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

ENERGETSKA OPTIMIZACIJA SRPSKIH KUĆA SA FOTONAPONSKIM PANELIMA I RAZLIČITIM GREJNIM SISTEMIMA

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Today, renewable energy plays an elementary role in resolving environmental pollution and global warming problems. Solar energy has become a promising alternative source due to its advantages: abundance, pollution free, and renewability. In this paper, possibilities to decrease energy consumption of residential buildings are analyzed. The buildings with electrical energy generated by PV system and different space heating systems (electric heating, district heating) are investigated. The major aims are to determine the area of the PV array installed on the roof and to minimize the energy consumption. Then, it is possible to achieve the zero-net energy building (ZNEB) or positive-net energy building (PNEB). The buildings were 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 during optimization.

Keywords: *ZNEB; Photovoltaic; Heating system, Optimization; Simulation*

Obnovljivi izvori energije danas imaju elementarnu ulogu u rešavanju problema zagadjenja zivotne sredine i i globalnog zagrevanja. Solarna energija je postala vodeći izvor obnovljive energije, zbog svojih prednosti: neiscrpnog izvora, osobine da ne zagadjuje životnu sredinu i obnovljivosti. U ovom radu analizirane su mogućnosti za smanjenje potrošnje energije kod porodičnih zgrada. Istraživana je zgrada sa PV sistemom za generisanje električne energije i sa različitim sistemima grejanja (električno grejanje, daljinsko grejanje). Glavni cilj istraživanja je da se odredi potrebna veličina PV panela, instaliranih na krovu zgrade, i da se minimizira potrošnja energije. Na taj način, moguće je dostići koncept neto-nulte energetske zgrade (zero net-energy building - ZNEB) ili neto-pozitivne energetske zgrade (positive 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 algoritam za optimizaciju, a GENOPT softver za izvršnu kontrolu softvera pri optimizaciji.

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

1. INTRODUCTION

The research and development of renewable energy resources and use have significant impact on the environment nowadays. The reasons for that are lower world reserves of oil, gas and coal, and, also, the increasing problems of global warming, greenhouse gases and air pollution [1].

An attractive option for clean and renewable electricity generation is solar photovoltaic (PV) technology. This technology represents the direct conversion of solar radiation into electricity. The PV systems are still an expensive option for producing electricity compared to other energy systems, but, many countries support this technology.

In Serbia, the building sector consumes more than 50% of the used energy. Around 24% of the total building floor area is heated by electricity [2]. 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 [3]. 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). However, a negative-net energy building (NNEB) may exist, and should be recognized and avoided.

In the recent years, many of scientists defined ZNEB, PNEB, and NNEB [4]. By definition, ZNEB produces all energy it consumes during year, and the yearly electrical energy supplied to the electricity grid balances that received from the electricity grid. The PNEB produces more energy than it consumes during year, and the yearly electrical energy supplied to the electricity grid is higher than that received from the electricity grid. The NNEB produces less energy than it consumes during the year and the yearly electrical energy supplied to the electricity grid is lower than that received from the electricity grid [3, 5].

In this paper, energy consumption is analyzed for a residential building with PV array installed on the roof - Figure 1 [6].

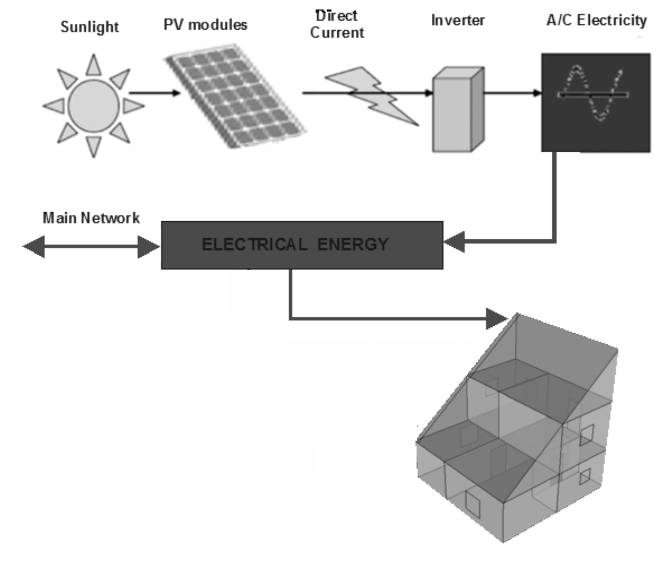

Figure 1 – Building with PV module

From solar energy, the building may usually produce electrical energy by the PV array on its roof. The generated electricity may feed either the building or the electricity grid. The main task for building design is to minimize the energy consumption of the building. This would minimize the required energy generation and the surface area required for the energy generation. In ZNEBs and PNEBs, energy may be used for space heating, space cooling, DHW heating, lighting, and appliances. In such buildings, their envelope should minimize heat transfer. In cold climate, the building envelope has to be super thermally insulated and air tight.

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, 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. When the 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 their PV system would satisfy the building needs for electrical energy, then the rest of PV generated electricity will be fed-in the electricity grid.

The investigated buildings were located in Kragujevac, Serbia. In these buildings, electricity was used to satisfy energy needs for space heating, lighting, appliances, and DHW heating. In these simulations, the heating devices would operate from 15 October to 14 April next year that is valid in practice for entire Serbia.

For these buildings, the paper will comment on consumption and generation of electrical energy by them. This will be reported for the entire year. In addition, the article will report the size of PV array and building type (ZNEB, PNEB or NNEB).

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.

2. SIMULATION SOFTWARES

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 [7] and it has been tested using the IEA HVAC BESTEST E100-E200 series of tests [8]. For PV electricity generation, EnergyPlus uses the different component, like PV array and inverter [9].

Open Studio plug-in in Google SketchUp software is a free 3D software tool that combines a tool-set with an intelligent drawing system [10]. 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 [11]. It can be coupled to any simulation program that reads its input from text files and writes its output to text files. GenOpt 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 [12, 13, 14]. 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 a reduction in computing time.

3. WEATHER CONDITIONS

The investigated residential building was located in the city of Kragujevac. Kragujevac lays in Balkan Peninsula in state of Serbia, around 120 km south of its capital city of Belgrade. Its average height is 209 m above sea-level. Its latitude is $44^0$10N, longitude $20^0$550E, and time zone GMT + 1.0 h. The city of Kragujevac has a moderate continental climate with a gradual transition between the four distinct seasons (winter, spring, summer, and autumn). 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.

4. MATHEMATICAL MODEL

4.1 EnergyPlus model for the residential building

The modeled residential building is shown in Figure 2. The building had the south-oriented roof with the slope o f 37.5^0, with installed PV array on its roof. The building had two floors and 5 conditioned zones. The air temperatures in the heated rooms were set at 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 was 15 min.

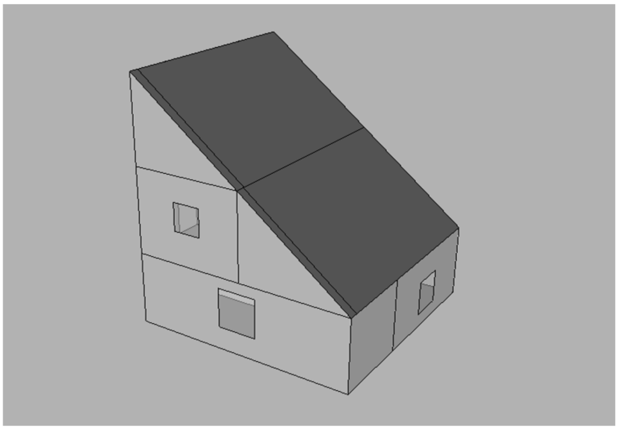

Figure 2 – Modeled residential building

The total floor area of the building was 160 m^2 and total roof area 80.6 m^2. The windows were double glazed. The concrete building envelope, roof, and the floor were thermally insulated by polystyrene. In this investigation, the polystyrene thickness was varied. It was 0.05 m, 0.1m, and 0.15m.

The main part of electricity, in the case of the electrical heating, was consumed for electrical space heating in the building (E_{EH}). Additionally, electricity was consumed for lighting, domestic hot water (DHW), and appliances (E_{EL*}). In the case of district heating, the main part of electricity was consumed by appliances. District heating energy is marked with E_{DH}.

The PV system consisted of the PV array and an inverter. It was an on-grid system. The life cycle of PV array was set to 20 years, and the embodied energy of PV panels to 3.75 GJ/m^2 [15, 16]. The PV panel was represented by the mathematical model of Photovoltaic: Simple from EnergyPlus [7].

4.2 Optimization procedure

According to the buildings energy needs, the mathematical optimization was performed. This optimization had the major goal to determine the optimal size of PV array, which will yield the minimal primary energy consumption of the building. The primary energy saving ($E_{primary,\ PV}$) consists of the primary energy covered by energy generated by PVs (E_{PV}), embodied energy in the PV array ($E_{em,PV}$), embodied energy of the thermal insulation ($E_{em,IZO}$) and embodied district heating energy. For the optimization, the following objective function was used

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

where: $E_{primary,\ PV}$ stands for the yearly avoided operative primary energy consumption due to operation of the PV array (J), p_{EL} = 3.04 stands for the primary conversion multiplier for electricity [17], E_{PV} stands for the yearly electrical energy generated by PV array (J), $E_{em,\ PV}$ – PV array embodied energy (J), C_m=1/LC; LC stands for the life cycle (years) and $E_{em,\ IZO}$ stands for the thermal insulation embodied energy (J).

The primary energy of total building consumption is

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

where E_{EL} stands for the yearly total electricity consumption by building (J); p_{DH}=2.03 stands for the primary conversion multiplier for district heating [17] and E_{DH} stands for the yearly district heating energy consumption in a building (J).

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

Alsema [15, 16] reported that the embodied energy in 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 (the module efficiencies were 13% and 14%, respectively). Sanchez [18] reported that the embodied energy in a frameless a-Si module was in the range of 710 - 1980 MJ/m^2 (the module efficiency of 7 %). Alsema [15] reported that the average PV life time was 30 years.

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 [19].

5. RESULTS AND DISCUSSION

The residential building was analyzed with variable thermal insulation thickness and different space heating systems – electrical heating and district heating, to achieve PNEB and minimize the consumption of primary energy.

5.1 Different thermal insulation thickness

To achieve the PNEB, the thermal insulation thickness was varied for the residential building with electric space heating (EH) and for the residential building with district space heating (DH). For each building, three cases were investigated. The first case was the building with 0.05 m, the second case with 0.10 m and the third case with 0.15 m of thermal insulation thickness.

Table 1 represents the total building energy consumption (E_{CONS}) and primary energy of E_{CONS} for all cases ($E_{primary,\ CONS}$). It is found that building with electrical space heating has higher values of primary energy of total energy consumption than that with the building with district heating system (for any value of thermal insulation thickness) – Figure 3, Figure 4.

The fraction of PV array on the roof was 0.99 in all cases, (the system is limited by software on this value), i.e., the whole roof was covered by the PV array. All the buildings with electric heating systems are NNEB (building type approach with taking in account the embodied energy). However, if the embodied energy of thermal insulation and installed PV array is not considered, then, due to the avoided operative primary energy consumption, the buildings will not be the NNEB (Table 2, Table 3) - the building with the highest value of thermal insulation thickness (0.15 m) will be PNEB. Each building with district heating system was a PNEB, (building type approach with or without taking in account the embodied energy) because it produces more energy than it consumes during year.

The building with electrical heating is the most unfavorable case, because of the high amount electricity consumption [6]. The building with district space heating has lower energy consumption, so for each thermal insulation thickness, all the buildings will be PNEB. In addition, the surplus electricity is higher at the buildings with district heating system.

Table 1 –Electricity consumption, space heating energy, total building energy consumption and primary energy consumption of the buildings with different thermal insulation thickness (Yearly)

		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

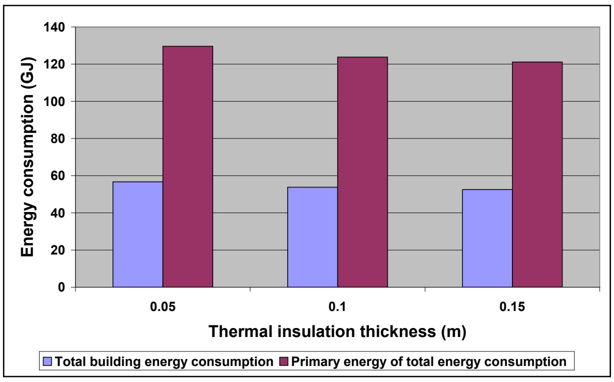

Figure 3 –Energy consumption for building with district space heating

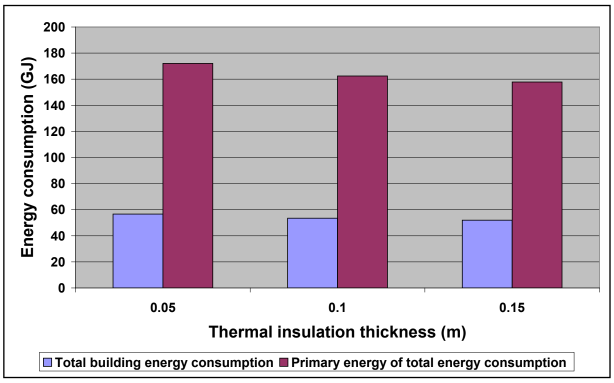

Figure 4 –Energy consumption for building with electrical space heating

Table 3 - Building with electric heating system: yearly values of energy characteristics

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			
E_{PV} - Total generated electricity by PV	0.99	0.99	0.99
$E_{PV,prim}$ - Primary energy of generated electricity	52.46 GJ	52.46 GJ	52.46 GJ
$E_{primary,PV}$ – maximum of avoided operative primary energy	**159.48 GJ**	**159.48 GJ**	**159.48 GJ**
$E_{PV,S}$ – electricity surplus sold	**144.54 GJ**	**143.94 GJ**	**143.34 GJ**
	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 4 - Building with district heating system: yearly values of energy characteristics

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			
E_{PV} - Total generated electricity by PV	0.99	0.99	0.99
$E_{PV,prim}$ - Primary energy of generated electricity	52.46 GJ	52.46 GJ	52.46 GJ
$E_{primary,PV}$ – maximum of avoided operative primary energy	**159.48 GJ**	**159.48 GJ**	**159.48 GJ**
$E_{PV,S}$ – electricity surplus sold	**144.54 GJ**	**143.94 GJ**	**143.34 GJ**
	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**

5.2 Different electricity consumption in residential buildings

The analyzed buildings were heated either by electricity or by district heating. In addition, they had different electricity consumption for other electricity services. Each building had the thermal insulation thickness of 0.15 m, the hot water consumption of 10 m^3/month, where the yearly electricity consumption by the water system was 6.52 GJ/a.

In the case 1, the considered 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, the considered building had higher electricity consumption by electric equipment (7.4 GJ) and lighting (1.96 GJ). The results were shown in Table 5.

Table 5 – Yearly values of energy characteristics for building with electrical heating system and building with district heating system: different electricity consumption for other electricity services

	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** **PNEB**	**143.34 GJ** **NNEB**	**143.34 GJ** **PNEB**	**143.34 GJ** **PNEB**
Building type (without embodied energy)	**NNEB**	**NNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)				

In all cases, the fraction of PV panels area on the roof y=0.99 and the yearly avoided operative primary energy consumption 143.34 GJ/a (including the embodied energy of thermal insulation and PV array), i. e. 159.48 GJ without the embodied energy of thermal insulation and PV array were obtained. All buildings with district heating are PNEB. Building with electric space heating and lower electricity consumption is PNEB if it is not taking in account the embodied energy, and NNEB if it is taking in account the embodied energy. Building with electric space heating and higher electricity consumption is NNEB (with or without consideration of embodied energy).

6. CONCLUSION

The major aim of this investigation was optimization 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 showed that in all cases there was the maximum roof coverage with PV arrays. Also, PNEB can be achieved with or without consideration of the embodied energy.

The building with electric space heating (unfavorable case) and the smallest thermal insulation thickness (0.05 m) was the NNEB with or without a consideration of embodied energy, but the building with electric space heating and the bigest thermal insulation thickness (0.15 m) was the PNEB without a consideration of the embodied energy in PV array and thermal insulation and NNEB with a consideration of the embodied energy in PV array and thermal insulation. All the buildings with district space heating were the PNEB in any case of thermall insulation thickness.

The buildings with district space heating and different electricity consumption were PNEB, with or without embodied energy. Building with electric space heating and lower electricity consumption was PNEB without consideration of embodied energy, and NNEB with consideration of embodied energy. If the electicity consumption is higher, this building will be NNEB (boath approach).

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