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ENERGY OPTIMIZATION OF SERBIAN BUILDINGS WITH PV PANELS AND DISTRICT HEATING SYSTEM

Danijela Nikolic[1], Milorad Bojic[2], Jasna Radulovic[3], Jasmina Skerlic[4], Saša Jovanović[5]

Summary: *Nowadays, for clean and renewable electricity generation, solar photovoltaic technologies is the best option. Solar energy has become a promising alternative source due to its advantages: abundance, pollution free and renewability. In this paper, the possibilities to decrease energy consumption of Serbian residential buildings are analyzed. The building with district space heating and electrical energy generated by PV system is investigated. The major aim is to determine the area of the PV array in order to minimize primary energy consumption. The residential buildings with variable thermal insulation thickness and variable electricity consumption are investigated in order to achieve zero- (ZNEB) or positive-net energy building (PNEB). 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.*

Key words: *PNEB; Photovoltaic; District heating system, Optimization; Simulation.*

1. INTRODUCTION

Today, the renewable energy systems have a significant impact on the environment, so the development of renewable energy resources and the use of renewable energy is essential. One of the more promising renewable energy technologies is photovoltaic (PV) energy conversion. PV energy conversion represents the direct conversion of sunlight into electricity. PV systems are still an expensive option for producing electricity compared to other energy sources, but many countries support this technology. Over the last five years, the global PV industry has grown more than 40% each year [1].

Kapsalaki says that a radical approach for the mitigation of the energy demand is the concept of the ZNEB [2]. By definition, Zero-Net Energy Building (ZNEB) produces all

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energy it consumes during year, while Positive-Net Energy Building (PNEB) produces more energy than it consumes during year. Negative-Net Energy Building (NNEB) produces less energy than it consumes during year [3].

In this paper, it is analyzed the energy consumption in residential building with district heating system, located in Kragujevac, Serbia. The building is designed with PV panels installed on the roof – Figure 1. Electricity generated by the PV array is limited with 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 needs for electrical energy, then the rest of PV generated electricity will be fed-in the electricity grid.

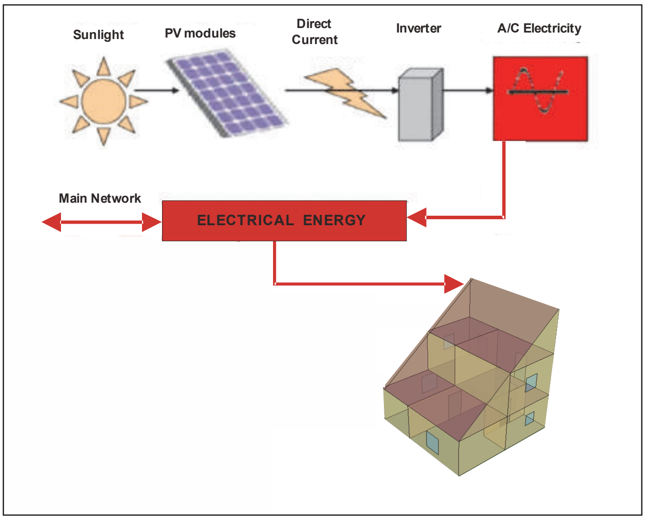

Figure 1 *Positive-Net Energy Building with PV module*

The major aim of this investigation is determining the portion of PV panels on the roof and, on that way, to minimize the primary energy consumption.

2. SIMULATION SOFTWARES AND WEATHER CONDITIONS

EnergyPlus software may be used for simulation of heating, cooling, ventilating, lighting and other energy and mass flows in the buildings. In this study, the version 7.0.0 was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA and it has been tested using the IEA HVAC BESTEST E100-E200 series of tests. For PV electricity generation, EnergyPlus uses the different component, like PV array and inverter [3].

Open Studio plug-in in Google SketchUp software - Google SketchUp is a free 3D software tool that combines a tool-set with an intelligent drawing system. 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. The software allows to the user to create, edit and view EnergyPlus input files within SketchUp [4].

GenOpt is an optimization program for the minimization of cost function evaluated by an external simulation program. GenOpt serves for optimization problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. 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 [4].
Climate - It is analyzed the building located in Kragujevac, Serbia. The latitude of Kragujevac is 44.1^{0}N, and the longitude is 20.55^{0}E. The time zone is GMT + 1.0 h. The summers are worm and humid with temperatures as high as 37^{0}C. The winters are cool with snow and temperatures as low as -19^{0}C. The EnergyPlus uses weather data from its own data base with weather file

3. MATHEMATICAL MODEL

3.1 EnergyPlus Model for modeled building

The modeled residential building is shown in Figure 2. The building has the south-oriented roof with a slope of 37.5^0, and PV array installed on the roof. The building has two floors and 6 conditioned zones. Air temperatures in the heated rooms are set to 20^{0}C from 07:00-09:00 and from 16:00-21:00, and to 15^{0}C from 09:00-16:00. The simulation time step is 15 min.

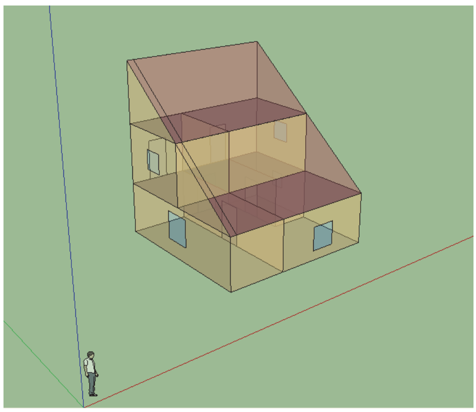

Fig 2 *Modeled residential building*

The total floor area of the building is 160 m^2 and total roof area 80.6 m^2. The windows are 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. Electricity is 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 [5]. The thermal insulation embodied energy is 86.4 MJ/kg, the density is 16 kg/m^3, and the thermal conductivity is 0.037 W/mK [6].

3.2 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, and on that way to minimize primary energy consumption. 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 ($E_{em,PV}$), and embodied energy of the thermal insulation ($E_{em,IZO}$). For the optimization, the next objective function was used [4]:

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

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 [7], E_{PV} stands for the yearly generated electricity 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 gas heating and E_{DH} stands for the yearly district heating energy consumption in a building (J) [7]. The roof area covered by the PV array is marked by y. The value y exists in the calculated total embodied energy and electrical energy generated by PV.

4. RESULT AND DISCUSSION

4.1 Different thermal insulation thickness

To achieve the PNEB, the thermal insulation thickness was varied for the residential building with district space heating (DH). Three cases were investigated - 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} ($E_{primary,\ CONS}$).

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

	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
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 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

Figure 3 represent energy consumption for building with district space heating system. 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.

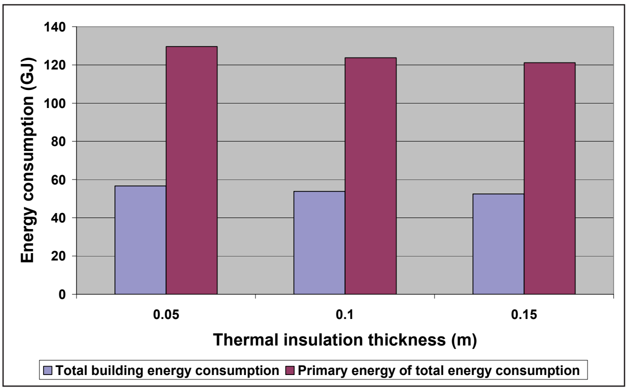

Fig 3 *Energy consumption for building with district heating system*

All the buildings with district heating are PNEB (building type approach with and without taking in account the embodied energy) - Table 2. Each building produces more energy than it consumes during year.

Table 2 *Building with district heating system: Energy consumption, generated electricity by PV, fraction of PV panels and avoided operative primary energy consumption of the buildings with different thermal insulation thickness*

	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
$E_{primary,CONS}$ - Primary en. 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
$E_{PV,prim}$ – Generated primary energy	**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**
Building type (without embodied en.)	**PNEB**	**PNEB**	**PNEB**
Building type (with embodied en.)	**PNEB**	**PNEB**	**PNEB**

4.2 Different electricity consumption

In these simulations, the analyzed buildings had different electricity consumption for 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 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 Case 2, the considered building had higher electricity consumption by electric equipment (7.4 GJ) and lighting (1.96 GJ). The results are in Table 3. In all cases, the fraction of PV panels on the roof is y=0.99 and the avoided operative primary energy consumption 143.34 GJ/a (including the embodied energy of thermal insulation and PV), i. e. 159.48 GJ without the embodied energy of thermal insulation and PV array were obtained. All buildings are PNEB.

Table 3 *Yearly values of energy characteristics for building with gas heating system: different electricity consumption for other electricity services*

	Case 1	Case 2
$E_{primary,CONS}$ - Primary energy consumption	**121.13 GJ**	**125.56 GJ**
y - Fraction of PV panels on the roof	0.99	0.99
E_{PV} - Total generated electricity by PV	52.46 GJ	52.46 GJ
$E_{PV,prim}$ - Generated primary energy	**159.48 GJ**	**159.48 GJ**
$E_{primary,PV}$ – maximum of avoided prim. en.	**143.34 GJ**	**143.34 GJ**
Building type (without emb. energy)	**PNEB**	**PNEB**
Building type (with emb. energy)	**PNEB**	**PNEB**

5. 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 investigation shows that in all cases it is the maximum roof coverage with PV arrays. All the buildings were PNEB - with or without consideration of embodied energy. All the buildings with district space heating were the PNEB in any case of thermal insulation thickness and electricity consumption.

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