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

Abstract: *For clean and renewable electricity generation, solar photovoltaic (PV) technology is the best option. Solar energy has become a promising alternative source due to its advantages: abundance, pollution free, and renewability. On the other hand, gas heating system is an low-temperature and low-energetic system. In this paper, the possibilities to decrease energy consumption of Serbian residential buildings are analyzed. The building with gas 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 the consumption of primary energy. The residential buildings with variable thermal insulation thickness, variable domestic hot water consumption and variable types of PV panels are investigated in order to achieve 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.*
Keywords: *PNEB; Photovoltaic; Gas heating system, Optimization; Simulation;*

1. INTRODUCTION

Nowadays, building sector consumes about 40 % of the consumed energy. In Serbia, building sector consumes more than 50 % of the consumed energy [1]. Also, the world's reserves of oil, gas and coal are lower, and problems of global warming, greenhouse gases and air pollution are increasing. Because of that, research and development of renewable energy resources and use have significant impact on the environment [2]. An attractive option for clean and renewable electricity generation is solar photovoltaic (PV) technology, which represents the direct conversion of solar radiation into electricity. On the other hand, gas heating system is a low-temperature heating system. So, the building with two of these systems can be zero-net energy building (ZNEB) or positive-net energy building (PNEB).

In the recent years, many of scientists defined ZNEB and PNEB [3]. 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 [4].

From solar energy, the building produces electrical energy by the PV array on its roof.

This article reports investigations of the possibilities to decrease energy consumption of Serbian residential buildings with PV array and gas heating systems, 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.

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

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

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 [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 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.

3. CLIMATE

The investigated residential building was located in the city of Kragujevac, Republic of Serbia. Its average height above sea-level is 209 m. Its latitude is $44^0$10 N and longitude $20^0$55 E. The time zone for Kragujevac is 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 very warm 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. MODELED BUILDING

The modeled residential building is shown in Figure 1. 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.

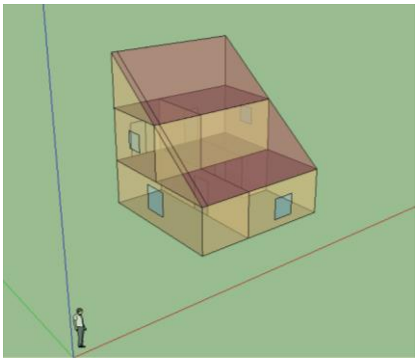

***Figure 1** - Modeled residential building*

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 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 gas heating, the main part of electricity was consumed by appliances. Gas heating energy is marked with E_{GH}.

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 [13, 14].

The PV array was represented by the mathematical model of Photovoltaic: Simple from EnergyPlus [5].

5. 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 ($E_{em,PV}$), and embodied energy of the thermal insulation ($E_{em,IZO}$). For the optimization, the next objective function was used [15]:

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

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 [16], 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

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

where E_{EL} stands for the yearly total electricity consumption by building (J); p_{GH}=1.1 stands for the primary conversion multiplier for gas heating and E_{GH} stands for the yearly district heating energy consumption in a building (J).

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.

Alsema [13,14] 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 [17] 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 [13] 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 [18].

6. RESULTS AND DISCUSION

The residential building is analyzed in order to achieve PNEB and minimize the consumption of primary energy. On that way, the green gases emission will be minimized.

6.1 Different thermal insulation thickness

To achieve the PNEB, the thermal insulation thickness was varied for the residential building with gas space heating (GH). 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. *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
E_{EL*} - Electricity consumption*	14.43 GJ	14.43 GJ	14.43 GJ
E_{GH} - 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	90.33 GJ	87.16 GJ	85.73 GJ

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

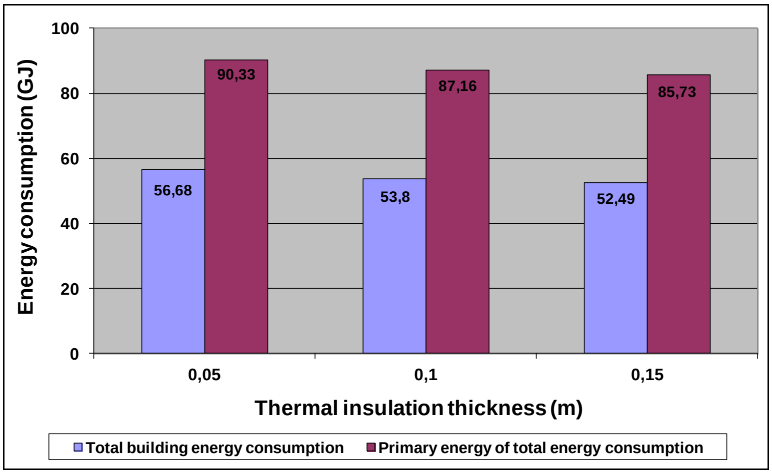

Figure 3 *- Energy consumption for building with gas space heating*

Table 2*. Building with gas 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	**90.33 GJ**	**87.16 GJ**	**85.73 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**
	144.54 GJ	**143.94 GJ**	**143.34 GJ**
Building type (without embodied energy)	**PNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)	**PNEB**	**PNEB**	**PNEB**

Table 1 represents the total building energy consumption (E_{CONS}) and primary energy of E_{CONS} ($E_{primary,\ CONS}$). Figure 2 represent energy consumption for building with gas 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. All the buildings with gas heating systems 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.

6.2 Different electricity consumption in residential buildings

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 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 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.

7. 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 gas heating systems.

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

	Gas heating	
	Case 1	Case 2
E_{EL*} - Electricity consumption *	14.43 GJ	15.89 GJ
E_{GH} - Space gas heating energy	38.06 GJ	38.06 GJ
E_{CONS} - Total building energy consumption	52.49 GJ	53.95 GJ
$E_{primary,CONS}$ - Primary energy of total energy consumption	**85.73 GJ**	**90.17 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
$E_{PV,prim}$ - Primary energy of generated electricity	**159.48 GJ**	**159.48 GJ**
$E_{primary,\ PV}$ – maximum of avoided operative primary energy	**143.34 GJ** **PNEB**	**143.34 GJ** **PNEB**
Building type (without embodied energy)	**PNEB**	**PNEB**
Building type (with embodied energy)		

The investigation shows that in all cases it is the maximum roof coverage with PV arrays. Also, all the buildings were PNEB - with or without consideration of embodied energy. All the buildings with gas space heating were the PNEB in any case of thermall insulation thickness. Also, the buildings with gas space heating were the PNEB in any case of analyzed electricity consumption.

REFERENCES:

[1] Bojić, M., Nikolić, N., Nikolić, D., Skerlić, J., & Miletić, I. (2011). A simulation appraisal of performance of different HVAC systems in an office building,. *Energy and Buildings*, *43*(6), 2407-2415.

[2] Nikolić, D., Bojić, M., Radulović, J., Skerlić, J., & Miloradović, N. (2014). Energy optimization of serbian buildings with pv panels and different heating systems. CD Conference proceedings, *45th International HVAC&R congress*, ISBN 978-86-81505-75-5, Beograd.

[3] Kapsalaki, M., Leal, V., & Santamouris, M. (2012). A methodology for economic efficient design of Net Zero Energy Buildings. *Energy and Buildings*, *55*, 765-778.

[4] Nikolić, D., Đorđević, Z., Bojić, M., Radulović, J., & Skerlić, J. (2013). Optimization of photovoltaics panels area at Serbian zero-net energy building. *Journal of renewable and sustainable energy*, *5*.

[5] Anonymous, ENERGYPLUS, Input Output Reference - The Encyclopedic Reference to EnergyPlus Input and Output, University of Illinois & Ernest Orlando Lawrence Berkeley National Laboratory, 2009.

[6] Henninger, R.H., Witte, M.J., & Crawley, D.B. (2004). Analytical and comparative testing of EnergyPlus using IEA HVAC BESTEST E100-E200 test suite. *Energy and Buildings*, *36*(8), 855-863.

[7] Lawrence Berkeley National Laboratory. EnergyPlus - Engineering documentation: the reference to EnergyPlus calculations. University of Illinois & Ernest Orlando Lawrence Berkeley National

Laboratory, 2001.
[8] Bojić, M., Skerlić, J., Nikolić, D., Cvetković, D., & Miletić, M. (2012). Toward future: positive net-energy buildings. *Proceedings 4thRenewable Energy Sources, EXPRES 2012*. Subotica, Serbia.
[9] Wetter, M., (2004). GenOpt, Generic Optimization Program. User Manual, Lawrence Berkeley National Laboratory, Technical Report LBNL- 54199, p. 109.
[10] Audet. C., & Dennis, J.E.Jr. (2003). Analysis of generalized pattern searches. *SIAM Journal on Optimization, 13*(3), 889-903.
[11] Wetter, M., & Polak, E. (2005). Building design optimization using a convergent pattern search algorithm with adaptive precision simulations. *Energy&Buildings, 37*, 603-612.
[12] Hooke, R., & Jeeves, T.A. (1961). Direct search solution of numerical and statistical problems. *Journal of the Association for Computing Machinery, 8*, 212-229.
[13] Alsema, E.A., Nieuwlaar, E. (2000). Energy viability of photovoltaic systems. *Energy Policy, 28*(14), 999-1010.
[14] Alsema, E.A. (2000). Energy pay-back time and CO2 emissions of PV systems. *Progress in Photovoltaics: Research and Applications, 8*(1), 17-25.
[15] Nikolić, D., Skerlić, J., Miletić, M., Radulović, J., & Bojić, M. Energy optimization of PV panels size at Serbian ZNEB and PNEB. *Proceedings 23th Confernita Nationala cu Participare Internationala Instalatii Pentru Constructii Si Confortul Ambiental*, Timisoara, Romania, pp.267-278.
[16] Bojić, M., Đorđević, S., Malešević, J., Miletić, M., & Cvetković, D. (2012). A simulation appraisal of a switch of district to electric heating due to increased heat efficiency in an office building. *Energy and Buildings, 50*, 324-330.
[17] Sanchez, J. PV Energy Payback Retrieved from: www.homepower.com.
[18] Bojić, M., Miletić, M., Marjanović, V., Nikolić, D., & Skerlić J. (2012). Optimization of thermal insulation to achieve energy savings. 25. *International conference on efficiency, cost, optimization, simulation and environmental impact of energy systems-ECOS 2012*, Perugia, Italy, pp. 174-1-174-10.

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