ELECTRICITY GENERETION AT SERBIAN ZNEB – SIZING OF REQUIRED PV PANELS AREA TO MINIMIZE THE PRIMARY ENERGY CONSUMPTION

GENERISANJE ELEKTRIČNE ENERGIJE KOD SRPSKIH KUĆA NETO-NULTE ENERGETSKE POTROŠNJE – ODREĐIVANJE POTREBNE VELIČINE FOTONAPONSKIH PANELA U CILJU MINIMIZIRANJA POTROŠNJE PRIMARNE ENERGIJE

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Abstract: Solar photovoltaic (PV) technologies are an attractive option for clean and renewable electricity generation. In this paper, the possibilities to decrease energy consumption of Serbian residential buildings are analyzed. The building with electrical energy generated by PV system is investigated. The major aim is to determine the area of the PV array in order to minimize the consumption of primary energy. The residential buildings with variable thermal insulation thickness, variable electricity consumption for electric equipment and lighting and variable hot water consumption are investigated in order to achieve zero-net energy building (ZNEB). The buildings are simulated in EnergyPlus environment. Open Studio plug-in in Google SketchUp was used for buildings design, Hooke-Jeeves algorithm for optimization and GENOPT software for software execution control. The obtained results gave the optimal size of PV array.

Keywords: ZNEB; Photovoltaic; Optimization; Simulation;

Rezime: Solarna fotonaponska (PV) tehnologija predstavlja atraktivno rešenje za čistu proizvodnju električne energije iz obnovljivih energetskih izvora. U ovom radu analizirane su mogućnosti za smanjenje potrošnje energije kod srpskih porodičnih zgrada. Istraživana je zgrada sa PV sistemom za generisanje elektične energije. Istraživane su porodične kuće sa različitom debljinom izolacije, različitom potrošnjom električne energije i različitom potrošnjom tople vode, sa ciljem postizanja koncepta neto-nulte energetske zgrade (zero net-energy building - ZNEB). Zgrade su simulirane u okruženju softvera EnergyPlus. Open Studio plug-in u Google SketchUp-u je korišćen za dizajniranje zgrade, Hooke-Jeeves algoriam za optimizaciju, a GENOPT softver za izvršnu kontrolu softvera pri optimizaciji. Dobijeni rezultati su dali optimalne vrednosti površine PV panela.

Ključne reči: Neto-nulta energetska zgrada (ZNEB); fotonaponski (PV) paneli; optimizacija; simulacija;

1. INTRODUCTION

Today, the renewable energy has a significant impact on the environment, so the research and development of renewable energy resources and the use of renewable energy is essential. The reserves of oil and gas, at current rates of consumption, would be adequate for another 40 and 60 years, respectively, and the reserves for coal could be adequate for at least the next 250 years. The problem is the global warming and increasing problem of greenhouse gases and air pollution [1].

One of the most prominent renewable energy technologies is a photovoltaic (PV) technology, which represents the direct conversion of solar radiation into electricity. The PV systems are still an expensive option for producing electricity compared to other energy sources, but, many countries support this technology.

Kapsalaki in his paper [2] says that a radical approach for the mitigation of the energy demand is the concept of the ZNEB. By definition, Zero-Net Energy Building (ZNEB) produces all energy it consumes during year, and yearly electrical energy supplied to the electricity grid balances the amount received from the electricity grid. Positive-Net Energy Building (PNEB) produces more energy than it consumes during year, and yearly electrical energy supplied to the electricity grid is higher than the amount received from the electricity grid, and Negative-Net Energy Building (NNEB) produces less energy than it consumes during the [3, 4].

In this paper, energy consumption is analyzed for a residential building located in Kragujevac, Serbia. The building is designed with PV array installed on the roof – Figure 1.

Figure 1 – Positive-Net Energy Building with PV module

Electricity generated by the PV array is limited by the size of PV array. When PV system would not directly satisfy the building needs for electrical energy, then the rest of electricity will be used from the electricity grid. When the PV system would satisfy the building electricity needs, then the rest of PV generated electricity will be fed-in the electricity grid. In buildings, energy is used for space heating and cooling, domestic hot water (DHW) heating, lighting, and electric equipment. The analyzed building has an electrical space heating system.

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. In order to achieve zero-net energy building, the buildings are investigated for variable thermal insulation thickness, variable electricity consumption by electric appliances and lighting, and variable hot water consumption.

In this paper, the EnergyPlus, Open Studio plug-in in Google SketchUp, Hooke-Jeeves algorithm, and Genopt were used to achieve this objective.

2. SIMULATION SOFTWARES AND CLIMATE

2.1 Software

EnergyPlus software simulates the energy use in a building and energy behavior of the building for defined period. In this study, the version 7.0.0 was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [5] and it has been tested using the IEA HVAC BESTEST E100-E200 series of tests [6]. For PV electricity generation, EnergyPlus uses the different component, like PV array and inverter [7].

Open Studio plug-in in Google SketchUp software is a free 3D software tool that combines a tool-set with an intelligent drawing system [8]. The software enables to place models using real world coordinates. 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 [9]. It can be coupled to any simulation program that reads its input from text files and writes its output to text files. GenOpt is written in Java so that it is platform independent. It has a library with adaptive Hooke-Jeeves algorithm.

Hooke–Jeeves optimization algorithm is used for the optimization, and it is direct search and derivative free optimization algorithm [10, 11, 12]. In this algorithm, only the objective functions and the constraint values are used to guide the search strategy. The main advantage of this algorithm is reducing the compute time.

2.2 Climate

The building located in Kragujevac, Serbia, is analyzed. The latitude of Kragujevac is 44.1^0N, and the longitude is 20.55^0E. The time zone is GMT+1.0 h. The summers are worm and humid with temperatures as high as 37^0C. The winters are cold with snow and temperatures as low as - 19^0C [3]. The EnergyPlus uses weather data from its own database file.

3. MATHEMATICAL MODEL

3.1 EnergyPlus Model for the residential building

The investigated building is shown in Figure 2. The building has the south-oriented roof with the slope of 37.5^0. On the roof, the PV array is installed. The building has two floors and 5 conditioned zones. There are two attic zones. The building accommodates a family of four. It is not surrounded with any object. The working period of the heating systems is from October 15^{th} to April 14^{th} (07:00–21:00 h). Air temperatures in the heated rooms are set to 20^0C from 07:00-09:00 and from 16:00-21:00, and to 15^0C from 09:00-16:00. The simulation time step is 15 min. The amount of infiltration is 1.5 ach^{-1}.

The building has the total floor area of 160 m^2. Total volume of conditioned zones is 264.64 m^3. Total area of external walls is 200 m^2 and total roof area is 80.6 m^2. The windows are double glazed, with the total area (including the exterior door) of 12.44 m^2. The concrete building envelope, roof and the floor are thermally insulated by polystyrene.

The main part of electricity is consumed for space heating in the building. In addition, electricity is consumed for lighting, domestic hot water (DHW), refrigerators, freezers, dishwashers, cloth washers etc.

The PV system consists of the PV array and an inverter. It is an on-grid system. The operations of the PV array and the electrical heating system are together simulated by using EnergyPlus. The life cycle of PV array is set to 20 years, and the embodied energy of PV panels is set to 3.75 GJ/m^2 [13, 14]. The main assumption is that when the PV system operates, all generated electricity would be immediately consumed. The PV panel is represented by the mathematical model of Photovoltaic:Simple from EnergyPlus [5], which describes a simple model of PV that may be useful for early phase design analysis.

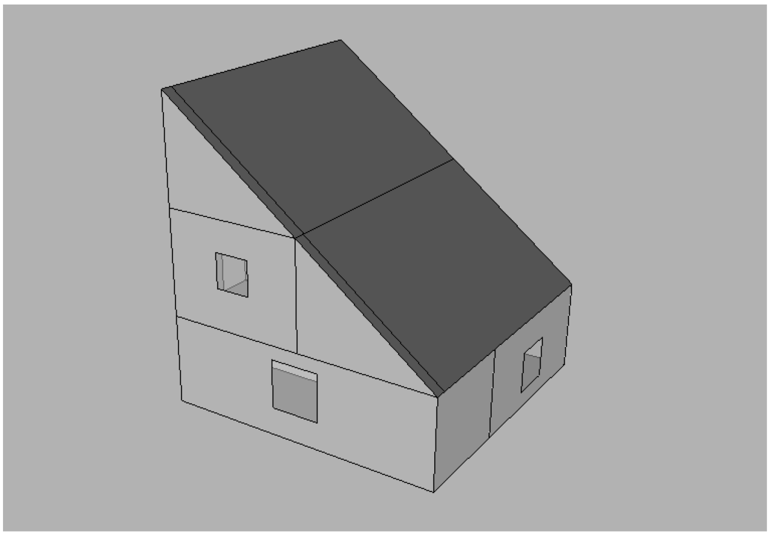

Figure 2 – Modeled residential building

3.2 Optimization procedure

In these investigations, 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 is minimized. The primary energy saving ($E_{S\text{-final},\ PV}$) consists of the primary energy covered by energy generated by PVs (E_{PV}) and embodied energy in the PV array ($E_{em,PV}$) [15]. For the optimization, the following objective function was used

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

Where: $E_{primary,\ PV}$ – the yearly avoided operative primary energy consumption due to operation of the PV array (J); p_{PV} = 3.04 - primary conversion multiplier [16]; E_{PV} – yearly electrical energy generated by PV array (J); $E_{em,\ PV}$ – PV array embodied energy (J); C_m=1/LC; where LC is life cycle, in years and $E_{em,\ IZO}$ – insultion embodied energy (J).

The part of the roof covered by the PV array is marked by y. The value y – ratio between PV panel area and roof area exists in the calculated total embodied energy and electrical energy generated by PV array.

Alsema [13, 14], reports that the energy requirement of crystalline silicon modules varies between 2400 and 7600 MJ/m^2 for mc-Si, and between 5300 and 16500 MJ/m^2 for sc-Si technology (module efficiencies 13% and 14%, respectively). Sanchez [17] reports that the total energy requirement of a frameless a-Si module is in the range of 710 - 1980 MJ/m^2 (module efficiency 7 %). Alsema [13] reports that the average PV life time is 30 years.

The thermal insulation has the embodied energy of 86.4 MJ/kg, density of 16 kg/m^3, and thermal conductivity of 0.037 W/mK [18].

4. RESULTS AND DISCUSION

The residential building is analyzed with variable thermal insulation thickness, variable electricity consumption by lighting and electric equipment, and variable hot water consumption in order to achieve PNEB and minimize the consumption of primary energy.

4.1 Different thermal insulation thickness

The thermal insulation thickness is varied to achieve ZNEB. The first case is the building with 0.05 m of thermal insulation thickness, the second case is the building with 0.10 m and the third case is the building with 0.15 m of thermal insulation thickness, respectively. Results are in Table 1.

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 (Yearly values)

	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
Total electricity consumption by building*	48.85 GJ	44.76 GJ	42.82 GJ
Space heating energy	35.05 GJ	31.26 GJ	29.01 GJ
Primary energy of total electricity consumption	148.5 GJ	136.07 GJ	130.17 GJ
Fraction of PV panels on the roof	0.99	0.99	0.99
Total generated electricity by PV	52.46 GJ	52.46 GJ	52.46 GJ
Primary energy of generated electricity	159.48 GJ	159.48 GJ	159.48 GJ
$E_{primary, PV}$ – maximum of avoided operative primary energy	144.37 GJ	143.76 GJ	143.27 GJ
Embodied energy in PV array	14.51 GJ	14.51 GJ	14.51 GJ
Embodied energy in thermal insulation	0.6 GJ	1.21	1.7 GJ
$E_{PV, S}$ – electricity surplus sold	35.61 GJ	36.33 GJ	36.69 GJ
Building type (without embodied energy)	**PNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)	**NNEB**	**PNEB**	**PNEB**

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

In all cases, the fraction of PV array on the roof is 0.99 (the system is limited by software on this value), i.e., the whole roof is covered by PV array. All the buildings are PNEB, (building type approach without embodied energy) because they produce more energy than it consumes during year. But, if we consider the embodied energy of thermal insulation and installed PV array, then, due to avoided operative primary energy consumption, the buildings will not be the PNEB. This case is also the most unfavorable case, because of electrical space heating system. If we had some another heating system, like heat pump, the situation would certainly be much batter.

4.2 Different electricity consumption in building

In these tests, the buildings electricity consumption is varied. In the case 1, the considered building has the thermal insulation thickness of 0.15 m, the hot water consumption of 10 m^3/month. Then, the distribution of the yearly electricity consumption is the following: water system 6.52 GJ/a, space heating system 29.01 GJ/a, the electric equipment 6.26 GJ/a, and lighting 1.02 GJ/a. Total building electricity consumption is 42.82 GJ/a.

In the case 2, the considered building had the same insulation thickness and hot water consumption as that in the case 1, but higher electricity consumption by electric equipment (7.4 GJ) and lighting (1.96 GJ). Then, the yearly value of electricity consumption of this building was 45.36 GJ. Results are shown in table 2.

Table 2 - Energy consumption, generated electricity by PV, fraction of PV panels and avoided operative primary energy consumption of the buildings with different electricity consumption (Yearly values)

	Electricity consumption	
	Case 1	Case 2
Total electricity consumption by building	42.82 GJ	45.36 GJ
Primary energy of total electricity consumption	130.17 GJ	137.9 GJ
Fraction of PV panels	0.99	0.99
Total generated electricity	52.46 GJ	52.46 GJ
Primary energy of generated electricity	159.48 GJ	159.48 GJ
$E_{primary, PV}$ – maximum of avoided operative primary energy	143.27 GJ	143.27 GJ
Embodied energy in PV array	14.51 GJ	14.51 GJ
Embodied energy in thermal insulation	1.7 GJ	1.7 GJ
$E_{PV, S}$ – electricity surplus sold	36.69 GJ	36.02 GJ
Building type (without embodied energy)	**PNEB**	**PNEB**
Building type (with embodied energy)	**PNEB**	**PNEB**

With the optimization procedure, the fraction of PV panels area on the roof in case 1 was 0.99 and the yearly avoided operative primary energy consumption 143.27 GJ/a (including embodied energy of thermal insulation and PV array), i. e. 159.48 GJ without embodied energy of thermal insulation and PV array. In case 2 - the fraction of PV panels area on the roof also was 0.99 and the yearly avoided primary energy consumption was as in the first case, 143.27 GJ/a (including embodied energy of insulation and PV array), i.e. 159.48 GJ without embodied energy of insulation and PV array. The both of buildings are PNEB.

4.3 Different hot water consumption

The building is investigated with the thermal insulation thickness 0.15 m. The hot water consumption is changed, and analyzed cases are with monthly hot water consumptions of 7.5 m^3, 10 m^3, 15 m^3 and 20 m^3. Results are shown in Table 3. If we consider the approach without embodied energy, all the buildings are PNEB, because they produce more energy than it consumes during year. The fraction of PV panels on the roof is 0.99. If we consider the embodied energy of thermal insulation and installed PV array, then all the buildings will not be PNEB – the building with the higher hot water consumption will be NNEB.

Table 3 - Energy consumption, generated electricity by PV, fraction of PV panels and avoided primary energy consumption of the buildings with different hot water consumption (Yearly values)

	Hot water consumption			
	7.5 m^3	10 m^3	15 m^3	20 m^3
Total electricity consumption	41.19 GJ	42.82 GJ	46.08 GJ	49.34 GJ
Electricity consumption for water heating	4.89 GJ	6.52 GJ	9.78 GJ	13,05 GJ
Primary energy of electricity consumption	125.21 GJ	130.17 GJ	140.08 GJ	150 GJ
Fraction of PV panels	0.99	0.99	0.99	0.99
Total generated electricity	52.46 GJ	52.46 GJ	52.46 GJ	52.46 GJ
Generated electricity as final energy	159.48 GJ	159.48 GJ	159.48 GJ	159.48 GJ
$E_{primary, PV}$ – maximum of avoided operative primary energy	143.27 GJ	143.27 GJ	143.27 GJ	143.27 GJ
Embodied energy of PV array	14.51 GJ	14.51 GJ	14.51 GJ	14.51 GJ
Insulation embodied energy	1.7 GJ	1.7 GJ	1.7 GJ	1.7 GJ
Building type (without embodied energy)	**PNEB**	**PNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)	**PNEB**	**PNEB**	**PNEB**	**NNEB**

5. CONCLUSION

This paper reports the investigation in low energy Serbian house optimization. The major aim of optimization procedure was to determine optimal area of PV array due to achieving the maximum avoided primary energy consumption due to installation and operation of PV array. The investigation shows that in all cases it is the maximum roof coverage with PV arrays. Also, PNEB can be achieved with or without consideration of embodied energy.

The building with the smaller thermal insulation thickness (0.05 m) is PNEB without embodied energy, but if we consider the embodied energy of PV array and thermal insulation, then it is NNEB. The other buildings with the higher thermal insulation thickness are PNEB in both of cases.

Buildings with different electricity consumption are PNEB, with or without embodied energy.

Also, wall the buildings with different hot water consumption are PNEB (without embodied energy). If we consider the embodied energy, only the building with the higher hot water consumption is NNEB, and the other buildings are PNEB.

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