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INFLUENCE OF DIFFERENT THERMAL INSULATION THICKNES ON BUILDING ENERGY CONSUMPTION

Abstract: *Today, one of the major research tasks is to improve building energy balance and to reduce building energy consumption. In this paper, the possibilities to decrease energy consumption of Serbian residential buildings are analyzed, through the variation of thermal insulation thickness. It is investigated the building with PV panels on the roof which generates the electricity for building needs. As the most unfavorable case due to energy consumption, the building with electrical space heating is investigated. The major aim was to determine the optimal values of thermal insulation thickness and the area of the PV array, in order to achieve the zero-net energy building (ZNEB). 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; Thermal insulation thickness, PV panels, Energy consumption, Optimization;*

1. INTRODUCTION

In Serbia, the building sector consumes more than 50% of the consumed energy. Around 24% of the total building floor area is heated by electrical energy [1]. An intention of our country to become a member of EU obliges us to reduce energy consumption by 20% and to obtain 20% of total energy from renewable energy sources by 2020 [2]. To achieve these goals, some advanced energy concepts for built environment should be applied such as zero-net energy building (ZNEB) and positive-net energy building (PNEB).

By definition, ZNEB produces all energy it consumes during year, PNEB produces more energy than it consumes during year, and negative-net energy building (NNEB) produces less energy than it consumes during year [3]. The ‘‘zero-net’’ concept means that yearly the excess electrical energy supplied to the electricity grid balances the amount received from the electricity grid. The ‘‘positive-net’’ concept means that yearly the excess electrical energy supplied to the electricity grid is higher than the amount received from the electricity grid. The ‘‘negative-net’’ concept means that yearly the excess electrical energy supplied to the electricity grid is lower than the amount received from the electricity grid [4].

From renewable energy, the building may usually produce electrical energy by the PV array on its roof. The generated electricity may feed either the building or the electricity grid. The main task for building design is to minimize the energy consumption of the building. This would minimize the required energy generation and the surface area required for the energy generation. In ZNEBs and PNEBs, energy may be used for space heating, space cooling, DHW heating, lighting, and appliances.

In such buildings, their envelope should minimize heat transfer. In cold climate, the building envelope has to be super insulated and air tight. To save energy and improve energy efficiency, investigations of building thermal insulation (materials, thickness, embodied energy) accelerates.

This article reports investigations of the possibilities to decrease energy consumption of Serbian residential buildings with PV array, through the variation of thermal insulation thickness. 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 (storage). When their PV system would satisfy the building needs for electrical energy, then the rest of PV generated electricity will be fed-in the electricity grid.

The building is located in Kragujevac, Serbia. In the building, the electricity is used to satisfy energy needs for space heating, lighting, appliances, and DHW heating. The building has an electric space heating system. In these simulations, it is taken that the heating devices may operate from 15 October to 14 April next year that is valid in practice for entire Serbia.

For this buildins, the paper will comment on consumption and generation of electrical energy by the building. This will be reported for the entire year. In addition, the article will report the size of PV array and building type (ZNEB, PNEB or NNEB).

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. SOFTWARES

In this study, the simulation software EnergyPlus (Version 7.0.0) was used. EnergyPlus is made available by the Lawrence Berkeley Laboratory in USA [5]. Its development began in 1996 on the basis of two widely used programs: DOE-2 and BLAST. The software serves to simulate building energy behavior and use of renewable energy in buildings. The renewable energy capabilities include solar thermal and photovoltaic simulation. Other simulation features of EnergyPlus include: variable time steps, user-configurable modular systems, and user defined input and output data structures. For Europe and different parts of the world, the software has been tested against analytical solutions, empirical results, and results of other software. The software has been tested using the IEA HVAC BESTEST series of tests [6]. To model the electrical space heating system and PV electricity generation in EnergyPlus environment, models of different components embedded in EnergyPlus are used such as PV array and inverter [7].

Open Studio plug-in in Google SketchUp 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 3D SketchUp environment [8].

GenOpt is an optimization program for the minimization of a cost function evaluated by an external simulation program [9]. 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. WEATHER CONDITIONS

The investigated residential building is located in the city of Kragujevac. Kragujevac lays in Balkan Peninsula in state of Serbia, around 120 km south of its capital city of Belgrade. Its average height above sea-level is 209 m. Its latitude is $44^0$10N, longitude $20^0$550E, and time zone 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 worm 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. SMULATION MODEL

The modeled residential building is shown in Figure 1. The building has the south-oriented roof with the slope of 37.5^0, with installed PV array on the roof. The building has two floors and 5 conditioned zones. 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 the total floor area of the building is 160 m^2, and 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.

The concrete building envelope, roof and the floor are thermally insulated by polystyrene. The thermal insulation thickness was varied in this investigation, and it was 0.05 m, 0.1m and 0.15m.

The main part of electricity is consumed for electrical space heating in the building. Additionally, electricity is consumed for lighting, domestic hot water

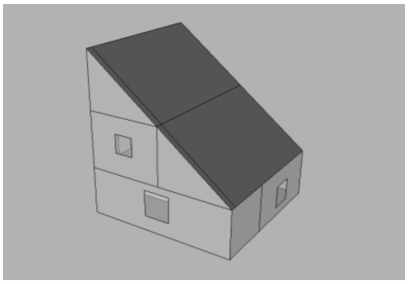

Figure 1 - Modeled residential building

(DHW) and appliances. The PV system consists of the PV array and an inverter. It is an on-grid system. 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].

5. OPTIMIZATION PROCEDURE

The main objective of optimization was to determine the optimal size of PV array, according to the buildings energy needs. In that case, the primary energy consumption would be 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 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], 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 thermal insulation thickness, in order to achieve PNEB and minimize the consumption of primary energy.

The thermal insulation thickness is varied to achieve ZNEB or PNEB. The first case is the building with 0.05 m of thermal insulation thickness, the second case is the building with 0.10 m and the third case is the building with 0.15 m of thermal insulation thickness, respectively. Results are in Table 1.

In all cases, the fraction of PV array on the roof is 0.99 (the system is limited by software on this value), i.e., the whole roof is covered by PV. All the buildings are PNEB, (building type approach without embodied energy) because they produce more energy than it consumes during year. But, if we consider the embodied energy of thermal insulation and installed PV array, then, due to avoided operative primary energy consumption, the buildings will not be the PNEB – the building with the smallest thermal insulation thickness from 0.05 m will be NNEB.

Table 1 – Building electricity consumption

	Thermal insulation thickness		
	0.05 m	0.1 m	0.15 m
Total electricity consumption by building*	48.85 GJ	44.76 GJ	42.82 GJ
Space heating energy	35.05 GJ	31.26 GJ	29.01 GJ
Primary energy of total electricity consumption	148.5 GJ	136.07 GJ	130.17 GJ
Fraction of PV panels on the roof	0.99	0.99	0.99
Total generated electricity by PV	52.46 GJ	52.46 GJ	52.46 GJ
Primary energy of generated electricity	159.48 GJ	159.48 GJ	159.48 GJ
$E_{primary,\ PV}$ – maximum of avoided operative primary energy	144.37 GJ	143.76 GJ	143.27 GJ
Embodied energy in PV array	14.51 GJ	14.51 GJ	14.51 GJ
Embodied energy in thermal insulation	0.6 GJ	1.21	1.7 GJ
Building type (without embodied energy)	**PNEB**	**PNEB**	**PNEB**
Building type (with embodied energy)	**NNEB**	**PNEB**	**PNEB**

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

If we consider electricity for speace heating, we can conclude that energy savin for building with thermal insulation thicknes of 0.15 m is 17 % compared to building with thermal insulation thicknes of 0.05m (Figure2). The total electricity consumption ih that case is lower and total energy saving is 12 %.

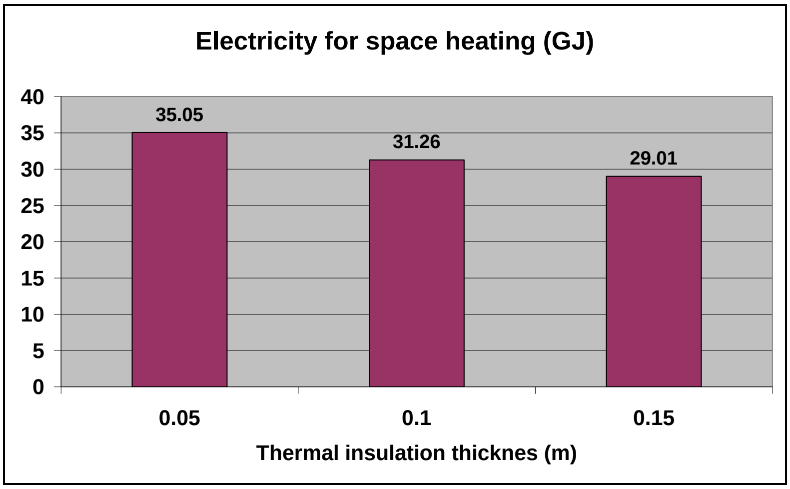

Figure 2 – Electricity for space heating

This case is also the most unfavorable case, because of the electrical space heating system which consumes the most amount of electrical energy compared to the other space heating systems. If we had some another heating system, like heat pump, the situation would certainly be much batter.

7. CONCLUSION

This paper reports the investigation in low energy Serbian building optimization. The major aim of the investigation was to determine the optimal area of PV array on the roof. On that way, it can be achieved the maximum avoided primary energy consumption. 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.

The building with the smaller thermal insulation thickness (0.05 m) is PNEB without embodied energy, but if we consider the embodied energy of PV array and thermal insulation, then it is NNEB. The other buildings with the higher thermal insulation thickness are PNEB in both of cases.

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