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OPTIMIZATION OF ENERGY CONSUMPTION OF SERBIAN POSITIVE-NET ENERGY BUILDING

Abstract: *Nowadays, a radical approach for the mitigation of the energy demand is the concept of the zero-net energy building (ZNEB) and positive-net energy building (PNEB). Also, the renewable energy has a significant impact on the environment, so the research and development of renewable energy resources and the use of renewable energy is essential. In this paper it is investigated the Serbian residential building with PV panels on the roof which generates the electricity for building needs. The major aim was to analyze the possibilities to decrease energy consumption, due to variation of electricity consumption and hot water consumption in building. On that way, it can be possible to determine the optimal values of the area of the PV array, in order to achieve the 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.*

Keywords: *Building; Energy consumption, PV panels, Simulation, Optimization;*

1. INTRODUCTION

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

Solar photovoltaic (PV) technologies are an attractive option for clean and renewable electricity generation. 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 sources, but, many countries support this technology.

In the recent years, many of scientists were involved in defininig the concepts of the zero-net energy building (ZNEB) and positive-net energy building (PNEB) [2]. By definition, the Zero-Net Energy Building (ZNEB) produces all energy it consumes during year, and yearly electrical energy supplied to the electricity grid balances the amount received from the electricity grid. Positive-Net Energy Building (PNEB) produces more energy than it consumes during year, and yearly electrical energy supplied to the electricity grid is higher than the amount received from the electricity grid, and Negative-Net Energy Building (NNEB) produces less energy than it consumes during the [3, 4].

In this paper, energy consumption is analyzed for a residential building located in Kragujevac, Serbia. The building is designed with PV array installed on the roof – Figure 1.

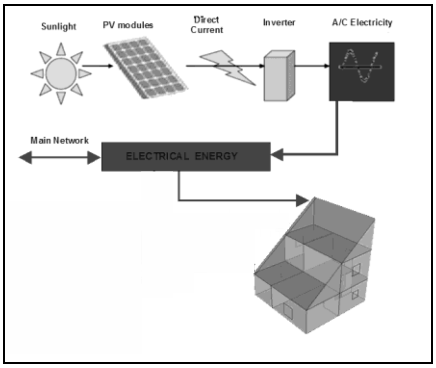

Figure 1 – Positive-Net Energy Building with PV module

Electricity generated by the PV array is limited by 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 electricity needs, then the rest of PV generated electricity will be fed-in the electricity grid. In the analyzed building, energy is used for space heating and cooling, domestic hot water (DHW) heating, lighting, and electric equipment. The analyzed building has an electrical space heating system.

The major aim was to analyze the possibilities to decrease energy consumption, due to variation of electricity consumption and hot water consumption in building. On that way, it can be possible to determine the optimal values of the area of the PV array, in order to achieve the 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 analyzed building is 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 in this region are worm and humid with temperatures as high as 37^{0}C. The winters are cold with snow and temperatures as low as - 19^{0}C [3]. The EnergyPlus uses weather data from its own database file.

4. MATHEMATICAL MODEL

The investigated building is shown in Figure 2. The building has the south-oriented roof with the slope of 37.5^0. On the roof, the PV array is installed. The building has two floors and 5 conditioned zones. The building accommodates a family of four. The working period of the heating systems is from October 15th to April 14th (07:00–21:00 h). 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. The amount of infiltration is 1.5 ach^{-1}.

The building has the total floor area of 160 m^2. Total volume of conditioned zones is 264.64 m^3. Total area of external walls is 200 m^2 and total roof area is 80.6 m^2. The windows are double glazed, with the total area (including the exterior door) of 12.44 m^2. The concrete building envelope, roof and the floor are thermally insulated by polystyrene.

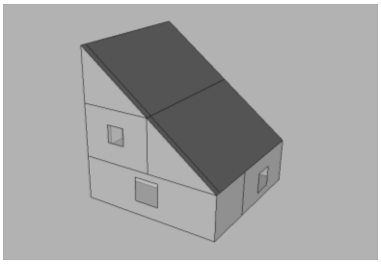

Figure 2 - Modeled residential building

The main part of electricity is consumed for space heating in the building. Additionally, electricity is consumed for lighting, domestic hot water (DHW), refrigerators, freezers, dish–washers, cloth washers etc.

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. The life cycle of PV array is set to 20 years, and the embodied energy of PV panels is set to 3.75 GJ/m^2 [13, 14]. The PV panel is represented by the mathematical model of Photovoltaic: Simple from EnergyPlus [5], which describes a simple model of PV that may be useful for early phase design analysis.

5. OPTIMIZATION PROCEDURE

In these investigations, the optimization was performed with the aim to determine the optimal size of PV array, according to the buildings energy needs. Then, the primary energy consumption is minimized. 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 ($E_{em,IZO}$) [15]. For the optimization, the following objective function was used

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

Where: $E_{primary,\ PV}$ – the yearly avoided operative primary energy consumption due to operation of the PV array (J); p_{PV} = 3.04 - primary conversion multiplier [16]; E_{PV} – yearly electrical energy generated by PV array (J); $E_{em,\ PV}$ – PV array embodied energy (J); C_m=1/LC; where LC is life cycle, in years and $E_{em,\ IZO}$ – insulation embodied energy (J).

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

Alsema [13, 14], reports the energy requirement of crystalline silicon modules. Sanchez [17] reports that the total energy requirement of a frameless a-Si module, and Alsema [13] reports that the average PV life time is 30 years.

The thermal insulation has the embodied energy of 86.4 MJ/kg, density of 16 kg/m^3, and thermal conductivity of 0.037 W/mK [18].

6. RESULTS AND DISCUSION

The residential building is analyzed with variable electricity consumption by lighting and electric equipment, and variable hot water consumption in order to achieve PNEB and minimize the consumption of primary energy.

6.1 Different electricity consumption

In these tests, the buildings electricity consumption is varied. In the case 1, the considered building has the thermal insulation thickness of 0.15 m, the hot water consumption 10m^3/month. Then, the distribution of the yearly electricity consumption is the following: water system 6.52 GJ/a, space heating system 29.01 GJ/a, the electric equipment 6.26 GJ/a, and lighting 1.02 GJ/a. Total building electricity consumption is 42.82 GJ/a (Fig 3).

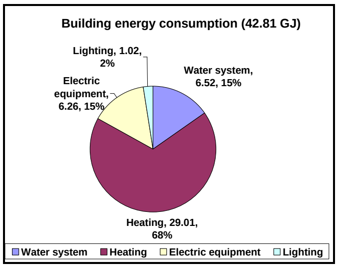

Figure 3 – Building electricity consumption (Case 1)

In the case 2, the building had the same insulation thickness and hot water consumption as that in the case 1, but higher electricity consumption by electric equipment (7.4 GJ) and lighting (1.96 GJ), so the yearly value of electricity consumption was 44.89 GJ (Figure 4).

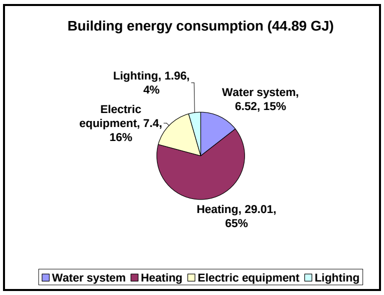

Figure 4 – Building electricity consumption (Case 2)

Table 1 – Building electricity consumption

	Electricity consumption	
	Case 1	Case 2
Total electricity consumption by building	42.82 GJ	45.36 GJ
Primary energy of total electricity consumption	130.17 GJ	137.9 GJ
Fraction of PV panels	0.99	0.99
Total generated electricity	52.46 GJ	52.46 GJ
Primary energy of generated electricity	159.48 GJ	159.48 GJ
$E_{primary,\,PV}$ – maximum of avoided operative primary energy	143.27 GJ	143.27 GJ
Embodied energy in PV array	14.51 GJ	14.51 GJ
Embodied energy in thermal insulation	1.7 GJ	1.7 GJ
Building type (without embodied energy)	**PNEB**	**PNEB**
Building type (with embodied energy)	**PNEB**	**PNEB**

With the optimization procedure, the fraction of PV panels area on the roof in case 1 was 0.99 and the yearly avoided operative primary energy consumption 143.27 GJ/a (including embodied energy of thermal insulation and PV), i. e. 159.48 GJ without embodied energy of thermal insulation and PV. In case 2 - the fraction of PV panels area also was 0.99 and the yearly avoided primary energy consumption was as in the first case, 143.27 GJ/a (including embodied energy of insulation and PV), i.e. 159.48 GJ without embodied energy of insulation and PV (Table 1). The both of buildings are PNEB.

6.2 Different hot water consumption

The building is investigated with the thermal insulation thickness 0.15 m. The hot water consumption is changed, and analyzed cases are with monthly hot water consumptions of 7.5 m^3, 10 m^3, 15 m^3 and 20 m^3. Results are shown in Table 2.

***Table 2 – Building electricity consumption* (GJ)**

	Hot water consumption			
	7.5 m^3	10 m^3	15 m^3	20 m^3
Total el. consumption	41.19	42.82	46.08	49.34
El. consumption for water heating	4.89	6.52	9.78	13,05
Primary energy of el. consumption	125.21	130.17	140.08	150
Fraction of PV	0.99	0.99	0.99	0.99
Total gener. elec.	52.46	52.46	52.46	52.46
Generated el. as final energy	159.48	159.48	159.48	159.48
$E_{primary, PV}$ – maximum of avoided operative primary energy	143.27	143.27	143.27	143.27
Emb. energy of PV	14.51	14.51	14.51	14.51
Insulation emb. energy	1.7	1.7	1.7	1.7
Building type (without em. en.)	**PNEB**	**PNEB**	**PNEB**	**PNEB**
Building type (with emb. en.)	**PNEB**	**PNEB**	**PNEB**	**NNEB**

If we consider the approach without embodied energy, all the buildings are PNEB, because they produce more energy than it consumes during year. The fraction of PV panels on the roof is 0.99. If we consider the embodied energy of thermal insulation and installed PV array, then all the buildings will not be PNEB – the building with the higher hot water consumption will be NNEB.

7. CONCLUSION

This paper reports the investigation in low energy Serbian building optimization. The major aim of optimization procedure was to determine optimal area of PV array due to achieving the maximum avoided primary energy consumption due to installation and operation of PV array. The investigation shows that in all cases it is the maximum roof coverage with PV arrays. Also, PNEB can be achieved with or without consideration of embodied energy.

Buildings with different electricity consumption are PNEB, with or without embodied energy.

Also, all the buildings with different hot water consumption are PNEB (without embodied energy). If we consider the embodied energy, only the building with the higher hot water consumption is NNEB, and all the other buildings are PNEB.

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