- The shape and dimension of solar systems
- The pattern, the color and the shine
- The characteristics of the surface layer - the texture

Even though many examples show that photovoltaic systems can be an aesthetically neutral or visually appealing element in architecture, many BIPV (Building Integrated Photovoltaics) systems exhibit several architectural qualities. When used properly, photovoltaic systems can enhance the character and value of a building. As part of the International Energy Agency's (IEA) Photovoltaic Power Systems (PVPS) Task 7 program (IEA Task 7), a team of architectural experts studied which key requirements need to be met (design innovation criteria for good quality photovoltaic projects) to produce successful photovoltaic integration.

2.1 *Functional characteristics of non-integrated façade photovoltaic systems:*

Non-integrated photovoltaic systems used in the materialization of the facade wall can be different types of modules as well as elements for protection from solar radiation where the photovoltaics are integrated. These elements can be movable and immovable for better capture of the sun's rays.

Non-integrated photovoltaic systems are placed at an optimal angle to better absorb sunlight, while in transparent facades, non-integrated photovoltaic modules are placed through the transparent parts in the form of sun protection elements (Figure 1).

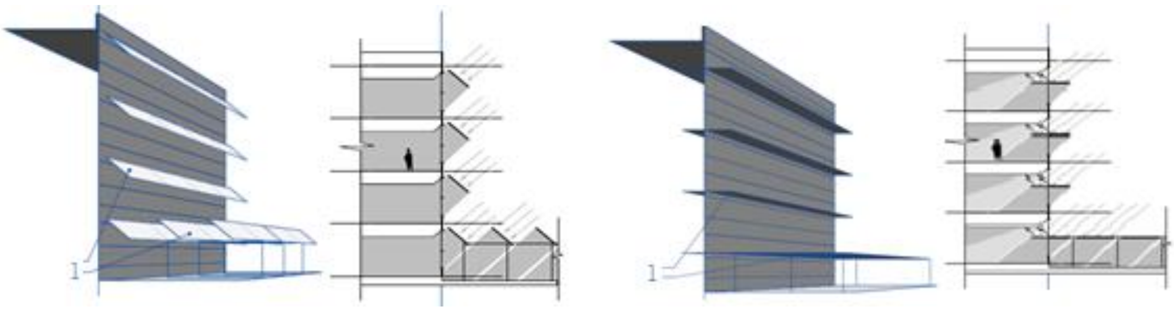

Figure 1. Non-integrated photovoltaic modules placed perpendicular to and at an angle above the façade wall, (Farrington, 1993)

2.2 *Technical characteristics of non-integrated façade photovoltaic systems:*

Facade non-integrated photovoltaic systems according to the method of installation can be divided into two groups:

- Photovoltaic modules that through certain supports are placed on the already- formed facade wall
- Elements for protection from solar radiation into which photovoltaic modules are integrated (figure 3)

Non-integrated photovoltaic systems are installed with the help of certain supports, usually over the non-transparent parts of the facade, such as the parapet or inter-window parts. In relation to the facade wall, the photovoltaic non-integrated systems are placed parallel or at an angle. This type is more commonly used in renovated buildings (figure 2).

The elements for protection from the solar radiation in which the photovoltaic modules are integrated are used in the materialization of the transparent parts of the facade wall. They are mounted in different ways depending on the type of element used (figure 3). There is a load-bearing structure on which these elements are placed, which can be:

- passive (fixed)
- active (moving)

Figure 2. "IMP-CNRS Perpignan", France, http://www.pvdatabase.org/projects_view_detailsmore.php?ID=265

Figure 3. Wirtschaftshof Linz, Austria, http://www.pvdatabase.org/projects_view_detailsmore.php?ID=265

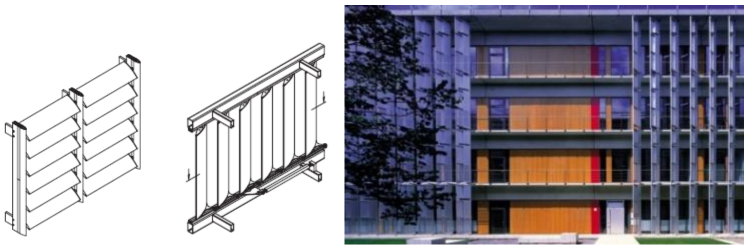

Figure 4. Integrated photovoltaic systems in horizontal and vertical slats or elements for protection against solar radiation, http://www.pvdatabase.org/projects_view_detailsmore.php?ID=265

Figures 4 shows fixed elements for protection against solar radiation with integrated photovoltaic modules, ie Shadovoltaic glass horizontal and vertical elements. Figure 4 shows the building "Sanitary complex of the Alzheimer's Project", in Madrid, Spain, where 400 photovoltaic modules are integrated on the facade as a standard fixed cover composed of horizontal elements to protect the building from solar radiation and heat. Transparent monocrystalline silicon modules are inclined at an angle of 60º. Annual production reaches about 17.4 MWh of electricity.

2.3 *Aesthetic-functional characteristics of facade non-integrated photovoltaic systems:*

Different types of non-integrated non-transparent photovoltaic modules are used in the materialization of non-transparent facade walls. Unlike integrated façade systems, non-integrated ones can also be installed over non-transparent parts so that they have no protection function and do not directly affect the comfort of the interior space. They can be placed parallel or at an angle to the formed façade wall. Figure 5 shows the non-integrated photovoltaic modules in the non-transparent part of the Catholic Apprentice Dormitory building, in Germany.

Figure 5. Integration of photovoltaic modules in the façade of the Catholic Apprentice Dormitory, Germany, http://www.pvdatabase.org/projects_view_detailsmore.php?ID=265

Non-integrated photovoltaic systems are often used in the reconstruction of buildings. These systems can be installed to cover the entire surface or part of the facade wall. Figure 6 shows an example of the application of a non-integrated photovoltaic system in the reconstruction of the facade of the Wilmersdorfer Straße, Freiburg, Germany.

	
Figure 6. Non-integrated photovoltaic systems in reconstruction the façade of Torregarena, Madrid, Spain, [69]	**Figure 7**. Elements of solar radiation on the façade of the on Wilmersdorfer Straße, Freiburg, Germany, http://www.pvdatabase.org/projects_view_detailsmore.php?ID=265

Non-integrated photovoltaic systems used in the materialization of transparent parts of the facade wall include different types of elements for protection from solar radiation in which there are integrated photovoltaic modules with different solutions in terms of design and function (figure 7). These elements can be placed in two ways, covering only parts of the transparent facades or covering the entire facade surface. The elements for protection from the solar radiation in which the photovoltaic modules are integrated and are used in different types of residential buildings, administrative, etc., and from the aspect of transparency they can be semi-transparent and non-transparent.

3 Analysis of selected buildings

According to the formal, and aesthetic characteristics of the photovoltaic modules that are applied in the structural facades of the selected building, will consider the possibilities given by photovoltaic modules, placed in non-integrated elements for sun protection.

The preliminary design was done for a specific residential-business building located in Gostivar, i.e., for the initial calculations, all the facades are considered individually. The place where the photovoltaic modules are planned to be installed is determined according to the aesthetic and formal characteristics of the building.

Figure 8 presents all the facades of the residential-business building, ie the provided area for installation of type A photovoltaic panels.

Figure 8. Facades of the residential-business building located in Gostivar

4 Defining types for software analysis and data analysis

The preliminary design will be made through a constructive facade that contains elements of sun protection as non-integrated elements. This type is considered in this research as Type A.

4.1 *Definition and division of type A- Elements for sun protection:*

Elements for sun protection (type A), as a non-integrated element in relation to the building envelope, in which the photovoltaic modules are integrated depending on the angle of inclination, as well as the degree of transparency can be divided as follows:

- A1. Fixed elements placed at an angle of 0° (A1/1 non-transparent, A1/2 semitransparent photovoltaic modules)
- A2. Fixed elements placed at an angle of 30° (A2/1 non-transparent, A2/2 semitransparent photovoltaic modules)
- A3. Fixed elements placed at an angle of 45° (A3/1 non-transparent, A3/2 semitransparent photovoltaic modules)

4.2 *Daily energy consumption :*

The method of preliminary design provides an opportunity to calculate the total required electricity for the needs of customers. Table 2 shows the main customer's requirement for electricity in the residential-business building where the preliminary design is performed. The values are calculated for a period of use of seven days a week for one year.

Table 2. Daily electricity consumption for one year

	Device type	Number of devices	Required energy (W/device)	Period of use (h/day)	Daily consumption (Wh)
1.	LED light	100	18	6.0	10800
2.	TV, personal computer	5	120	3.0	1800
3.	Home appliances	3	1000	0.1	300
4.	Ordinary and deep	2	1200	24	2400

	freezers				
5.	Washing machine and dishwasher	2	2200	24	4400
6.	Other devices	5	125	5	625
7.	*Stand- by* devices	5	25	24	600
Total daily consumption: 20925 Wh / day Total monthly required energy: 627.8 kWh / month Total annual energy consumption: 7.53 MWh					

4.3 *Results while applying type A and subtypes:*

Based on the nature of the sun protection elements, the subtypes can be applied individually, as fixed non-transparent elements or as fixed semi-transparent elements. Table 3 shows the values obtained in the preliminary calculation for different angles of inclination of the receiving area of 53 m^2 at the east facade.

Table 3. Results while applying the preliminary design of the elements for protection from the sun radiation on the eastern façade

Type A	Angle of inclination	Transparensy (%)	Rated power (kWp)	Total annual production (MWh)
A1/1	0˚	100	3.2	3.57
A1/2		50	1.6	1.90
A2/1	30˚	100	3.2	3.36
A2/2		50	1.6	1.68
A3/1	45˚	100	3.2	3.19
A3/2		50	1.6	1.59

Table 4 shows the values obtained in the preliminary calculation for different angles of inclination of the receiving area of 7 m^2 at the southeast facade.

Table 4. Results while applying the preliminary design of the elements for protection from solar radiation belonging to the

Type A	Angle of inclination	Transparency (%)	Rated power (kWp)	Total annual production (MWh)
A1/1	0˚	100	0.4	0.50
A1/2		50	0.2	0.25
A2/1	30˚	100	0.4	0.39
A2/2		50	0.2	0.19
A3/1	45˚	100	0.4	0.33
A3/2		50	0.2	0.16

south-east façade

Table 5 shows the values obtained in the preliminary calculation for different angles of inclination of the reception area of 12 m^2 at the south facade.

Table 5. Results by applying the preliminary design of the elements for protection from the sun radiation on the south façade

Type A	Angle of inclination	Transparency (%)	Rated power (kWp)	Total annual production (MWh)
A1/1	0˚	100	0.8	0.90
A1/2		50	0.4	0.45
A2/1	30˚	100	0.8	0.62
A2/2		50	0.4	0.31
A3/1	45˚	100	0.8	0.49
A3/2		50	0.4	0.24

Table 6 shows the values obtained in the preliminary calculation for different angles of inclination of the receiving area of 7 m^2 at the southwest facade.

Table 6. Results at applying the preliminary design of the elements for protection from solar radiation belonging to the south-west façade

Type A	Angle of inclination	Transparency (%)	Rated power (kWp)	Total annual production (MWh)
A1/1	0˚	100	0.4	0.50
A1/2		50	0.2	0.25
A2/1	30˚	100	0.4	0.39
A2/2		50	0.2	0.19
A3/1	45˚	100	0.4	0.33
A3/2		50	0.2	0.16

Table 7 shows the values obtained in the preliminary calculation for different angles of inclination of the reception area of 25 m^2 at the west façade.

Table 7. Results while applying the preliminary design of the elements for protection from the sun radiation on the western

Type A	Angle of inclination	Transparency (%)	Rated power (kWp)	Total annual production (MWh)
A1/1	0˚	100	1.5	1.79
A1/2		50	0.8	0.90
A2/1	30˚	100	1.5	1.68
A2/2		50	0.8	0.84
A3/1	45˚	100	1.5	1.57
A3/2		50	0.8	0.79

façade

5 Results and conclusions

5.1 *Total energy production for type A:*

For fixed elements for protection from solar radiation which have integrated photovoltaic modules, the total annual production of electricity during installation in the structural facade is obtained for each subtype separately because the fixed elements can either be non-transparent or semi-transparent. The total electricity produced will be different for each subtype. These values are shown in Table 8.

Table 8. Total annual electricity production for type A

Orientation	**A1/1** (MWh)	**A1/2** (MWh)	**A2/1**(MWh)	**A2/2** (MWh)	**A3/1**(MWh)	**A3/2**(MWh)
East	3.57	1.90	3.36	1.68	3.19	1.59
Southeast	0.50	0.25	0.39	0.19	0.33	0.16
South	0.90	0.45	0.62	0.31	0.49	0.24
Southwest	0.50	0.25	0.39	0.19	0.33	0.16
West	1.79	0.90	1.68	0.84	1.57	0.79
Total	**7.26**	**3.75**	**6.44**	**3.21**	**5.91**	**2.94**

5.2 *Comparison of values (total energy production for type B and required electricity for the users):*

Diagram 1 shows the values of produced electricity for type A1 / 1; A1 / 2; A2 / 1; A2 / 2; A3 / 1 and A3 / 2, i.e., the fixed elements for protection from the solar radiation with an area of 85.5 m2.

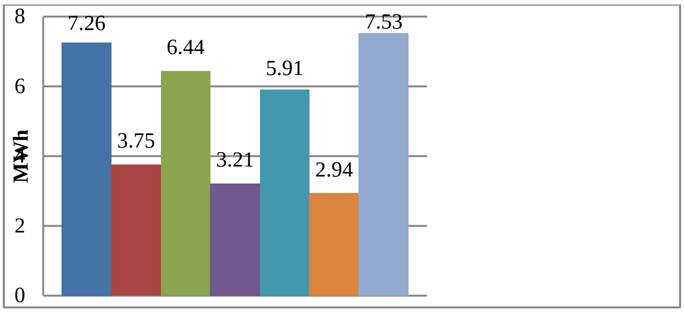

Figure 9. Total annual production of electricity of type B.

Analyzing the data on the total required electricity during one year for the specific facility, which is 7.53 MWh, as well as the data obtained from the preliminary design for each type and subtype of the photovoltaic part of the eastern structural facade, we can conclude that the required amount of electrical energy can be satisfied only with the application of type A1/1. Figure 9 shows all values of electricity produced for all subtypes compared to the annual required electricity.

5.3 *Conclusion:*

The above leads to a single conclusion, which is that the cooperation of architects and engineers should be closely linked to achieve the desired end results:

- Active solar systems aesthetically integrated with energy-efficient facade constructions
- The optimally designed system enables maximum contribution
- Quality built-in modules and accompanying equipment that ensure the longelivity of the system
- Economic viability includes government projects in cooperation with the World Bank, distribution companies' projects, and their interest in leasing surplus electricity
- A great contribution to the preservation of the human environment using unlimited (green) energy resources

The application of active solar systems for energy efficiency of facade constructions is experiencing great development in developed countries, but they are still not used in our country. The reason for this situation is located in the unpreparedness of the Macedonian market in terms of the lack of information on architects and engineers as well as the current use of inadequate solar installations (collectors), (Popovska, 2009). I hope that in the future the awareness and interest of architects and companies working with active solar systems will be awakened that with the cooperation of all factors, the necessary conditions for their use will be provided in our country.

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