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Review article

SOLAR RENOVATION CONCEPT IMPACT ON ARCHITECTURE

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Abstract

Modern solar architectures are based on direct (passive), indirect (active), and combined (passive and active) absorption of solar radiation. Building geometries and surrounding area characteristics can affect the availability and use of solar energy and the energy demands of a building. The shape of a building and the urban conditions in which it is located directly affect the availability of solar radiation. Most solar retrofit concepts claim to affect a building's thermal energy requirements. That is, reduce the heat supply of HV and/or hot water. However, most solar renovation projects also include traditional renovation activities (such as additional insulation or window replacement), so the specific benefits of a solar property are masked in the overall impact. Often some 'active solar' schemes can also be viewed as building energy efficiency measures, and some applied schemes require a more clearly defined aspect of solar. The main solar retrofit concept analyzed in this study is the clamshell/glazed facade combined with facade-integrated photovoltaics, which can affect the estimated energy performance of the building. The results discussed in this study include different public buildings in North Macedonia. Facility maintenance cycle

Keywords: Energy efficiency, solar concepts, renovation, photovoltaic systems, energy efficiency, public buildings.

1 Introduction

Major solar renovation concepts with the possible influence are described and discussed as:

- Double skin/glazed facade;
- Building Integrated photovoltaics

The double skin facade is a technological advancement in architecture that recognizes the need for a lower cost (compared to high-tech panels) “energy efficient” system and aesthetics in achieving controllable variables for the wellness and comfort of the users, the owner’s savings in terms of operational cost, and the efficiency of the building in terms of sustainability and environmental impacts.

The outer layer of the double skin facade is extremely suitable for integrating photovoltaics since it consists of single glazing and the modules can also provide solar shading. Building-integrated photovoltaics (BIPV) is proving to be the most rapidly emerging technology within the solar industry globally with an estimated capacity growth of about 50% (Delisle, 2014). Some of its applications are found in shading devices for windows, semi-transparent glass facades, building exterior cladding panels, and parapet units or roofing systems (Norton, 2011).

2 Solar concepts in the function of architectural expression

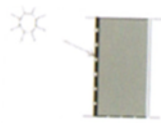
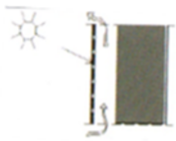
Solar systems integrated into the building envelope in the function of architectural expression are defined by two concepts of visualization (Kosoric, 2008):

- The photovoltaic systems can be applied in the building envelope so that they will be unobtrusive and unnoticeable. The photovoltaic modules should not be visible especially when it comes to renovating old buildings of historic importance. In this case will be applied as photovoltaic roofing systems.

- The photovoltaic systems can be applied in an envelope of the buildings so they determine the architectural image of the building. Thus, photovoltaic systems can provide a basic seal for the building.

While analyzing the formal- functional characteristics of facade integrated photovoltaic systems, cases of interest are semi-transparent and opaque photovoltaic modules applied on parts of the facade wall. The possibilities for application of opaque and semi-transparent photovoltaic modules are listed in (Kosoric, 2008). Opaque photovoltaic modules are apply in the materialization of a massive wall, while semi-transparent photovoltaic modules are used in the materialization of structural glass facades. Such utilization or method of applying is shown in table 1.

TABLE 1: APPLICATION OF OPAQUE AND SEMI-TRANSPARENT PV MODULES IN THE MATERIALIZATION OF THE FACADE WALLS (KOSORIC, 2008)

Aplication of opaque photovoltaic modules		Aplication of semi-transparent photovoltaic modules		
				
Cladding the facade wall with transparent photovoltaic modules without ventilation space	Cladding the facade wall with transparent photovoltaic modules with ventilation space	Semitransparent photovoltaic modules such as glazing with function of onelayer sunscreen glass	Semitransparent photovoltaic modules with the function of shading - a system of fixed elements or double facade	Semitransparent photovoltaic modules with the function of shading - a system of rotating elements or double facade

2.1 *Parameters that determine functional characteristics of photovoltaic systems:*

Based on that work the elements constituting a final layer of the facade wall, all integrated photovoltaic systems occupy the function of a protective layer from the weather and provide indoor hygrothermal comfort.

Integrated photovoltaic systems applied in the materialization of opaque parts of the facade wall can be of different types of opaque modules that represent opaque coating on the facade wall. As they have the function of allowing light and have no effect on visual comfort, can be integrated into the parapet wall of the facade. To achieve different visual and aesthetic effects, opaque modules can be combined with different materials that are used as facade coatings.

The solar glazing consists of semitransparent glazed solar cells and a suitable metal frame. The color and the design of photovoltaic modules depend on the type of solar cells, their dimensions, and their shapes. Solar glazing produces electricity while releasing a certain amount of light inside the buildings. Visibility through semi-transparent modules reaches about 20-50% depending on the applied photovoltaic modules.

2.2 *Parameters that determine formal characteristics of photovoltaic systems:*

To achieve quality in the architectural integration of PV certain requirements need to be fulfilled. The global integration quality depends not just on module shape, size and color but also on all formal characteristics (Probst, 2011):

- Field size and position of PV systems
- Materials and surface texture
- Color of the cells for PV systems

- Shape and size of the modules

For successful integration, the above-mentioned characteristics must all be coherent with the overall building design logic. The characteristics with the relevant examples of the use of PV are described below.

Field Size and Position: The size and position of the PV systems must be coherent with the overall architectural composition of the whole building and not just within the facade or part of the building where they are being installed. However, it may always not be easy to achieve this, and to achieve it; certain parameters have to be followed. The parameters that influence the location, shape, and size of the PV systems are (Probst, 2011)

- Position and dimension of the available exposed surface of the roof or facade
- Orientation of the surface available
- Energy requirements desired
- Solar technology
- Architectural needs of the building

The surface or part of the building that is available for integration directly influences the energy production of the solar systems. In the case of new construction, available exposed surfaces can be created according to the energy requirement aimed for. However, for retrofit projects, the energy production has to be adjusted according to the available exposed surfaces. In addition, the choice of solar technology also influences production and exposed surface requirements. In the case of PV systems, crystalline cells produce much more electricity than amorphous solar cells. So, for the yield of the same amount of power, amorphous solar cells have to be installed on a larger surface than crystalline cells.

An effective approach to the positioning and dimensioning issue is to use the PV as multifunctional elements serving both as energy generators and facade elements. With this, the architect has to design in such a way that he uses fewer elements as possible as each fulfills several functions. The use of PV all over the surface may often be unnecessary and difficult due to practicalities. So, the use of dummy elements will help to decouple the geometric dimensioning of the system and bring uniformity to the appearance of the system. However, the downside of this is that on most occasions, such applications require the development of a tailored product specific to just one project, and are therefore very expensive. (Probst, 2011).

Materials and surface texture: The characteristic of the material and their surface texture used in PV systems must be in harmony with the same characteristics of other elements of the building envelope.

In the case of PVs, both opaque and semitransparent modules can be used in the building fabric as desired. Semi-transparency of PV cells and modules is an important design feature, offering new application possibilities and providing good potential for architectural integration. Glass as a shiny material that is commonly used as module cover, strongly contrasts with the matt and respectively uneven finish of traditional building material like brick, render or roof tiles and the reflections on its surface make the modules highly visible at a distance and occasionally cause undesirable glare. To overcome this, matt surfaces have been created by sandblasting producing all kinds of regular and irregular patterns. Various types of structured glass can also be used as a glass cover to create a matt finish. (Hermannsdorfer, 2005)

Color: Performance characterization of semi-transparent photovoltaic (PV) modules usually includes data on electric power generation and visible light transmittance. However, when the modules are used as facade material, they also affect the colors rendered in the indoor environment. It is important to quantify the color rendering property of these modules to ensure the visual comfort of occupants (Lynn, at al.2012).

The colors of the crystalline and amorphous silicon cells are normally blue. By modifying the anti-reflection layer, it is possible to create other colours. Thin film solar cells consisting of amorphous silicon or CIS are black while CdTe-cells have a greenish look. The range of colors gives the possibility to produce any kind of pattern that is desired in a building fabric (Hermannsdorfer, 2005).

Within the chosen technology, the different products available in the market should be explored to find the color and surface texture most suitable for the given application. However, it would be a clever approach to define the materials of the other envelope elements to be compatible with the materials, textures, and colors of the chosen collectors which is possible in new construction.

Shape and size of the modules: The shapes of the modules of the PV systems have to be compatible with the building composition grid and with the various dimensions of the other facade elements (Probst, 2011). It is the choice of technology that affects the basic form of the module. For PV systems, mono and polycrystalline modules come in standard sizes and can be bulky while thin films can have varied shapes and sizes. Even though most of the products in the market come in standard module sizes, there is maximum freedom in the use of PVs on roofs and facade elements.

3 Case study- Public Buildings in the Republic of Macedonia

Conditions for major reconstruction of old buildings with an accent on energy efficiency are defined in the actual Energy Law in the Republic of North Macedonia. The Energy Law regulates the goals of the national energy policy and the manner of its implementation, the energy activities and the regulation of the energy activities, construction of energy buildings, the energy market, the natural gas market, the oil market, and heating energy market, the requirements for energy efficiency and promotion of Renewable Energy utilization and the other issues with relevance for the energy sector. (Energy Law, 2011)

Table 2 presents data on the amount of solar radiation on surfaces inclined at different angles to the weather conditions, the Skopje with coordinates 41°59'N, 21°26'E.

TABLE 2. GLOBAL OPTIMAL- INCLINED IRRADIATION (HWANG, AT AL,2012)

Month	**Angle of inclination of the modules to the horizon, [deg]**				
	0	**27**	**42**	**57**	**90**
January	52.08	79.67	89.28	93.93	85.87
February	68.04	91.56	98.28	99.68	84
March	106.33	126.17	128.65	124.62	94.55
April	126	133.2	128.4	117.9	79.2
May	158.41	157.17	146.32	128.65	78.43
June	183.6	174.3	159	136.5	78.3
July	192.82	188.48	172.98	149.42	85.25
August	170.5	177.32	168.64	151.59	94.55
September	122.1	140.4	140.7	133.8	96.6
October	85.25	110.05	115.94	115.94	95.17
November	50.4	72	78.9	81.6	72.3

December	41.54	63.86	71.92	76.26	70.37
Year	1357.07	1514.18	1499.01	1409.89	1014.59

The available data used in the preparation of the public building stock includes 2 441 buildings with a total floor area of 2 564 116 m2. The main sources for the data were the National Program for Energy Efficiency in Public Buildings in Macedonia 2012-2018 and the System for Monitoring of energy efficiency (Ex CITE), which is a database operated by the Association of the Units of local self -government of the Republic of Macedonia – ZELS, and the input data in the database is from the municipalities. Not all of the buildings are covered in the Public Building Stock. The estimation is that 70% of the buildings are covered by the current analysis (Radulov, et al. 2016). Table 3 depicts the distribution of the analyzed buildings by total built-up floor area.

TABLE 3: PARAMETERS OF THE MAIN BUILDING CATEGORIES AND SUB-CATEGORIES (RADULOV, AT AL. 2016)

No	Category / sub-category	Number of buildings	Total floor area (built-up area), m²	Total useful conditioned floor area (heated and/or cooled), m²
1	Residential	154	189 542	174 249
2.	Offices / Public administration	195	121 804	92 783
3.	Educational buildings	1 607	1 713 569	1 510 945
4	Health-care facilities	485	539 201	487 967
	TOTAL	2 441	2 564 116	2 265 944

Regarding the energy performance of existing public building stock, Table 4 presents the main thermal characteristics of the building envelope as defined in the national ordinances for the reference year 2008.

TABLE 4: THERMAL CHARACTERISTICS OF THE BUILDING ENVELOPE FOR THE REFERENCE YEAR 2008

No.	**Category / sub-category**	**Reference values – baseline year 2008**			
		Wall [W/m²K]	**Roof [W/m²K]**	**Floor [W/m²K]**	**Windows [W/m²K]**
1	Residential	1.3	0.8	0.6	3.5
2	Offices / Public administration	1.3	0.8	0.6	3.5
3	Educational buildings	1.3	0.8	0.6	3.5
4	Health-care facilities	1.3	0.8	0.6	3.5

(Source: National Program for Energy Efficiency in Public Buildings in Macedonia 2012-2018)

3.1 *Selection of building categories in the Republic of Macedonia*

The public building stock data included several classes of buildings as shown in table 3. The Offices / public administration buildings will be considered. The most influential determinants were the ratio of building class to total floor area and the flow of people.

In the Office/Public Administration building category, buildings of the subcategory of Regional and Local Administration (RLA) will be examined. The building of (RLA) in the Municipality of Želino is selected as the subject of the research. Below are analyses and pictures of the existing building and basic data for the building, located in the city of Municipality of Želino.

Figure 1: The building of the RLA building of the Municipality of Želino: a) north facade, b) entrance hall

TABLE 5: REFERENCE BUILDING FOR PUBLIC ADMINISTRATION - INPUT DATA ON THE BUILDING OF THE RLA BUILDING OF THE MUNICIPALITY OF ŽELINO

Category		**Office/Public Administration**	
Subcategory		**Regional and Local Administration (RLA)**	
The useful area of the building A_k	m^2	730	
Volume of the heated part of the building V_e	m^3	2263	
Geometry of the building			
Walls on north side	m^2	115,00	
Walls on east side	m^2	198,20	
Walls on south side	m^2	152,60	
Walls on west side	m^2	200.00	
Roof	m^2	419,52	
The floor	m^2	364,80	
Building properties			
U-wall	W/m^2K	Before investment 0,59	Request 0,35
U-window	W/m^2K	Before investment 2,00	Request 1,10
Window frame ratio	%	20%	

U-roof	W/m²K	Before investment 2,54	Request 0,25
U- floor	W/m²K	Before investment 0,85	Request 0,40

TABLE 6: DAILY CONSUMPTION OF ELECTRICITY DURING THE YEAR IN RLA BUILDING IN THE MUNICIPALITY OF ŽELINO

Device type	**Number of devices**	**Required energy (W/device)**	**Period of use (h/day)**	**Daily consumption (Wh)**	**Annual energy consumption (MWh/year)**
LED light	24	18	3	1296	0,31104
Personal computer	12	250	8	24.000	5,76
Printers	6	426	1	2556	0,61344
Fax	6	65	0,5	195	0,0468
LCD projector	3	260	0,2	156	0,03744
Air conditioners	4	3200	8	102.400	24,576
Other devices	4	20	2	160	0,0384
Receivers	4	50	2	400	0,096
***Stand-by* devices**	8	5	24	960	0,2304
Pumps	3	385	10	11.550	2,772
Total annual energy consumption (MWh/year)					34,4815

3.2 *Installation of a Photovoltaic system at Office Buildings as an energy efficiency measure*

The suggested power of a photovoltaic system depends on the annual electricity consumption of the building, the geometric parameters of the roof, and the national regulations in force. Considering the annual electricity need of this type of reference building is low the proposed power of the PV system is max.15 k W p. Table 7 shows the types in different angles of inclination named Type A, B, C, and D. It also shows the appearance of the northern facade of the building of the RLA of the Municipality of Želino: planned (partially covered) double facade with integrated photovoltaic panels.

TABLE 7: TYPES AND APPEARANCE

Type of double glazed-facade	Type	The appearance of the northern facade of the building of the RLA of the Municipality of Želino: planned (partially covered) double facade with integrated photovoltaic panels
Vertical walls with integrated photovoltaic modules	A	
Sawtooth wall across vertical axle with integrated opaque and semitransparent photovoltaic modules	B	
Accordion profiled curtain wall with integrated opaque and semitransparent photovoltaic modules	C	
Sawtooth wall across horizontal axle with integrated opaque and semitransparent photovoltaic modules	D	

The newly designed double facade of four different types on the RLA building of the Municipality of Želino, which produces different values of electricity for each of the applied types, are shown in Table 8.

TABLE 8: DATA ON THE AREA AND TOTAL ENERGY PRODUCED BY THE NEWLY DESIGNED TYPES AT THE RLA BUILDING OF THE MUNICIPALITY OF ŽELINO

Type	Designed surface (m^2)	Required electricity for users (MWh)	Total energy produced (MWh)
A	448,76		25,70
B	635,57	34,48	35,60
C	576,45		48,40
D	518,3		35,00

Figure 2 shows the values of electricity produced by the needs of the RLA in the Municipality of Želino. For each type, the quantity that meets the user's needs is specified, except for type A, where the required electrical energy has higher values than the total produced. With types B, C, and D, an approximately and greater amount of energy is produced.

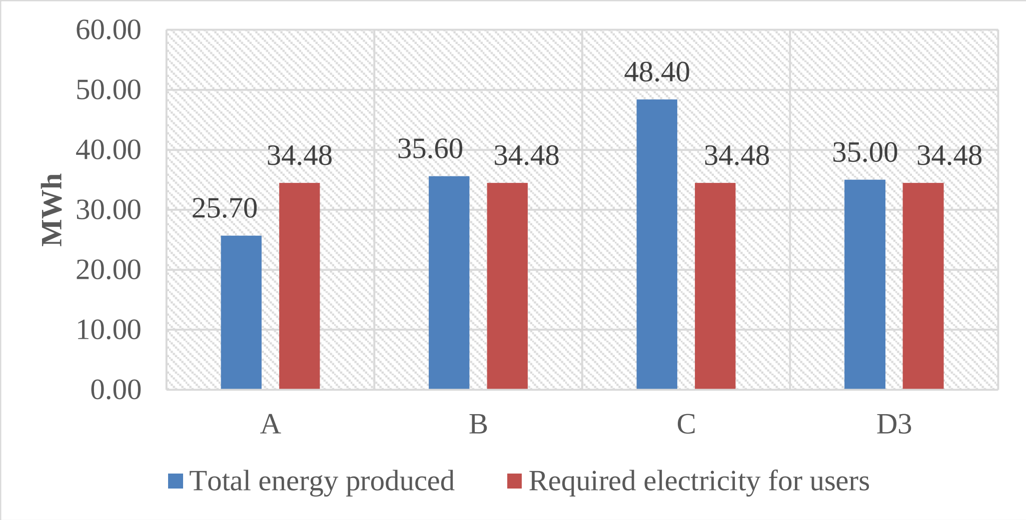


Figure 2: The values of electricity produced in accordance with the needs of the RLA in the Municipality of Želino

Conclusions

Although each newly designed type meets the user's needs except for type A, solar renovation has an impact on architecture. Solar architecture is a simple building block in clean energy technologies that goes beyond converting buildings from traditional buildings to energy-efficient buildings through the use of solar energy. The ability of the designer to incorporate it integrated as architectural elements to be inspired in the design of the building, the aesthetic value or acceptance that needs to be achieved is a very important issue, and today's technology tries to provide the architectural design required to achieve this and the choice of designer for the way he wants to employ solar systems in architectural production will depend primarily on the specifications of the solar system, and the properties and potentials such as diversity in shape, body, size and color and the impact on the facades of buildings, the necessity of convincing the designer of the importance of the integration of solar systems and how to link them with the building to produce a new character and model has environmental objectives, form and functional.

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