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ENERGY ANALYSIS OF SERBIAN BUILDING WITH PV PANELS AND DIFFERENT HEATING SYSTEMS

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Abstract: Buildings consume a significant part of energy and they are responsible for large emissions of harmful gases, primarily CO_2. The largest building energy consumer is the heating system, so it is necessary to investigate all aspects of energy consumption to minimize the total final and primary energy consumption. To reduce energy consumption, it is very important to apply principles for improving energy efficiency. One of the most acceptable solutions is the installation of renewable energy technologies. This paper simulates the operation of the PV system, which can generate a significant amount of electricity and cover part or all of the building energy consumption. Simulation in EnergyPlus software was provided for buildings with three different heating systems - electric heating, district heating, and gas heating. The paper shows annual total final and primary energy consumption, energy savings and possibilities for the generation of a larger amount of electricity, by installing PV panels with higher cell efficiency, in order to minimize building energy consumption.

Key words: Building, Heating systems, PV system, Energy consumption

1 INTRODUCTION

Buildings represent large energy consumers in modern society, with a share of 30% of the total energy consumption [1]. In Serbia, the share of energy consumption in the building sector is 35%, however, when it comes to family buildings with individual heating systems, it is even more than 50 % [2]. Heating system is certainly the biggest energy consumer (share of 60%), then the domestic hot water (DHW) system, cooling system and electrical appliances. Over the past decades, increasing energy consump-

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tion led to a large environmental pollution due to the intensive emission of greenhouse gases, primarily CO_2. The total CO_2 emission originating from the building sector in the European Union amounts to 36% [3]. For the above reasons, it is clear that the building sector represents a significant field for improvement of energy efficiency and reduction of greenhouse gasses emissions which contributes to the reduction of global warming. Energy efficiency in buildings means the efficient use of energy with optimal measures aimed at reducing energy consumption with financial savings for the end-user, comfortable and quality living, reducing maintenance costs and extending the building lifetime, and contributing to environmental protection [4].

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. Solar systems should be used whenever possible to achieve sustainable development and a sustainable future. One of the more promising renewable energy technologies is photovoltaic (PV) energy conversion [5, 6].

This paper reports investigations of the possibilities to decrease energy consumption of Serbian residential buildings with PV array and three different heating systems (electric, district, and gas heating), through the variation of thermal insulation thickness and photovoltaic cell efficiency. Electricity generated by the PV array may be used for space heating, space cooling, DHW heating, lighting, and appliances, and it is limited by the size of PV array. When the PV system does not directly satisfy the building's needs for electrical energy, then the rest of the electricity will be used from the electricity grid. When the PV system satisfies the building's needs for electrical energy, then the rest of the generated electricity will be fed-in the electricity grid.

The analyzed building is simulated in the EnergyPlus environment, while the Open Studio plug-in in Google SketchUp was used for building design. The investigated building is located in Kragujevac, Serbia. In these simulations, the heating devices operate from 15 October to 14 April next year which is valid in Serbia.

2 MODEL OF THE ANALYZED BUILDING

The modeled residential building is shown in Figure 1. The building has two floors and 6 conditioned zones. The total floor area of the building was 160 m^2 and total roof area 80.6 m^2. The roof is south-oriented with a slope of 37.5^0, and installed PV array on it.

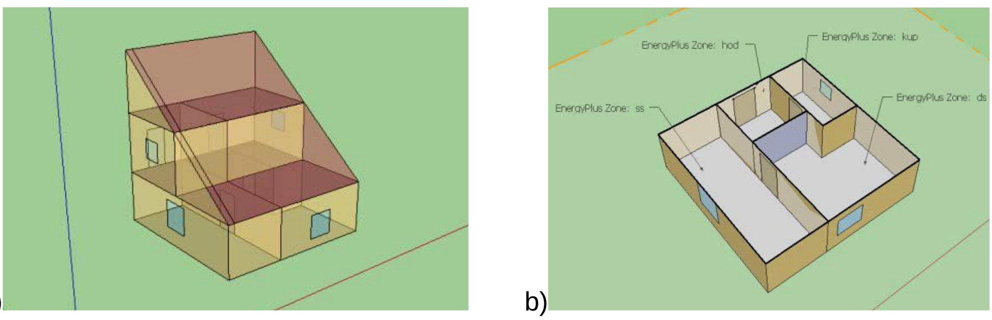
a)


Figure 1. *Modelled building: a) Schematics (X-ray); b) Cross-section of the first floor*

The windows are double glazed. The concrete building envelope, roof, and the floor are thermally insulated by polystyrene. In this investigation, the polystyrene thickness was varied. In referent case, thermal insulation thickness is 0.05 m, and values of 0.1m, and 0.15m of insulation thickness were investigated. The thermal insulation density is 16 kg/m^3, and the thermal conductivity is 0.037 W/mK [7]. 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 main part of electricity, in the case of electrical heating, was consumed for electrical space heating in the building (E_{EH}). Electricity was consumed for lighting, domestic hot water (DHW), and appliances (E_{EQ}). In the case of district and gas heating, the main part of electricity is consumed by DHW. District heating energy is marked with E_{DH}, while gas heating energy is marked as E_{GH}.

The PV system consists of a PV array and an inverter. It is an on-grid system. The operation of the PV array (and the electrical heating system) is simulated by using EnergyPlus. Photovoltaic cell efficiency was initially set as 12 %. Through the simulations, PV cell efficiency varied, and it was 16 % and 18 %. Solar fraction was 0.85. The area of considered PV array was 40 m^2. The PV array is represented by the mathematical model of Photovoltaic:Simple from EnergyPlus [8]. This model describes a simple model of PV that may be useful for early phase design analysis. It allows quick and easy modifications during the simulation routines. The user can set up values for cell efficiency, area and solar fraction.

3 RESULTS AND DISCUSSION

3.1 Building energy consumption

The results for building energy consumption in the analyzed residential building were obtained by simulations in EnergyPlus environment. Three different heating systems were considered: electric heating, district heating and gas heating. From the aspect of energy consumption, electric heating represents the least favorable heating system, because it has the is extremely high primary energy consumption, and that is why it is very important to analyze the parameters that can lead to a reduction in the consumption of the primary energy. A more favorable heating system from the aspect of primary energy consumption is a district heating system, and an even more favorable solution is gas heating, due to the lower value of the primary conversion multiplier of final energy. Unlike the electric heating system, the district heating system, which is widely used in urban areas, has a significant emission of harmful gases into the atmosphere, which must be paid a lot of attention. Gas heating is the most environmentally friendly heating system. It has a great advantage because gas combustion takes place with much lower emission of harmful gases. In the case of application of these systems in residential buildings, electricity is used only for lighting, electrical appliances and for DHW.

The total final energy consumption E_T in investigated referent building (thermal insulation 0.05m) is a sum of electricity consumption for lighting (E_{EL}), domestic hot water (E_{DHW}), appliances (E_{eq}), and heating energy consumption E_H (E_{EH}, E_{DH} or E_{GH}):

$$E_T = E_{EL} + E_{DHW} + E_{EQ} + E_H \tag{1}$$

Primary energy consumption in the investigated building with electric space heating, is:

$$E_{PRIM} = p_{EL} E_{EL} \quad (2)$$

where p_{EL}=3.04 stands for the primary conversion multiplier for electricity [9].
In the analyzed buildings with district and gas heating, building primary energy consumption is given in equations (3) i (4), respectively:

$$E_{PRIM} = p_{EL}(E_{EL} + E_{DHW} + E_{EQ}) + p_{DH} E_H \quad (3)$$

$$E_{PRIM} = p_{EL}(E_{EL} + E_{DHW} + E_{EQ}) + p_{GH} E_H \quad (4)$$

where p_{DH}=2.03 stands for the primary conversion multiplier for district heating, and p_{GH}=1.1 stands for the primary conversion multiplier for gas heating [7].

Table 1 presents the results of the annually building energy consumption in referent case. Building with district heating system has significantly lower primary energy consumption, compared to the building with electric heating (51.17 GJ or 23 %). Better solution is gas heating system - primary energy saving of 82.57 GJ (37,2%).

Table 1. *Energy consumption in referent building (thermal insulation thickness of 0.05m), without photovoltaics*

Energy consumption (GJ)	Final energy	Primary energy
Lighting	1.02	
Electric equipment	6.91	
DHW system	22.89	
Heating	42.24	
Electric heating	73.06	222.11
District heating		179.44
Gas heating		139.54

PV array, installed on the roof of the building, generates electricial energy, which covers buildings energy needs (partially or complete). If the yearly amount of generated electricity is E_{PV}, than net final energy consumption in the building is:

$$E_{NET} = E_T - E_{PV} \quad (5)$$

while net-primary energy consumption can be calculated as:

$$E_{NET-PRIM} = p_{EL}(E_{EL} + E_{DHW} + E_{EQ} - E_{PV}) + p_X E_H \quad (6)$$

where p_X stands for primary conversion multiplier. Table 2 shows building energy and net-energy consumption, in a case with PV panels and three different heating systems.

Table 2. *Energy consumption in referent building with photovoltaics*

Energy consumption (GJ)	Heating system		
	Electric heating	District heating	Gas heating
Finaly	73.06	73.06	73.06
Primary	222.11	179.44	139.54
Generated	26.35	26.35	26.35
Net-finaly	46.71	46.71	46.71
Net-primary	142.01	99.34	59.44

With PV array instalations, it can be achieved a significant energy savings. PV array with an area of 40 m^2 and cell efficiency of 12 %, generates 26.35 GJ of electricity during the year. Net-final energy consumption in the analyzed buildings is 46.71 GJ, and finaly energy saving is 36 %. Net-primary energy consumption in the case of EH is 142.01 GJ (primary energy saving is 36 %). In the case of district and gas heating, Net-primary energy consumption is 99,34 GJ and 59.44 GJ, respectively, and primary energy saving is 44.6 % and 57.4 %, respectively. If buildings with PV, district and gas heating,were be compared to the referent building without PV, than the primary energy saving for district heating is 55.3 %, and for gas heating it is 73.2 %.

Figure 2 gives the graphical presentation of the obtained results, from Table 2.

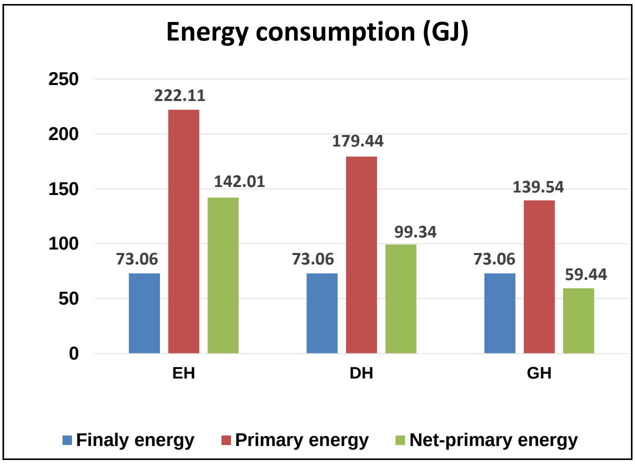


Figure 2. *Generated energy and primary energy consumption in referent building (insulation thickness 0.05 m) with PV and different heating systems*

3.2 Different thermal insulation thickness

To reduce building energy consumption, and to improve energy efficiency of the analyzed building, thermal insulation thickness was varied. In addition to the reference case, buildings with thermal insulation thickness of 0.01 m and 0.015 m were investigated. All three heating systems were considered. Table 2 provides a detailed description of the energy consumption in the buildings, for all analyzed cases.

The amount of electricity used for lighting, electrical appliances and DHW is the same in all cases (30.82 GJ). Only the amount of heating energy differs - it decreases, as well as the total annual energy consumption (final and primary), with the increase in the insulation thickness. The conclusion is that with the increase of thermal insulation thickness, final and primary energy consumption decreases, too.

In the analyzed buildings, for thermal insulation thickness of 0.1 m and 0.15 m, total final energy consumption is 70.45 GJ and 68.98 GJ, respectively. Final energy savings are 2.6 GJ (3.6 %) and 4.08 GJ (5.6 %). Net final-energy consumptions are 44.1 GJ and 42.63 GJ (energy saving of 5.6 % and 8.7 %), respectively. Total primary energy consumptions are 212.28 GJ (primary energy saving of 4.4 %) and 207.81 GJ (primary energy saving of 6.4 %), respectively, and net-primary energy consumptions are 132.18 GJ and 127.71 GJ (energy saving of 6.9 % and 10.1 %), respectively.

When building has PV and district heating system, and insulation thickness increases from 0.05 m to 0.1 m and 0.15 m, then building total primary energy consumption decreases from 179.94 GJ to 173.6 GJ and 170.94 GJ, respectively; primary energy saving is 6.34 GJ or 3.5 %, and 9.9 GJ or 5.5 %, respectively, while net-primary energy saving is 6.4 % and 9 %, respectively. Compared to the referent building without PV, primary energy saving for building with district heating and 0.1 m of insulation is 57.9 %, and for 0.15 m of insulation it is 59.1 %.

Better results for energy consumption are achieved ih the building with PV and gas heating system. When insulation thickness increases from 0.05 m to 0.1 m and 0.15 m, then building total primary energy consumption decreases from 139.54 GJ to 136.03 GJ and 134.96 GJ, respectively; primary energy saving is 3.52 GJ and 4.6 GJ, respectively, while net-primary energy saving is 6 % and 7.9 %, respectively. Compared to the referent building without PV, primary energy saving for building with gas heating and 0.1 m of insulation is 74.8 %, and for 0.15 m of insulation it is 75.3 %.

Table 3. *Energy consumption in buildings with different thermal insulation thickness*

		Thermal insulation thickness (m)		
Energy consumption (GJ)		0.05 - ref	0.1	0.15
Electricity Heating Generated energy		30.82 42.24 26.35	30.82 39.63 26.35	30.82 38.16 26.35
Final energy				
Total final		73.06	70.45	68.98
Net-final		46.71	44.1	42.63
Primary energy				
Electric heating	Total primary	222.11	212.28	207.81
	Net-primary	142.01	132.18	127.71
District heating	Total primary	179.94	173.6	170.94
	Net-primary	99.84	93.5	90.84
Gas heating	Total primary	139.54	136.03	134.96
	Net-primary	59.55	55.93	54.86

Figure 3 and Figure 4 shows the building finaly and primary energy consumption, in the building with PV array and electrical and gas heating sytem.

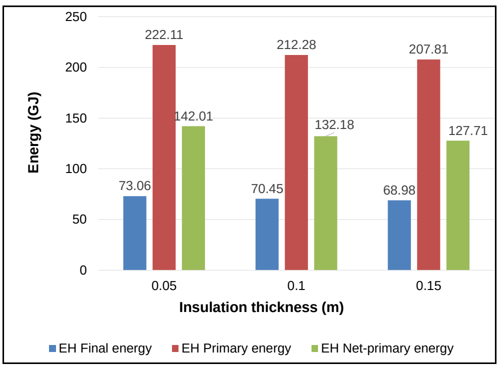


Figure 3. *Energy consumption in the building with electrical heating*

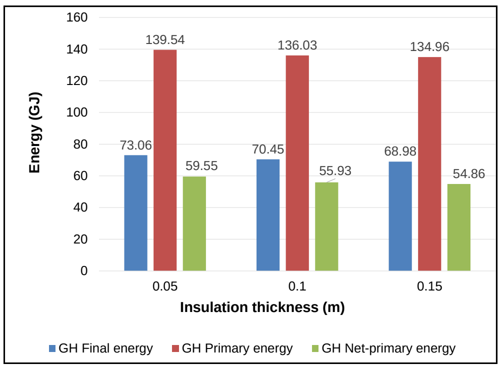


Figure 4. *Energy consumption in the building with gas heating*

3.3 Different photovoltaic cell efficiency

In the second part of the investigation, different photovoltaic cell efficiency is analyzed. The aim was to get a higher value of generated energy, and, on that way, to achieve higher energy saving in the building. The amounts of energy consumption in the analyzed buildings were the same as in previous cases. For this investigation, building with a thermal insulation thicknes of 0.15 m is analyzed, due to the greatest improvement of energy efficiency. Obtained results are given in Table 4.

Table 4. *Energy consumption in buildings with different PV cell efficiency*

Energy (GJ)		PV cell efficiency (%)		
		12	16	18
Generated energy		26.35	35.84	40.59
Final energy consumption				
Total final		68.98		
Net-final		42.63	33.14	28.39
Primary energy consumption				
Electric heating	Total primary	207.81	207.81	207.81
	Net-primary	127.71	98.86	84.42
District heating	Total primary	170.94	170.94	170.94
	Net-primary	90.84	61.99	47.55
Gas heating	Total primary	134.96	134.96	134.96
	Net-primary	54.86	26.01	11.57

In the case of the building with a PV cell efficiency of 16%, 35.84 GJ of electricity is generated (PV panel area of 40m^2), which is an increase of 9.49 GJ or 36% compared to the case of 12 % of PV cell efficiency (26.35 GJ of generated energy). Net-final energy consumption is 33.14 GJ (energy saving is 22.3 %).

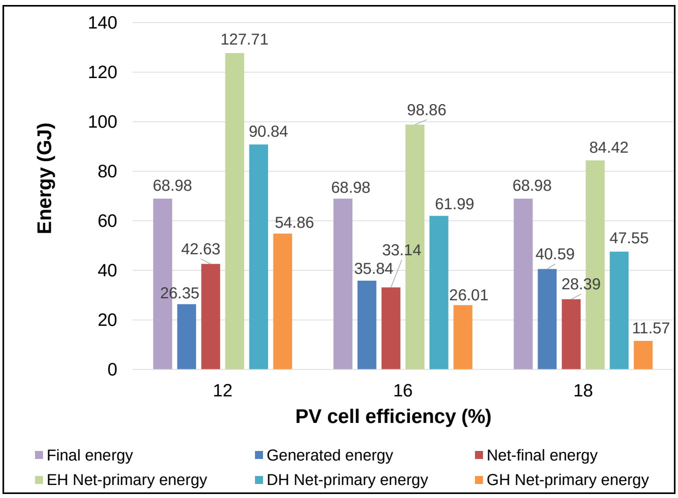


Figure 5. *Energy consumption in buildings with different PV cell efficiency*

Fig. 5 shows the building final and primary energy consumption, for the different PV cell efficiency. For the building with EH, net-primary energy consumption is 98.86 GJ (energy saving is 28.85 GJ or 22.3 %). In a case of DH, net-primary energy consumption is 61.99 GJ (energy saving is 31.8 %), and for the building with GH, net-primary energy consumption is 26.01 GJ (energy saving is 52.6 %). When PV modul with 18 % of cell efficiency was used, the generated electricity is 40.59 GJ, which is an increase of 14.24 GJ or even 54 %, compared to the case of PV cell efficiency of 12 %. Net-final energy consumption is 28.39 GJ (energy saving of 14.24 GJ, i.e. 33.4 %). In the building with EH, net-primary energy consumption is 84.42 GJ (energy saving is 43.29 GJ or 33.4 %). In the case of DH, net-primary energy consumption is 47.55 GJ (energy saving is 47.7 %), and for the building with GH, net-primary energy consumption is 11.57 GJ (energy saving of 78.9 %).

Based on the data from Table 4, it was calculated that it is possible to achieve *zero net-energy building (ZNEB)* in the case of the building wit GH if the installed PV panel array has an area of 43.75 m^2.

4 CONCLUSION

The major aim of this investigation was to present the possibilities for improving the energy efficiency of residential building with PV aray and different heating systems (electric, district, and gas). In the first part of the investigation, it is presented how thermal insulation thickness influence to energy consumption, while the second part of the investigation refers to the possibilities for electricity generation with PV panels with higher cell efficiency. The conclusion is that with proper thermal insulation thickness (0.15 m), and PV cell efficiency of 18 %, it is possible to achieve energy savings in the range from 33.4 % (EH) to 78.9 % (GH). It is possible ti achieve the ZNEB with PV area of 43.75 m^2 and cell efficiency of 18 %, in the building with GH.

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