Improvement of Energy Performances of Existing Buildings in Suburban Settlements

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ABSTRACT: The research on improvement of energy performances of the existing building in suburban settlement Konjarnik in Belgrade, by application of active solar systems: solar thermal collectors and PV modules, is presented in the paper. The case study shows different design variants of integration of solar thermal collectors and PV modules in envelope of a multifamily building. Considering integration complexity of active solar systems, the following aspects of active solar systems integration are analyzed in the paper: energy, architectural, ecological and economic aspects. Keeping in mind all these aspects, parameters and criteria for evaluation of design variants are established. According to the established evaluation methodology, the design variant with the highest evaluation value is selected as optimal.
Keywords: building refurbishment, solar systems application, architectural integration, improvement of energy performances, reduction of CO_2 *emissions.*

INTRODUCTION

Sustainable approach to building refurbishment represents methodology that includes decision-making based on coordination between demands, aims, building refurbishment technologies and capacity to change indicator. Methodological access includes application of appropriate phases, procedures and measures, depending on aims (Fig. 1).

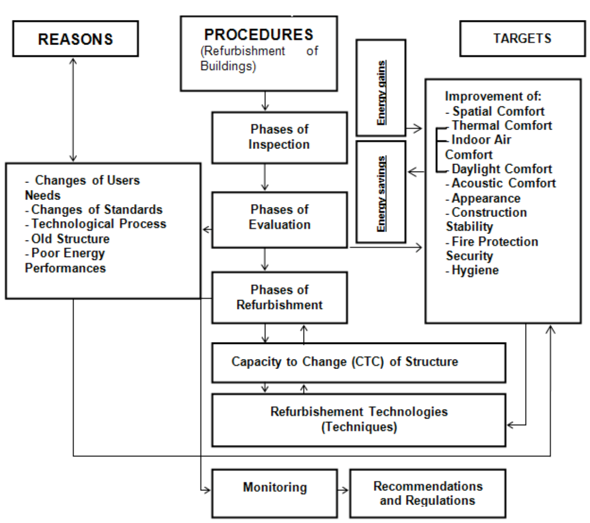

Figure 1: Methodological access to building refurbishment [1]

Main target on which this paper is directed is achieving energy savings through building refurbishment, more exactly by application of solar thermal collectors and PV modules, achievement of solar energy gains and reduction of fossil fuels consumption.

METHODOLOGY

After II World War, lot of suburban settlements had been built in Belgrade. The residential buildings in settlement "Konjarnik" are selected as the model on which possibilities for improvements of energy performances by application of solar systems are analysed in the paper.

Figure 2: Location of „Konjarnik" on the map of city of Belgrade

Figure 3: Typical south-west facade

The analysis in the paper is hypothetical and it aims to show benefits of active solar systems application on residential buildings in Belgrade climate conditions. Methodological access includes treatments of existing state, consumer, solar system, architectural integration of solar system, reduction of CO_2 emissions, simple payback period and evaluation of proposed design variants.

Existing State Settlement “Konjarnik” begins 4 km south-east of downtown Belgrade and stretches itself over 2 km (Fig.2). It is selected for analyzes as settlement consisted mainly of typical buildings built in 1960s and 1970s.

Belgrade is the city with global irradiance of 1341.8 kWh/m^2 (Polysun 4), and 2123.25 sunny hours per year [4]. The settlement is characterized by large rectangular shaped residential buildings with typical south-north orientation, more exactly deviation of 10° to southwest is present (Fig. 4).

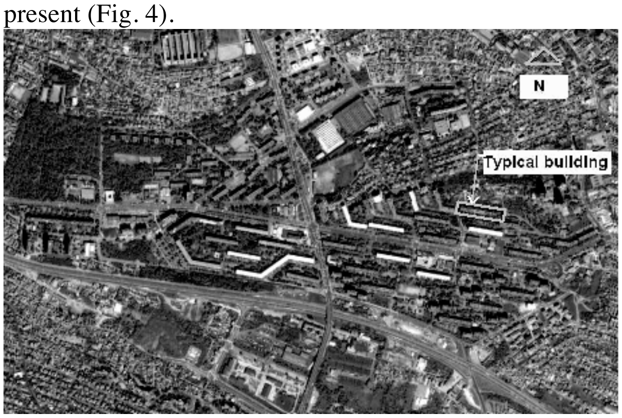

Figure 4: Buildings disposition in “Konjarnik” settlement

Facades oriented south and north consist rows of windows and parapets, which represent 70% and loggias, which represent 30% of facade surfaces (Fig. 3). Existing refurbishment strategies applying on these residential buildings are transformations of flat roofs into slopping roofs by attic annex, which is municipality organized action (Fig. 5, 6) and glazing of loggias, which is usually realized by tenants as illegal action.

Figure 5: Typical building before attic annex

Figure 6: Typical building after attic annex

As the buildings in the analyzed settlement consisted number of lamellas, the analyses in the paper were done for one lamella. Possibilities for both solar thermal collectors and PV modules application on south-west oriented facade and roof surfaces were analyzed.

Consumer There are 28 apartments in one lamella and 90 occupants inside them altogether. The initial idea was to explore potential and effects of solar system based on solar thermal collectors to meet energy demands for hot water, and potential and effects of solar system based on PV modules to meet energy demands for artificial lighting. In calculations, real thermal and electrical energy consumption were taken into consideration. Thermal energy for hot water: 80 l of hot water per person per day, 80 l x 90 = 720 l (20-50°C) per day for one lamella which presents 251 kWh per day, i.e. 91618.3 kWh per year for one lamella. Electrical energy for artificial lighting: 0.3 kWh per person per day, i.e. 9855 kWh per year for one lamella.

Solar System Calculations and simulations of solar thermal systems for all design variants were done in Polysun 4 Version 4.3.0.1. In calculations, the existing water heating system fully based on electricity was substituted with the new system – solar thermal collectors (AKS Doma –manufacturer), with the auxiliary system powered by electricity.

Calculations and simulations of PV systems for all design variants were done in PVSYST Version 4.33. The standard modules with monocrystalline cells were used for calculations.

Architectural Integration of Solar System 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).

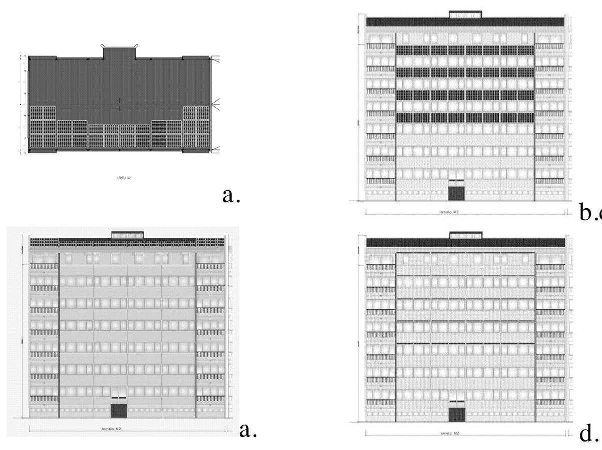

Figure 7: Analyzed design variants: a. I Design Variant: roof 40° (roof and facade layouts), b. II Design Variant: parapet 90°, c. III Design Variant: parapet 45°, d. IV Design Variant: sun shading 0°

For analysis four distinctive variants of positions on building envelope for both solar thermal collectors and

PV modules, were selected:

I Design Variant: roof 40˚, area of 100 m^2 (Fig. 7-a) - solar panels with slope of 40˚ applied on the roof,

II Design Variant: parapet 90˚, area of 90 m^2 (Fig. 7-b)- vertical position of solar panels,

III Design Variant: parapet 45˚, area of 120 m^2 (Fig.7-c)- solar panels with slope of 45 applied on parapets,

IV Design Variant: sun shading 0˚, area of 55 m^2 (Fig. 7-d) - horizontal position of solar panels.

Reduction of CO_2 Emissions In calculations of CO_2 emissions of the consumer, for case in which solar system substitutes electricity based system, 0.81 kg CO_2/kWh reduction is used. [2]

Simple Payback Period For calculations of simple payback period for analyzed design variants following parameters were used: 700 EUR - total system costs per 1 m^2 of solar thermal collectors, 900 EUR - total system costs per 1 m^2 of PV modules, 0.45 EUR/kWh – price of energy produced from solar systems [3].

Evaluation of proposed design variants In the paper the evaluation of proposed design variants is based on aesthetical, mounting options, energy and ecological criteria. As aesthetical criteria might be characterized by subjectivity, it is adopted to be related to solar thermal collector's compatibility to the facade and roof technical characteristics (dimensions, form, color, material), for which reliable evaluation can be established. Generally, evaluation is based on the fact that experts make decisions in the design process, and some of them are polled in order criteria values to be established. Following evaluation criteria are established:

- c1: Aesthetic characteristics (1 (lowest)-3 (highest)),
- c2: Mounting options (1 (lowest)-3 (highest)),
- c3: Energy Production per year/total system costs (kWh/EUR),
- c4: Energy Production per year/Panel area (kWh/m^2),
- c5: Energy Demands Satisfaction per year (%),
- c6: Reduction of CO_2 emissions (kg/year).

Every criteria (c1-c6), to the design variant with highest value of that criteria gets 5 points, and other variants get points proportionally. Weights of all adopted criteria were defined and Evaluation Value (E) is calculated as: E=0.3xc1+0.2xc2+0.2xc3+0.1xc4+0.1xc5+0.1xc6.The design variant with the highest evaluation value is conceived as optimal solution.

According to established evaluation system and evaluation values calculations, evaluation of both proposed solar thermal and PV design variants were done (Tab. 2, 4).

RESULTS

Results of solar thermal and PV systems integrations were considered and presented through reduction of energy consumption, reduction of CO_2 emissions, simple payback period and evaluation of proposed design variants.

RESULTS OF SOLAR THERMAL SYSTEM INTEGRATION

Reduction of Energy Consumption For comparative analysis of energy performances for design variants of solar thermal collectors integrations, monthly thermal energy production, hot water demands satisfaction and thermal energy production per m^2 of solar thermal collector were calculated and presented in Figures 8, 9 and 10. It is evident that different positions of solar thermal collectors give different results regarding mentioned parameters:

-Solar thermal collectors integrated on the roof 40˚ can produce monthly thermal energy from min 1492 kWh in December to max 6605 kWh in August; they can meet demands for hot water from min 19.6% in December to max 84.9% in August; thermal energy production per m^2 is from min 14.9 kWh/m^2 in December to max 66.1 kWh/m^2 in August;

- Solar thermal collectors integrated in parapets 90˚ can produce monthly thermal energy from min 1858 kWh in January to max 3603 kWh in September; they can meet demands for hot water from min 23.9% in January to max 47.8% in September; thermal energy production per m^2 is from min 20.6 kWh/m^2 in January to max 40 kWh/m^2 in September;

- Solar thermal collectors integrated in parapets 45˚ can produce monthly thermal energy from min 1780 kWh in January to max 6169 kWh in August; they can meet demands for hot water from min 22.9 % in January to max 79.3 % in August; thermal energy production per m^2 is from min 14.8 kWh/m^2 in January to max 51.4 kWh/m^2 in August;

- Solar thermal collectors integrated as sun shadings 0˚ can produce monthly thermal energy from min 208 kWh in January to max 3524 kWh in August; they can meet demands for hot water from min 2.7 % in January to max 45.3 % in August; thermal energy production per m^2 is from min 3.8 kWh/m^2 in January to max 64.1 kWh/m^2 in August.

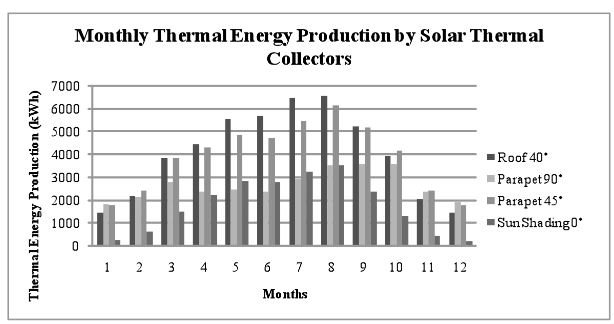

Figure 8: Monthly Thermal Energy Production by Solar Thermal Collectors

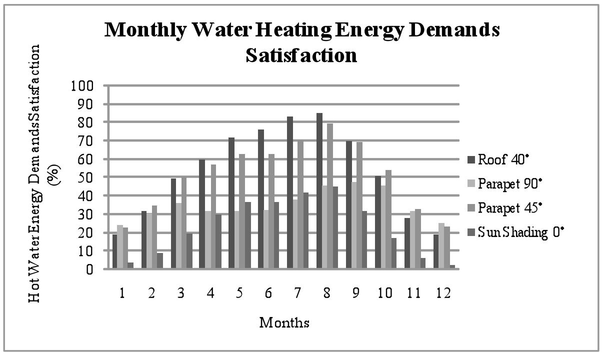

Figure 9: Monthly Water Heating Energy Demands Satisfaction

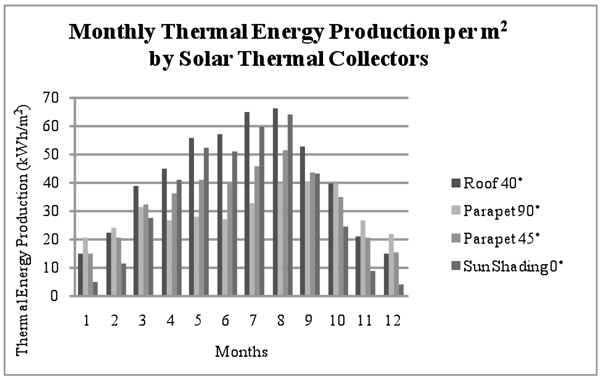

Figure 10: Monthly Thermal Energy Production per m^2 of Solar Thermal Collectors

Reduction of CO_2 Emissions In Table 1, values for CO_2 emissions reduction are presented for all proposed design variants.

Table 1: CO_2 reduction achieved by solar thermal collectors

	roof 40˚	parapet 90˚	parapet 45˚	sun shading 0˚
kg/year	39908	26013	38402	17395

Simple Payback Period Simple payback periods for Design Variants 1, 2, 3 and 4 are sequently 7, 9, 8 and 8 years.

Evaluation of proposed design variants According to established evaluation system, I Design Variant has the highest evaluation value (E), (Tab. 2), and therefore it is optimal solution.

Table 2: Evaluation of Design Variants (I-IV) with solar thermal collectors integration

c	I		II		III		IV	
	p	e	p	e	p	e	p	e
1	3	5	3	5	2	3.3	1	1.7
2	3	5	2	3.3	2	3.3	2	3.3
3	0.7	5	0.5	3.6	0.6	4.3	0.6	4.3
4	492.7	5	356.8	3.6	395.1	4	390.5	3.9
5	53.6	5	35	3.3	51.7	4.8	23.4	2.2
6	39908	5	26013	3.3	38402	4.8	17395	2.2
E	5		3.9		3.87		2.86	

RESULTS OF PV SYSTEM INTEGRATION

Reduction of Energy Consumption For comparative energy performances for design variants analysis of PV modules integrations, monthly electrical energy production, artificial lighting demands satisfaction and electrical energy production per m^2 of PV modules were calculated and presented in Figures 11, 12 and 13.

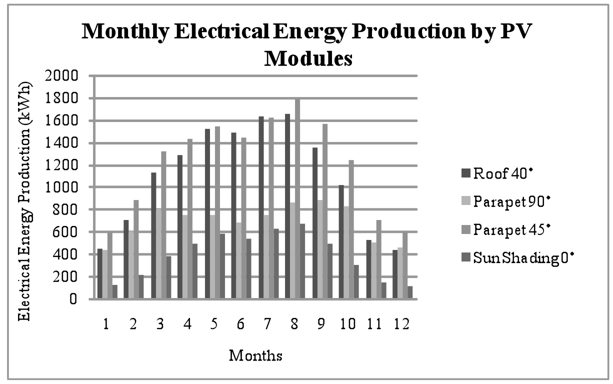

Figure 11: Monthly Electrical Energy Production by PV Modules

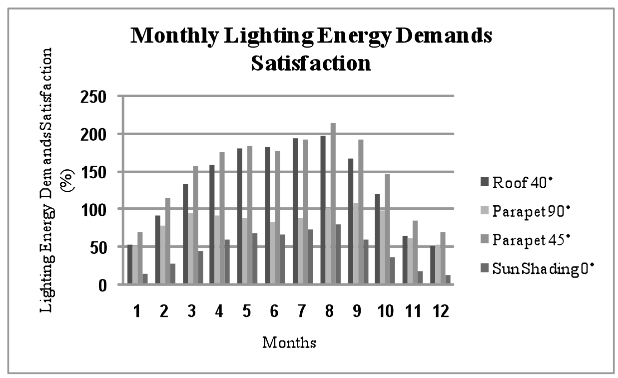

Figure 12: Monthly Lighting Energy Demands Satisfaction

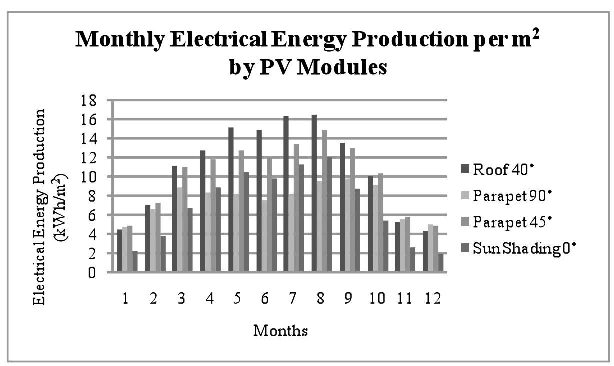

Figure 13: Monthly Electrical Energy Production per m^2 by PV Modules

It is evident that different positions of PV modules give different results regarding mentioned parameters:

- PV modules integrated on the roof 40˚ can produce monthly electrical energy from min 440.6 kWh in

December to max 1651.2 kWh in August; they can meet demands for artificial lighting from min 52.6 % in December to max 197.3 % in August; electrical energy production per m^2 is from min 4.4 kWh/m^2 in December to max 16.5 kWh/m^2 in August;

- PV modules integrated on the parapets 90˚ can produce monthly electrical energy from min 431.6 kWh in January to max 885.5 kWh in September; they can meet demands for artificial lighting from min 51.6 % in January to max 109.3 % in September; electrical energy production per m^2 is from min 4.8 kWh/m^2 in January to max 9.8 kWh/m^2 in September;
- PV modules integrated on the parapets 45˚ can produce monthly electrical energy from min 594 kWh in January to max 1793 kWh in August; they can meet demands for artificial lighting from min 71 % in January to max 214.2 % in August; electrical energy production per m^2 is from min 4.9 kWh/m^2 in January to max 15 kWh/m^2 in August;
- PV modules integrated as sun shadings 0˚ can produce monthly electrical energy from min 108.3 kWh in December to max 669.6 kWh in August; they can meet demands for artificial lighting from min 12.9 % in December to max 80 % in August; electrical energy production per m^2 is from min 2.3 kWh/m^2 in December to max 12.2 kWh/m^2 in August.

Reduction of CO_2 Emissions In Table 3, values for CO_2 emissions reduction are presented for all proposed design variants.

Table 3: CO_2 reduction achieved by PV modules

	roof 40˚	parapet 90˚	parapet 45˚	sun shading 0˚
kg/year	10679	6712	11922	3774

Simple Payback Period Simple payback periods for Design Variants 1, 2, 3 and 4 are sequently 15, 21, 16 and 23 years.

Evaluation of proposed design variants According to established evaluation system, I Design Variant has the highest evaluation value (E), (Tab. 4), and therefore it is optimal solution.

Table 4: Evaluation of Design Variants (I-IV) with PV modules integration

c	I		II		III		IV	
	p	e	p	e	p	e	p	e
1	3	5	3	5	2	3.3	1	1.7
2	3	5	2	3.3	2	3.3	2	3.3
3	0.09	5	0.06	3.3	0.08	4.7	0.06	3
4	131.8	5	92.1	3.5	122.7	4.7	84.7	3.2
5	133.6	4.5	84.1	2.8	149.2	5	47.2	1.6
6	39908	5	26013	3.3	38402	4.8	17395	2.2
E	4.95		3.78		4.04		2.47	

CONCLUSION

Contribution of application variants of active solar systems to improvement of energy performances of existing buildings is estimated through comparative analyzes of predictive variants. For comparative analysis of energy performances of solar thermal integrations design variants at the yearly basis, calculation of thermal energy production, hot water energy demands satisfaction and average thermal energy production per m^2 per year were carried out and shown in Figures 14, 15 and 16.

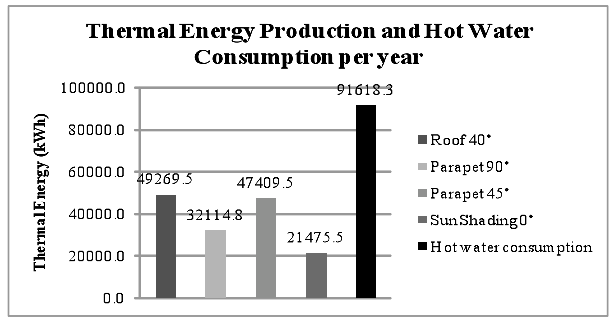

Figure 14: Thermal Energy Production and Hot water Consumption per year

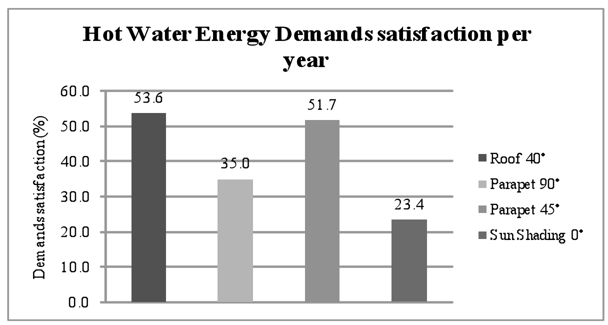

Figure 15: Hot Water Heating Energy Demands Satisfaction per year achieved by solar thermal collectors

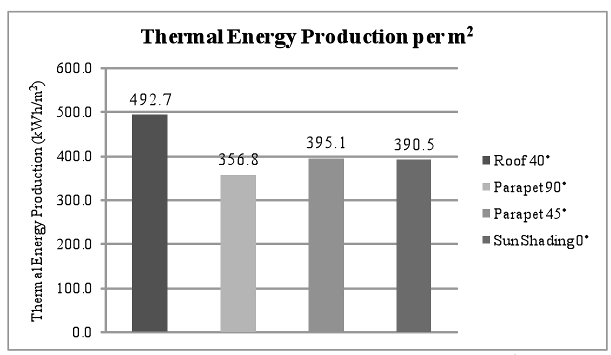

Figure 16: Hot Water Energy Production per m^2 of Solar Thermal Collectors

At the yearly basis, it is evident that design variants with solar thermal collectors can produce thermal energy from min 21475.5 kWh (Sun shading 0˚) to max 49269.5 kWh (Roof 40˚); these design variants can meet from min 23.4 % (Sun Shading 0˚) to max 53.6 % (Roof 40˚)

hot water demands; thermal energy production per m^2 varies from min 356.8 kWh/m^2 (Parapet 90˚) to max 492.7 kWh/m^2 (Roof 40˚).

For comparative analysis of energy performances of PV modules integrations design variants at the yearly basis calculation of electrical energy production, artificial lighting energy demands satisfaction and average electrical energy production per m^2 of PV modules per year were calculated and shown in Figures 17, 18 and 19.

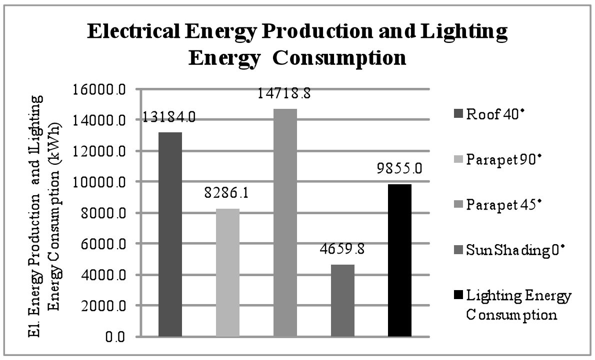

Figure 17: Electrical Energy Production by PV Modules and Lighting Energy Consumption

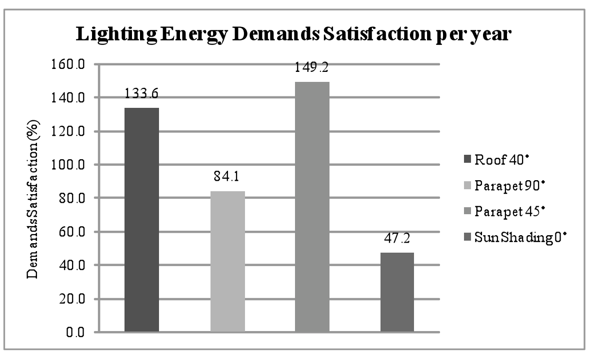

Figure 18: Lighting Energy Demands Satisfaction per year achieved by PV modules

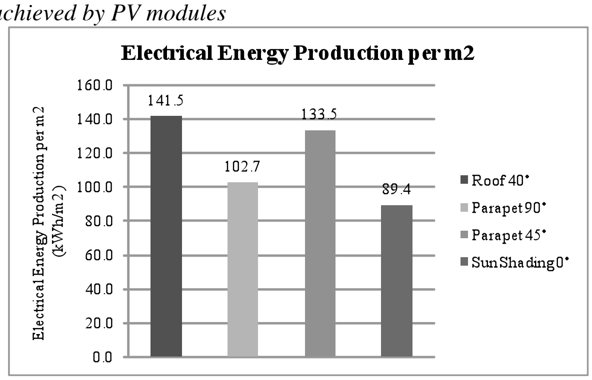

Figure 19: Electrical Energy Production per m^2 of PV Modules

At the yearly basis, it is evident that design variants with PV modules can produce electrical energy from min 4659.8 kWh (Sun shading 0˚) to max 13184 kWh (Roof 40˚); these design variants can meet from min 47.2 % (Sun Shading 0˚) to max 149.2 % (Parapet 45˚) artificial lighting demands; electrical energy production per m^2 varies from min 89.4 kWh/m^2 (Sun shading 0˚) to max 141.5 kWh/m^2 (Roof 40˚).

In order to achieve adequate comprehensive approach, multi-criteria decision making method is included in the process of evaluation and selection of design solutions. According to established evaluation system in the paper, for both solar thermal and PV systems, I design variants, in which panels are 40˚ tilted on the roof of building, were indicated as optimal. Through design variants given and discussed in the paper, it can be found out that by application of solar thermal collectors and photovoltaic modules in building refurbishment, numerous benefits can be achieved as reduction of conventional energy consumption and environmental pollution, and obtaining of opportunities for new aesthetic potentials in refurbishment of the existing buildings. In Belgrade, as well as in Serbia, there are a large number of housing settlements with the same or similar prefabricated buildings, as in the case of settlement Konjarnik, indicating that significant energy savings and CO_2 emission reductions can be obtained. As the similar prefabricated systems were in use all over the Europe, the methodological accesses to improvement of energy performances of existing buildings and results presented in the paper might be helpful to wide sphere of professionals engaged in building refurbishment, especially in the parts of Europe with the similar climatic conditions as in Belgrade territory, and contribute to application of solar systems in building refurbishment.

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REFERENCES

1. Krstić- Furundžić, A. (2005). Methodical approach to building refurbishment. In Estimation of condition, conservation and reconstruction of buildings and settlements Conference, Union of Civil engineers and Technicians of Serbia and Montenegro, Belgrade, ISBN 86-904089-1-6: p. 447-454.
2. Krstić-Furundžić A., Kosorić V. (2008). Reduction of CO_2 emissions through solar thermal collectors application on student housings in Belgrade. In Low Carbon Urban Built Environments Conference, Munich, Germany: p. 3-14.
3. Tariff System for Electricity Production from Renewable Energy Sources and Cogeneration. (2007), Official Gazette, No. 33/07. The Croatian Parliament. [Online], Available: http://www.strategija.hr/lgs.axd?t=16&id=515/.
4. Republic Hydro meteorological Service of Serbia.