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CONTENT

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Influence of solar fraction on photovoltaic generated energy at Serbian residential building

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Abstract *In buildings, which are large consumers of energy, it is necessary to use technologies of renewable energy sources. One of the best solutions is solar energy, because solar energy is the most promising and reliable energy source, due to its clean and inexhaustible energy source that does not cause pollution. This paper analyzes the energy consumption in a single-family residential building with photovoltaic array. Electricity in the building is used for space heating, lighting, DHW system and electrical appliances. Energy consumption and energy generation data were obtained by simulations performed in the EnergyPlus software, while building was designed in Open Studio plug-in for Google Sketch Up. The analyzed building has located in the city of Kragujevac. This investigation shows the possibility for energy saving in residential Serbian building, with variable solar fraction at photovoltaic array and variable cell efficiency of photovoltaics. Obtained results also shown that concept of Positive net-energy building concept (PNEB) can be achieved, with solar fraction of 0.85, PV cell efficiency of 16 % and proper PV surface area.*

Keywords *building, photovoltaic, solar fraction, generated energy, energy saving*

1. INTRODUCTION

Today, building sector consumes about 40% of total energy consumption in a modern world, while in Serbia this amount is as much as 50% [1]. Buildings energy consumption is related to their exploitation conditions. The largest energy consumer is heating system, then domestic hot water system, electrical appliances and lighting.

Concept of energy efficiency building can reduce energy consumption. Energy efficient building means a lower total energy consumption, lower greenhouse gas emission and partially or completely satisfying energy needs with the energy generated by its own systems of renewable energy sources. These sources do not pollute the environment, which directly contribute to the global warming reduction through lower greenhouse gas emission [2, 3]. Systems of renewable energy generates electrical or thermal energy, and on that way they contribute also to the longer life cycle of the building.

Solar energy is the most promising source of renewable energy and represents the most reliable source of energy because it does not bring pollution, which is disproportionately large in the use of fossil fuels [4]. Photovoltaic (PV) technology represents the direct conversion of solar radiation into electricity. The PV system generates electricity for space heating, lighting, electrical appliances, etc. The rest of the building energy needs are compensated by purchasing electrical energy from the electricity distribution system.

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This article reports investigations of the possibilities to decrease energy consumption of Serbian single-family residential buildings with PV array and electric heating systems, through the variation of PV array surface (one or/and two roof surface with PV panels), solar fraction and photovoltaic cell efficiency. The investigated building was located in the city of Kragujevac, Serbia. The building is designed with PV panels on the roof. Electricity generated by the PV array is limited with the size of PV array. Heating system operated from 15 October to 14 April next year. The major objective of this investigation is to determine energy savings in the building when PV array has different cell efficiency and different solar fraction. In this paper, the EnergyPlus software and Open Studio plug-in in Google SketchUp were used.
The analysis show various parameters such as total energy consumption, energy consumption in heating energy consumption, and generated energy by PV array.

2. MODEL OF ANALYZED BUILDING

The modelled single-family residential building is shown in Figures 1 and 2. It is two-store building and it has 10 conditioned zones (2 living rooms with kitchens, 2 halls, 2 bathrooms and 4 bedrooms). The building also has an attic zone.

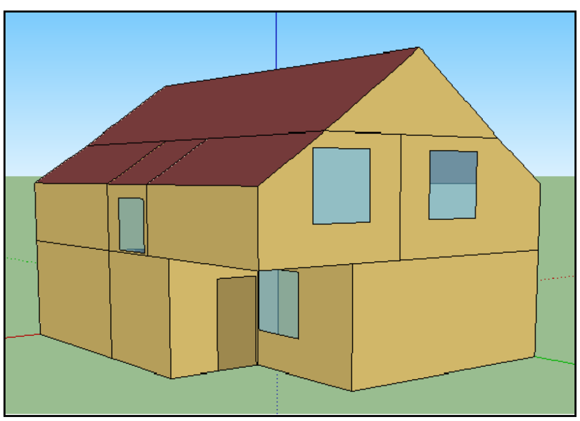

Fig. 1. Modeled building in EnergyPlus

The total floor area of the building is 169 m^2. First floor has the area of 77 m^2, while second floor has the area of 92 m^2. The windows are double glazed with the air gap of 15 mm with the U-value of 2.72 W/(m^{2}K). Inward opening side-hung windows are implemented in modelled buildings.
The building envelope and roof are thermally insulated by polystyrene (thermal insulation thickness - 0.15 m). The building has the south and north oriented roof with a slope of 37.5^0, which is the optimal orientation for slope of solar systems in the region of the Kragujevac [5]. The total roof area (both identical sides) is 114 m^2. The external wall consists of brick, heavy concrete, insulation, air space and gypsum board, with U value 0.177 W/(m^{2}K). The inner wall consists of two layers of gypsum boards with air space between them. The floor construction consists of lightweight concrete, air layer and acoustic plate, U value 0.517 W/(m^{2}K). The ceiling consists of lightweight concrete, air space and an acoustic plate. Above the ceiling is the non-conditioned attic zone.

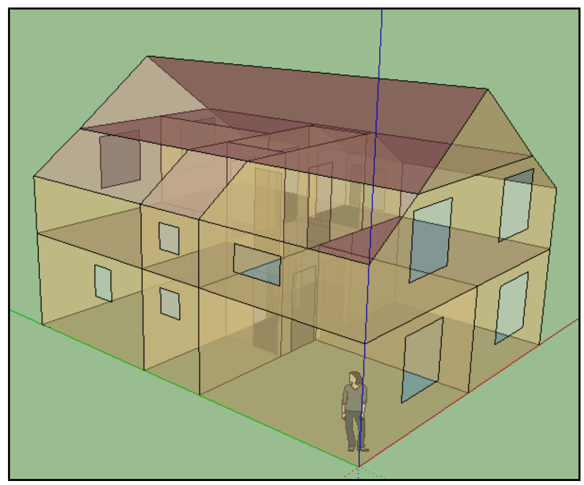

Fig. 2. Modelled building in EnergyPlus - X ray view

The building was simulated through a one year. Heating system (with an electric baseboard heater in every conditioned) operates from October 15 to April 15, which is a common practice in Serbia. Air temperatures in the heated zones 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.

3. LOCATION AND CLIMATE

The analyzed building is located in the city of Kragujevac, Serbia. Kragujevac belong to Sumadija region - the central part of the Republic of Serbia. Its average height above sea level is 209 m. Its latitude is 44^{0}10 N and

longitude 20°55 E. The time zone for Kragujevac is GMT+1 h. Kragujevac has a moderate climate, with warm and humid summers, and cold and snowy winters [6].
The EnergyPlus uses weather data from its own database file. This database input file has a large variety of parameters for solar radiation calculating for every day in the year. Daily average solar radiation for Central Serbia, where the analysed house is located, is 1550 kWh/m² [7].

4. MODEL OF PV SYSTEM

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. Photovoltaic system is installed on the roof of the building (slope angle of 37.5°). Photovoltaic cell efficiency initially set as 12 %. Through the simulations, PV cell efficiency varied, and it was 16 %. Solar fraction at the first moment was 0.5; in the further simulations it was 0.85. The area of considered PV array was 14 m². Through different simulations, PV array is considered on south or north roof side (or both of them).
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 [6], which describes a simple model of PV that may be useful for early phase design analysis. This model allows quick and easy modifications during the simulation routines. The user can set up value for cell efficiency, area and solar fraction [6].

5. RESULTS AND DISSCUSSION

5.1 Building energy consumption

The amount of energy consumption in the analysed single-family residential building is obtained by simulations in software package EnergyPlus (Table 1).
The results show the annually energy consumption for heating system, domestic hot water system, electrical equipment and lighting, as well as the total final energy consumption.
The largest part of energy consumption (electricity) is related to the heating system (6610 kWh), then to the domestic hot water system (3702 kWh). Electrical appliances consume 2357 kWh and lighting consumes 578 kWh annually. Total yearly building energy consumption is 13247 kWh.

Table 1. Energy consumption in building

Energy consumption (kWh)	
Heating	6610
Lighting	578
Electric equipment	2357
DHW system	3702
Total energy consumption	**13247**

Figure 3 shows the distribution of building energy consumption, in kWh and %. The largest share of energy, 50%, is spent in heating system, then 28% on DHW system. Electrical equipment and lighting spent 8 % and 1 % of total energy consumption, respectively.

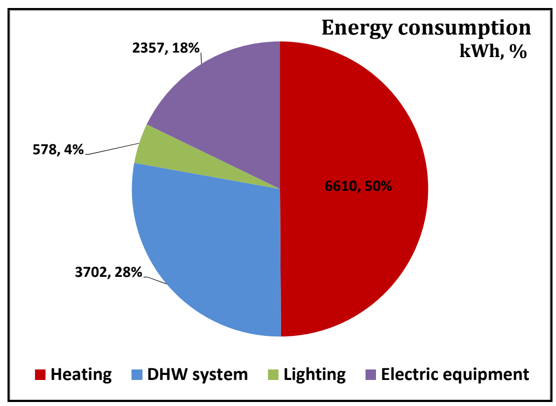

Fig. 3. Distribution of building energy consumption

5.2 Case 1 – 12 % PV cell efficiency, SF 0.5

Case 1 represents the case of 12 % PV cell efficiency. Solar fraction (SF) is 0.5. This value of solar fraction can be explained with shading PV array by other buildings or trees, in combination with presence of dirtiness, or incomplete function of the PV panel due to its damage (hot spot, high temperature, etc.).
Case 1a presents PV array installed at the south roof, Case 1b presents PV array installed at the north roof, and Case 1c presents PV array installed at the complete roof.
Figure 4 shows generated energy by PV array, building energy consumption and building net-

energy consumption. In a Case 1a – with PV array on the south roof, 1731.3 kWh of electricity can be generated, which means that the net-energy consumption in the building is 11515.7 kWh. In a Case 1b – with PV array on the north roof, 1206.7 kWh of electricity can be generated, so net-energy consumption is 12040.3 kWh. When PV array is installed to the both roof sides (Case 1c), generated electricity is 2938 kWh, and net-energy consumption is 10309 kWh. With installing the greater PV array, the amount of generated electricity increases and net-energy consumption decreases, so in the Case 1c, net-energy consumption is lower for 22.2 %, compared to the building without PV array.

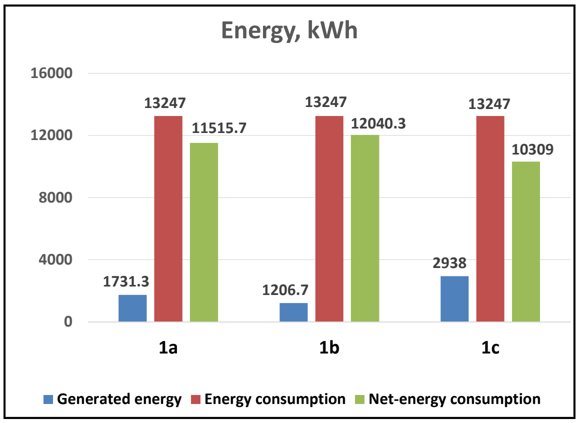

Fig. 4. Case 1 - building energy consumption and generated energy

5.3 Case 2 – 12 % PV cell efficiency, SF 0.85

Case 2 represents the case of 12 % PV cell efficiency and solar fraction of 0.85. Case 2a presents PV array installed at the south roof, Case 2b presents PV array installed at the north roof, and Case 2c presents PV array installed at the complete roof.
The higher value of solar fraction influence to the amount of generated energy. With the solar fraction increasing, generated electricity is increasing too, and building net-energy consumption is decreasing (Figure 5).
In a Case 2a – with SF of 0.85 and PV array on the south roof, the amount of 2943.2 kWh of electricity can be generated, and net-energy consumption in the building is 10303.8 kWh. In a Case 2b – with SF of 0.85 and PV array on the north roof, 2051.4 kWh of electricity can be generated, while net-energy consumption is 11195.6 kWh. When PV array is installed to the both roof sides (Case 2c) and solar fraction is 0.85, generated electricity is 4994.6 kWh, and net-energy consumption is 8252.4 kWh. With higher solar fraction and with installing the PV array of greater surface area, the generated energy increases and net-energy consumption decreases (Figure 5). Compared to the building without PV array, net-energy consumption is lower for 22.2 %, 15.5% and 37.7% for Case 2a, 2b and 2c, respectively.

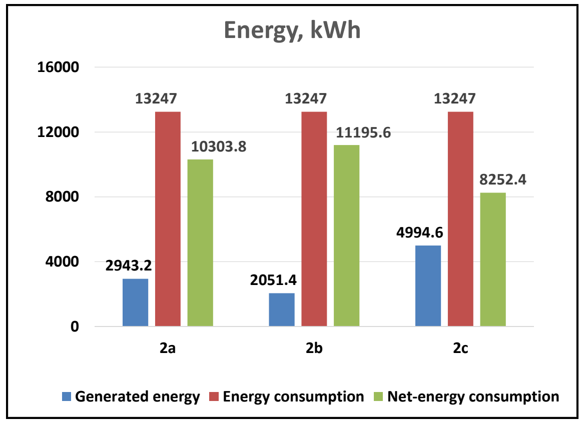

Fig. 5. Case 2 – building energy consumption and generated energy

5.4 Case 3 – 16 % PV cell efficiency, SF 0.85

Case 3 represents the case of 16 % PV cell efficiency and solar fraction of 0.85. As in previous cases, here, Case 3a presents PV array installed at the south roof, Case 3b presents PV array installed at the north roof, and Case 3c presents PV array installed at the complete roof.

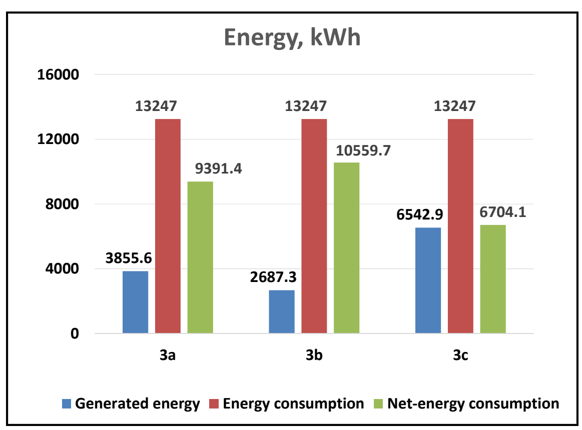

Fig. 6. Case 3 – building energy consumption and generated energy

The higher value of PV cell efficiency directly influence to the amount of generated energy. With the increasing of ell efficiency, generated energy, is increasing too. In that case, net-energy consumption is decreasing (Figure 6).
In a Case 3a – with PV cell efficiency of 16 %, solar fraction of 0.85 and PV array on the south roof, the 3855.6 kWh of electricity can be generated, and net-energy consumption in the building in that case is 9391.4 kWh. In a Case 3b – with PV cell efficiency of 16 %, solar fraction of 0.85 and PV array on the north roof, the amount of generated electricity is 2687.3 kWh, while net-energy consumption is 10559.7 kWh. When PV array with 16 % of cell efficiency is installed to the both roof sides (Case 3c) and solar fraction is 0.85, generated energy has the highest value – 6542.9 kWh, and net-energy consumption is 6704.1 kWh. With higher solar fraction and with installing the PV array with 16 % of cell efficiency to the both roof sides, the generated energy increases and net-energy consumption decreases (Figure 6). Compared to the building without PV array, net-energy consumption is lower for 29.1 %, 20.3% and 49.4% for Case 3a, 3b and 3c, respectively.

5.5 Case 4 – Zero Net-Energy Building

In accordance with previous investigation, it can be concluded that concept of Positive Net-Energy Building (PNEB) can be achieved with the greater surface area of photovoltaic array. In all analysed cases, photovoltaic surface area was 14 m² (in a case of installing at one roof side), i.e. 28 m² (in a case of both roof side).

Table 2. Energy consumption in PNEB building (PV cell efficiency 16 %, PV surface area 57 m², solar fraction 0.85 - Case 4)

Building energy consumption (kWh)	13247
Generated energy (kWh)	13319
Net-energy consumption	-72

Simulation results obtained by EnergyPlus software shown that the concept of PNEB building can be achieved with PV cell efficiency of 16 %, solar fraction of 0.85 and PV surface area of 57 m². In that case (Case 4), generated electricity is 13319 kWh and net-energy consumption is -72 kWh. This means that with PV array of 57 m², surplus of electricity is 72 kWh annually (Table 2).

5.6 Comparison of the obtained results

Figure 7 compared the building energy consumption and generated energy for most favourable analysed cases (Case 1c – PV cell efficiency of 12 %, PV surface area of 28m² and solar fraction of 0.5, Case 2c – PV cell efficiency of 12 %, PV surface area of 28m² and solar fraction of 0.85, Case 3c– PV cell efficiency of 16 %, PV surface area of 28m² and solar fraction of 0.85 and Case 4 – PNEB with PV cell efficiency of 16 %, PV surface area of 57 m² and solar fraction of 0.85).
Based on the obtained simulation results, it can be concluded that installation of PV array can significantly improve building energy efficiency.
By comparing Case 1c and 2c, it can be concluded that with increasing of solar fraction from 0.5 to 0.85, there is significant increasing in generated energy (70 %), and also, significant decreasing in net-energy consumption (24.9%).
By comparing Case 2c and Case 3c, it can be concluded that with increasing of PV cell efficiency from 12 % to 16 %, there is also significant increasing in generated energy (31%), and also, significant decreasing in building net-energy consumption (18.8 %).
By comparing Case 1c and Case 3c, it can be concluded that with increasing of photovoltaic cell efficiency from 12 % to 16 %, and with increasing of solar fraction from 0.5 to 0.85, there is also significant increasing in generated energy (122,7%), and also, significant decreasing in building net-energy consumption (53,8 %).

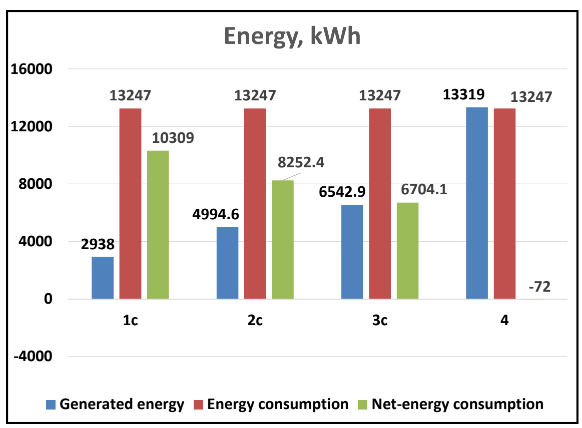

Fig. 7. Comparison of the most favorable cases with Case of PNEB - building energy consumption and generated energy

6. CONCLUSION

The major aim of this investigation was to determine the energy saving in single-family residential building, with different solar fraction on PV array and different photovoltaic cell efficiency. All analysed buildings have had the electric space heating system.

By using PV array with cell efficiency of 16%, it is possible to generate significantly greater amount of electrical energy, compared with PV array of 12% cell efficiency. With the increasing of photovoltaic cell efficiency, there is a significant decrease in the building net-energy consumption.

Solar fraction also influence to energy generation: with increasing the solar fraction, generated electricity is increasing too, while the net-energy consumption is decreasing.

Simulation results shown that it is possible to achieve the concept of positive net-energy building. That is the case with PV cell efficiency of 16 %, solar fraction of 0.85 and PV surface area of 57 m^2. Then, generated energy is 13319 kWh (which is greater than building energy consumption of 13247 kWh) and net-energy consumption is -72 kWh.

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Long term simulation of vertical GCHP system for a building with asymmetric cooling and heating loads

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Abstract *This paper presents the results of numerical simulations of the operation of heating and cooling system of a smaller commercial building in two different climatic zones in Montenegro. The climatic conditions and building physics are such that the cooling load is greater than the heating load. Vertical-borehole ground coupled heat pump uses 16 vertical boreholes in 4-by-4 configuration as the heat sink/source. Numerical simulations performed using EnergyPlus software are conducted to indicate the possibility of optimizing the system in terms of energy savings through increased efficiency or in terms of reduced investment. To this end, two cases are analysed: Case 1 as a baseline case in which only a geothermal exchanger is used for heat rejection and Case 2 as a hybrid system that uses a cooling tower and a plate heat exchanger in the condenser loop as an additional heat rejecter. Simulation results for a 200-year period indicate that the hybrid system with cooling tower should be seriously considered in similar building-climatic conditions cases characterized by such asymmetry between the cooling and heating load.*

Keywords *Ground-coupled heat pump (GCHP), hybrid systems, borehole heat exchanger, cooling tower, EnergyPlus.*

1. INTRODUCTION

At the local, regional and global level, various measures are being implemented to combat climate change. The European Union is leading the way in this, showing a strong determination to reduce greenhouse gas emissions.
The well-known 2020 climate and energy package set by EU leaders in 2007 had three key targets: reducing GHG emissions by 20% compared to the 1990 level, increasing the share of renewables to 20% and reducing energy consumption by 20% by applying energy efficiency measures. The European Green Deal, approved in 2020 is even more ambitious, setting an overarching aim of making the European Union climate neutral by 2050. As the building sector is responsible for about 40% of EU energy consumption, one of the ways to achieve these goals is the use of more efficient heating and cooling systems, which certainly include geothermal heat pumps. Ground coupled heat pumps systems (GCHP) have not found widespread use in Montenegro so far, but are expected to be an attractive solution for space cooling and heating in the near future. In particular, wide use of the vertical borehole heat exchanger (BHE) configuration is expected, which consists of boreholes (typical diameter DN80-DN125 and depth 100 m) in which one or two U-bended HDPE pipes are placed [1]. Heat

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