ENERGY OPTIMIZATION OF SERBIAN BUILDINGS WITH PV PANELS AND DIFFERENT HEATING SYSTEMS

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- Nowadays, research, development and using the renewable energy resources have significant impact on the environment – just because of the lower world reserves of fosil fuels and the increasing problems of global warming, greenhouse gases and air pollution.
- An attractive option for clean and renewable electricity generation is solar photovoltaic (PV) technology - the direct conversion of solar radiation into electricity.
- In Serbia, the building sector consumes more than 50% of the used energy. An intention of our country to become a member of EU obliges us to reduce the energy consumption by 20% and to obtain 20% of total energy from renewable energy by 2020.
- To achieve these goals, some advanced energy concepts for built environment should be applied such as a zero-net energy building (ZNEB) and a positive-net energy building (PNEB).

- In this paper, energy consumption is analyzed for a residential building with PV array, located in Kragujevac, Serbia.
- This article reports investigations of the possibilities to decrease energy consumption of Serbian residential buildings with PV array and different heating systems (electric space heating and district heating), through the variation of thermal insulation thickness and electricity consumption in building.
- The major objective of this investigation is to determine the size of PV panels on the roof in order to minimize the consumption of primary energy.

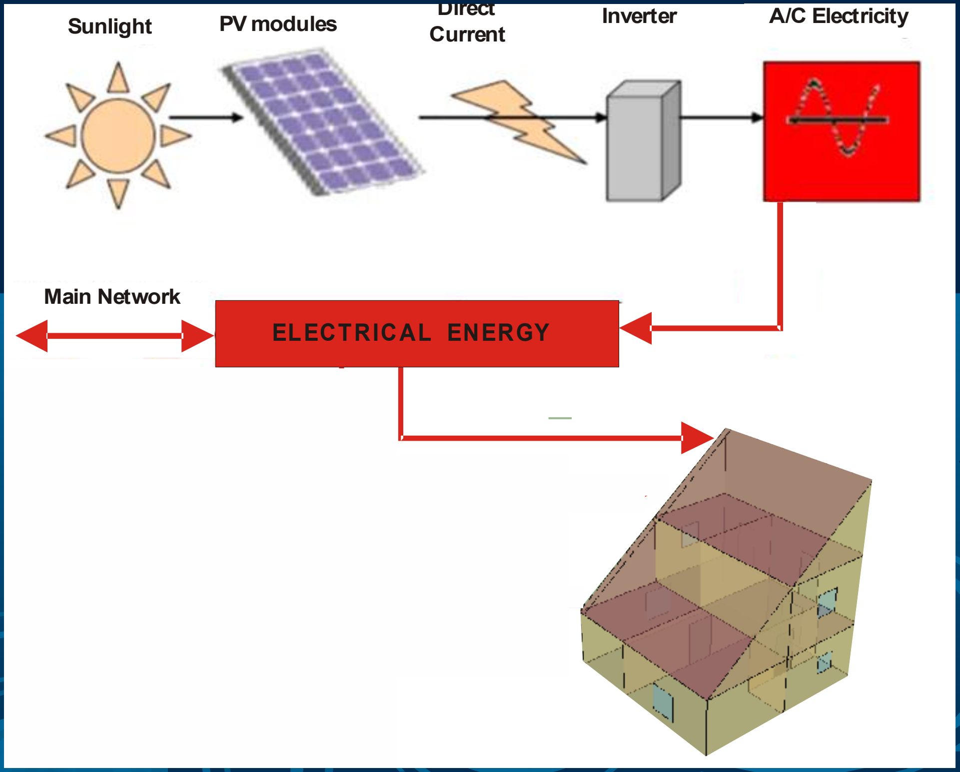

Figure 1 – Building with PV module

SIMULATION SOFTWARES AND CLIMATE

- **EnergyPlus -** simulates the energy use in a building and energy behavior of the building for defined period. Version 7.0.0 was used.
- **Open Studio plug-in in Google SketchUp -** The OpenStudio is free plug-in that adds the building energy simulation capabilities of EnergyPlus to the 3D SketchUp environment.
- **GenOpt** is an optimization program for the minimization of a cost function evaluated by an external simulation program. It has a library with adaptive Hooke-Jeeves algorithm.
- **Hooke–Jeeves Algorithm** is used for the optimization, and it is direct search and derivative free optimization algorithm.

- **WEATHER CONDITIONS** - The investigated residential building was located in the city of Kragujevac, Serbia. The city of Kragujevac has a moderate continental climate. The summers are worm and humid, with temperatures as high as 37 ^{0}C. The winters are cool and snowy, with temperatures as low as -12 ^{0}C. The EnergyPlus uses weather data from its own database file.

MATHEMATICAL MODEL

EnergyPlus Model for the residential building

- The building has the south-oriented roof area with the slope of 37.5. The PV array is installed on the roof.
- The building has two floors, 5 conditioned (heated) zones and two attic zones.

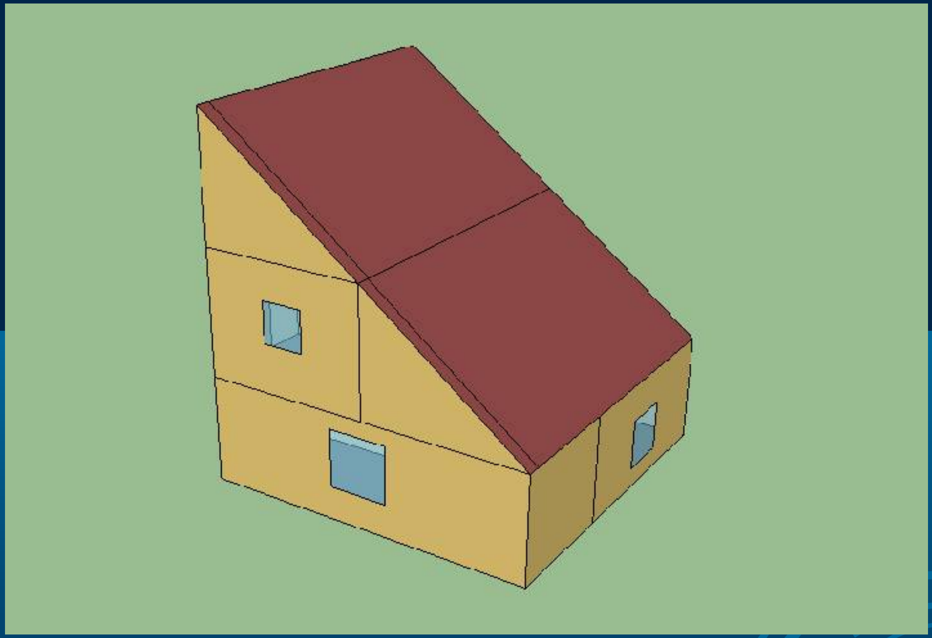

Figure 2 – Modeled residential building

- The working period of the heating systems is from October 15th to April 14th (07:00–21:00 h).
- The air temperatures in the heated rooms were set at 20^0C from 07:00-09:00 a.m. and from 4:00-9:00 p.m., and to 15^0C from 09:00 a.m.-4:00 p.m.
- The main part of electricity, in the case of the electrical heating, was consumed for electrical space heating in the building. Additionally, electricity was consumed for lighting, domestic hot water and appliances.
- In the case of district heating, the main part of electricity was consumed by appliances. Also, electricity is consumed for lighting, domestic hot water and appliances.
- The PV system consists of the PV array and an inverter. It is an on-grid system. The life time of PV array is set to 20 years. The embodied energy of PV panels is set to 3.75 GJ/m2.

Optimization procedure

- The optimization was performed with the aim to determine the optimal size of PV array, according to the buildings energy needs. Then, the primary energy consumption would be minimized.
- The value of the primary energy saving ($E_{primary,\ PV}$) consist of three parts: energy generated by PVs (E_{PV}), embodied energy of PV panels ($E_{em,PV}$) and embodied energy of thermal insulation ($E_{em,IZO}$).
- For the optimization, the following objctive function was used:

$$E_{primary,PV} = p_{EL} E_{PV} - C_m (E_{em,PV} - E_{em,IZO})$$

- $E_{primary,\ PV}$ – the yearly avoided operative primary energy consumption due to operation of the PV array (J);
- P_{EL} = 3.04 - primary conversion multiplier for electricity;
- E_{PV} – yearly electrical energy generated by PV array (J);
- $E_{em,PV}$ – PV array embodied energy (J);
- Cm=1/LC; where LC is life time, in years;
- $E_{em,\ IZO}$ – thermal insulation embodied energy (J).

- The part of the roof covered by the PV array is marked by y - ratio between PV panel area and roof area, which exists in the calculated embodied energy and electricity generated by PV array.
- The thermal insulation had the embodied energy of 86.4 MJ/kg, the density of 16 kg/m^3, and the thermal conductivity of 0.037 W/mK
- The primary energy of total building consumption is

$$E_{primary,CONS} = p_{EL} E_{EL} + p_{DH} E_{DH}$$

- E_{EL} – yearly total electricity consumption by building(J);
- P_{DH} = 2.03 - primary conversion multiplier for district heating;
- E_{DH} – yearly district heating energy consumption in a building(J);

RESULTS AND DISCUSSIONS

1. Different thermal insulation thickness

The building is investigated with different thermal insulation thickness - 0.05m, 0.10m and 0.15 m.

		Thermal insulation thickness		
		0.05 m	0.1 m	0.15 m
DH	E_{EL*} - Electricity consumption*	14.43 GJ	14.43 GJ	14.43 GJ
	E_{DH} - Space district heating energy	42.24 GJ	39.36 GJ	38.06 GJ
	E_{CONS} - Total building energy consumption	56.68 GJ	53.8 GJ	52.49 GJ
	$E_{primary,CONS}$ - Primary energy of total energy consumption	129.61 GJ	123.77 GJ	121.13 GJ
EH	E_{EL*} - Electricity consumption*	13.8 GJ	13.8 GJ	13.8 GJ
	E_{EH} - Space heating energy - electricity	42.24 GJ	39.63 GJ	38.16 GJ
	E_{CONS} - Total building energy consumption	56.64 GJ	53.43 GJ	51.96 GJ
	$E_{primary,CONS}$ - Primary energy of total energy consumption	172.18 GJ	162.43 GJ	157.87 GJ

* - electricity consumption by building includes the electricity consumption by electric equipment, lighting and domestic hot water heating

Table 1 - Energy consumption, generated electricity by PV, fraction of PV panels and avoided operative primary energy consumption of the buildings with different thermal insulation thickness

Table 2 - Building with electric heating system: yearly values of energy characteristics - energy consumption, primary energy of total energy consumption, generated electricity by PV, fraction of PV panels and avoided operative primary energy consumption of the buildings with different thermal insulation thickness

Building with electric heating system	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
E_{CONS} - Total building energy consumption	56.64 GJ	53.43 GJ	51.96 GJ
$E_{primary,CONS}$ - Primary energy of total energy consumption	**172.18 GJ**	**162.43 GJ**	**157.87 GJ**
y - Fraction of PV panels on the roof	0.99	0.99	0.99
E_{PV} - Total generated electricity by PV	52.46 GJ	52.46 GJ	52.46 GJ
$E_{PV,prim}$ - Primary energy of generated electricity	**159.48 GJ**	**159.48 GJ**	**159.48 GJ**
$E_{primary,PV}$ – maximum of avoided operative primary energy	**144.54 GJ**	**143.94 GJ**	**143.34 GJ**
$E_{PV,s}$ – electricity surplus sold	34.89 GJ	34.21 GJ	35.42 GJ
Building type (without embodied energy)	**NNEB**	**NNEB**	**PNEB**
Building type (with embodied energy)	**NNEB**	**NNEB**	**NNEB**

Table 3 - Building with district space heating system: yearly values of energy characteristics - energy consumption, primary energy of total energy consumption, generated electricity by PV, fraction of PV panels and avoided operative primary energy consumption of the buildings with different thermal insulation thickness

Building with district heating system	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
E_{CONS} - Total building energy consumption	56.68 GJ	53.8 GJ	52.49 GJ
$E_{primary,CONS}$ - Primary energy of total energy consumption	129.61 GJ	123.77 GJ	121.13 GJ
y - Fraction of PV panels on the roof	0.99	0.99	0.99
E_{PV} - Total generated electricity by PV	52.46 GJ	52.46 GJ	52.46 GJ
$E_{PV,prim}$ - Primary energy of generated electricity	159.48 GJ	159.48 GJ	159.48 GJ
$E_{primary,PV}$ – maximum of avoided operative primary energy	144.54 GJ	143.94 GJ	143.34 GJ
$E_{PV,s}$ – electricity surplus sold	43.37 GJ	43.37 GJ	43.37 GJ
Building type (without embodied energy)	PNEB	PNEB	PNEB
Building type (with embodied energy)	PNEB	PNEB	PNEB

2. Different electricity consumption in building

- In these tests, the buildings electricity consumption is varied for the building with electric space heating and for the building with district space heating.
- In the both of cases, the considered buildings has the thermal insulation thickness of 0.15 m, the monthly hot water consumption of 10 m^3 and the yearly electricity consumption by the water system was 6.52 GJ/a.

- In the case 1, building had the yearly electricity consumption of 6.26 GJ/a by the electric equipment, and 1.02 GJ/a by lighting.
- In the case 2 – case of higher electricity consumption, the considered building had higher electricity consumption by electric equipment (7.4 GJ) and lighting (1.96 GJ).

	Electric heating		District heating	
	Case 1	Case 2	Case 1	Case 2
E_{EL*} - Electricity consumption *	13.8 GJ	15.26 GJ	14.43 GJ	15.89 GJ
E_{DH} - Space district heating energy	38.16 GJ	38.16 GJ	38.06 GJ	38.06 GJ
E_{CONS} - Total building energy consumption	51.96 GJ	53.42 GJ	52.49 GJ	53.95 GJ
$E_{primary,CONS}$ - Primary energy of total energy consumption	**157.87 GJ**	**162.4 GJ**	**121.13 GJ**	**125.56 GJ**
y - Fraction of PV panels on the roof	0.99	0.99	0.99	0.99
E_{PV} - Total generated electricity by PV	52.46 GJ	52.46 GJ	52.46 GJ	52.46 GJ
$E_{PV,prim}$ - Primary energy of generated electricity	**159.48 GJ**	**159.48 GJ**	**159.48 GJ**	**159.48 GJ**
$E_{primary,PV}$ – maximum of avoided operative primary energy	**143.34 GJ**	**143.34 GJ**	**143.34 GJ**	**143.34 GJ**
Building type (without embodied energy)	**PNEB**	**NNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)	**NNEB**	**NNEB**	**PNEB**	**PNEB**

able 4 - Yearly values of energy characteristics for building with electrical heating system and building with district heating system: different electricity consumption for other electricity services

CONCLUSION

- This paper reports the investigation in low energy Serbian building optimization.
- The major aim of optimization was to determine the optimal area of PV array due to achieving the maximum avoided primary energy consumption of the buildings.
- The considered buildings had the PV array on the roof and different space heating systems.
- The investigation shows that in all cases it is the maximum roof coverage with PV arrays.
- Concept of PNEB can be achieved with or without consideration of the embodied energy. All the cases of buildinds with district heating were PNEB, while buildings with electric space heating were PNEB or NNEB.

THANK YOU FOR YOUR ATTENTION !