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QUALITY FEST 2017

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PROCEEDINGS

1st International Conference for Quality Research (B&H)
11th International Quality Conference (Serbia)
11th International Conference ICQME (Montenegro)

26th – 28th October 2017.
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Hotel Bistrica

Organization:	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
Publisher:	University of East Sarajevo Faculty of Mechanical Engineering East Sarajevo
For publisher:	Prof. dr Ranko Antunović
Editors:	Prof. dr Radoslav Grujić Prof. dr Slaviša Moljević
Technical treatment and desing:	Ranka Gojković, senior asisstant Aleksija Đurić, senior asisstant Jelica Anić, asisstant
Printing:	1st
Register:	ISBN 978-99976-719-1-2 COBISS.RS-ID 6852632

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

005.6(082)(0.034.2)

QUALITY Fest (2017 ; East Sarajevo - Jahorina)
Proceedings [Elektronski izvor] / Quality Fest 2017 [u okviru manifestacije] 1st International Conference for Quality Research (B&H) [i] 11th International Quality Conference (Serbia) [i] 11th International Conference ICQME (Montenegro), 26th - 28th October 2017. East Sarajevo - Jahorina ; [organization University of East Sarajevo, Faculty of Mechanical Engineering] ; [editors Radoslav Grujić, Slaviša Moljević]. - 1. izd. - East Sarajevo =Istočno Sarajevo : Faculty of Mechanical Engineering =Mašinski fakultet, 2017 ([s. l. : s. n.]). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Bibliografija uz svaki rad

ISBN 978-99976-719-1-2

1. International Conference for Quality Research (B&H) (1 ; 2017 ; East Sarajevo - Jahorina) 2. International Quality Conference (Serbia) (11 ; 2017 ; East Sarajevo - Jahorina) 3. International Conference ICQME (Montenegro) (11 ; 2017 ; East Sarajevo - Jahorina)

COBISS.RS-ID 6852632

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University of East Sarajevo
Faculty of Mechanical Engineering
QUALITY FEST
October 26th-28th, 2017.
Jahorina, RS, B&H

ENVIRONMETAL IMPACT OF SOLAR SYSTEMS – CASE OF SERBIAN RESIDENTIAL BUILDING WITH SOLAR COLLECTORS AND PV PANELS

Danijela Nikolic[1], Jasmina Skerlic[2], Jasna Radulovic[3], Aleksandar Miskovic[4]

Abstract: In the recent years, solar energy became the most common renewable energy source, because of its abundance and small pollution of environmental. In this paper, it is analyzed the environmental impact of installed solar system at Serbian residential building. The building has gas space heating or electric space heating and PV panels and solar collectors installed on the roof. Installed solar systems emit a certain amount of carbon dioxide in the atmosphere when generating electricity and heat. The investigations in this paper were carried out with the aim of determining the optimal size of solar systems, in which the minimum consumption of primary energy is realized. The residential buildings with variable types of PV panels are investigated. For optimal size of solar systems, emissions of carbon dioxide and emission payback-time (EPBT) are calculated. 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.

Key words: Building; Solar systems; carbon dioxide emission; emission payback-time.

1 INTRODUCTION

The rapid population growth on Earth causes a steady increase of energy needs. Therefore, humanity is in constant researching of new energy sources that would cover the growing energy needs. The world currently covered their energy needs with conventional energy sources, mainly fossil - nonrenewable energy sources, which have a large number of negative impacts, especially on the environment. The currently available way to reduce the levels of use of fossil fuels and thus reduce their harmful effects (greenhouse effect, climate change, the phenomenon of acid rain, global warming, etc.), is the development of new technologies using renewable energy sources. However, at present there is no completely ecologically clean way of using energy, so the use of the renewable energy sources, in addition to a series of benefits and

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advantages, has some negative impacts on the environment, though considerably less and in a milder form.

Solar energy is the most capable of the alternative energy sources and it is considered an attractive source of renewable energy that can be used for electricity generation and domestic water heating in residential buildings. Photovoltaic (PV) technology is an attractive option for clean and renewable electricity generation because it represents the direct conversion of solar radiation into electricity. Solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide most of hot water required by a family. Using photovoltaics and solar collectors together, represent a great opportunity for reducing the consumption of primary energy in residential buildings [1].

This paper reports investigations of the environmental impact of solar systems (PV panels and solar collectors) installed on the building roof. The major aim of investigation was determining the optimal size of solar systems, in which the minimum consumption of primary energy is realized. The residential buildings with electric and gas space heating are analyzed, with variable PV cell efficiency. The investigated building is located in Kragujevac, Serbia. Generated heat energy is used for domestic hot water heating. Electricity generated by the PV may be used for space heating, cooling, lighting, and electric equipment.

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 AND WEATHER CONDITIONS

2.1 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 8.1.0 was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA [2].

Open Studio plug-in in Google SketchUp software is a free 3D software tool that combines a tool-set with an intelligent drawing system [3]. 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 cost function evaluated by an external simulation program. It can be coupled to any simulation program that reads its input from text files and writes its output to text files. It has a library with adaptive Hooke-Jeeves algorithm [4].

Hooke–Jeeves optimization algorithm is used for the optimization, and it is direct search and derivative free optimization algorithm [5]. 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.

2.2 Weather conditions

The investigated residential building was located in the city of Kragujevac, Republic of Serbia. Its latitude is $44^{0}10$ N and longitude $20^{0}55$ E. In the city of Kragujevac 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.

3 MODEL OF THE ANALYZED SERBIAN BUILDING

The modeled residential building is shown in Figure 1. The building has the south-oriented roof with PV array and solar collectors installed on the roof. The building has two floors and 6 conditioned zones. 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 0.15m [1].

Electricity is consumed for heating (case with electric space heating), lighting, domestic hot water (DHW) and appliances. In the case of gas heating, the main part of electricity was consumed by appliances.

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 [6, 7] and embodied CO_2 emission of PV array was 40 g/kWh of generated electric energy [8]. It is analyzed the PV array with variable cell efficiency. The first case is the PV array with 12 % of cell efficiency, the second case is the PV array with 14 % and the third case is PV array with 16 % of cell efficiency.

The life cycle of solar collectors is also set to 20 years, the embodied energy of solar collectors is set to 1.85 GJ/m^2 [11], and the embodied CO_2 emission of flat plate solar collectors was 300 kg/ m^2 of solar collector area [8].

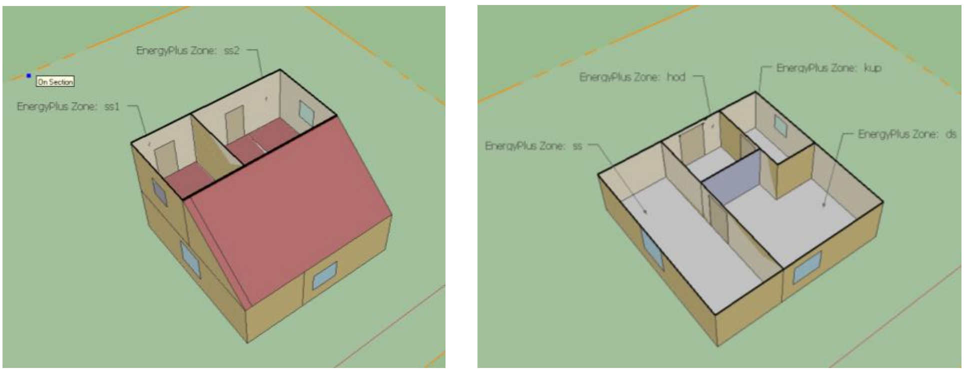

Figure 1. *Analyzed building with intersections*

4 ENVIRONMENTAL IMPACTS OF SOLAR SYSTEMS

When we talk about environmental analysis and adverse impacts on the environment, all analyzes are primarily related to carbon dioxide emissions. Carbon dioxide is a gas that is very low in the earth's atmosphere (0.037 %), but in addition to methane, nitrogen dioxide and other harmful gases, it is most commonly found in the structure of greenhouse gases as much as 83 %. About 98 % of CO_2 emissions come from combustion of fossil fuels, while the rest is emitted by combustion of waste, cement and lime production, in various technological processes, etc.

Installed solar systems discussed in this paper emit a certain amount of carbon dioxide in the atmosphere when generating electricity and heat. Regardless of the fact that they are systems that have minimal harmful effects on the environment, their carbon dioxide emissions are calculated according to the following equation:

$$S_{CO_2} = S_{CO_2,PV} + S_{CO_2,KOL} \quad (1)$$

where:

S_{CO_2} – CO_2 emission (kg/GJ annualy);

$S_{CO_2,PV}$ – CO_2 emission from PV array (kg/GJ annualy);

$S_{CO_2,KOL}$ – CO_2 emission from solar collectors (kg/GJ annualy).

Carbon dioxide emitted from the PV array, according to [9], is 50 g of CO_2/kWh of generated electricity, and carbon dioxide emission from solar collectors amount to 72 g CO_2/kWh of generated heat [10].

Total carbon dioxide emission is the sum of the carbon dioxide emission of installed solar systems and the incorporated (embodied) carbon dioxide emissions emitted from the production of analyzed solar systems. The total carbon dioxide emissions are calculated according to the form

$$S_{TOT,CO_2} = S_{CO_2} + S_{CO_2,PV,emb} + S_{CO_2,KOL,emb} \quad (2)$$

where:

$S_{CO_2,PV,emb}$ – embodied CO_2 emission from PV array (kg/GJ annualy);

$S_{CO_2,KOL,emb}$ – embodied CO_2 emission from solar collectors (kg/GJ annualy).

Embodied carbon dioxide emissions from photovoltaic array and solar collectors are given in [8].

An important parameter which shows the effect of solar systems on the environment, is their emission payback time – EMPB.

Emission payback time is defined as the time during which the emission is avoided due to the use of solar systems and is equal to the ratio of emissions generated during the production and use of the installed solar systems (PV array and solar collectors).

5 RESULTS AND DISCUSION

In this paper it is analyzed the influence of solar systems on the environment, through energy optimization of yearly building energy consumption. This optimization had the major goal to determine the optimal size of PV array and solar collectors, which will yield the minimal primary energy consumption of the building. In this calculations, the embodied energy of solar systems and building insulation was taken into account. In the reference case, the photovoltaics cell efficiency was 12%.

Figure 2 shows the consumption of final and primary energy for a reference building with two heating systems - electrical and gas space heating.

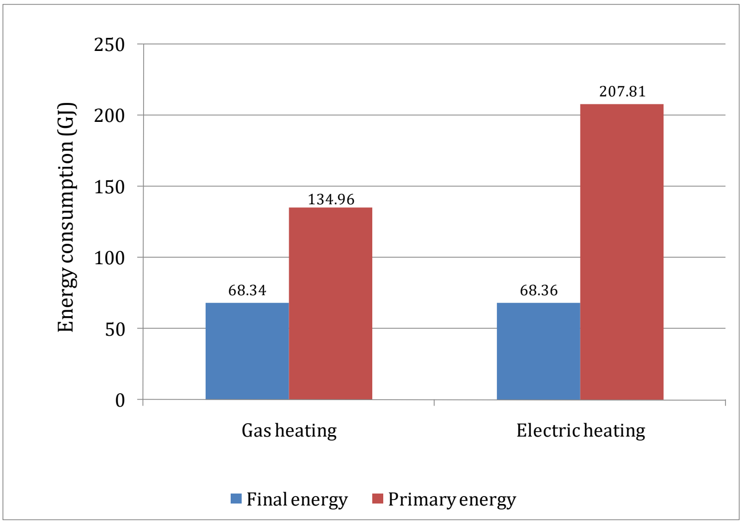

Figure 2. *Final and primary energy consumption in building with different heating systems*

Primary energy consumption is less for the building with gas heating system, because of great value of primary conversion multiplier for electricity (3.04), compared to the primary conversion multiplier for gas.

According to the energy optimization, building with electrical space heating has optimal ratio of PV array on the roof of 91.25 %, which means PV array area of 73.6m^2 and solar collector area of 7 m^2. Building with gas heating system has optimal ratio of PV array on the roof of 91.88 %, which means PV array area of 74.1m^2 and solar collector area of 6.5 m^2. These data means that in the case of building with electric heating, the annual carbon dioxide emission of solar systems is 11.86 kg CO_2/m^2 of solar installation, while in the case of a gas heating building, the annual emissions of carbon dioxide of solar systems is 11.57 kg CO_2/m^2 of solar installations. Total amount of CO_2 emissions of solar systems for a building with electric heating is 44.6 kg CO_2/m^2 of solar installation, and for the building with gas heating, total CO_2 emissions amount is 42.5 kg CO_2/m^2 of solar installation. The graphical representation of the results is given in Figure 3.

The parameter that shows the influence of solar systems on the environment is the emission payback time (EPBT). For analyzed buildings with electric heating system, the emission payback time is 2.8 years, and for the building with gas heating system, the emission payback time is slightly less - 2.7 years.

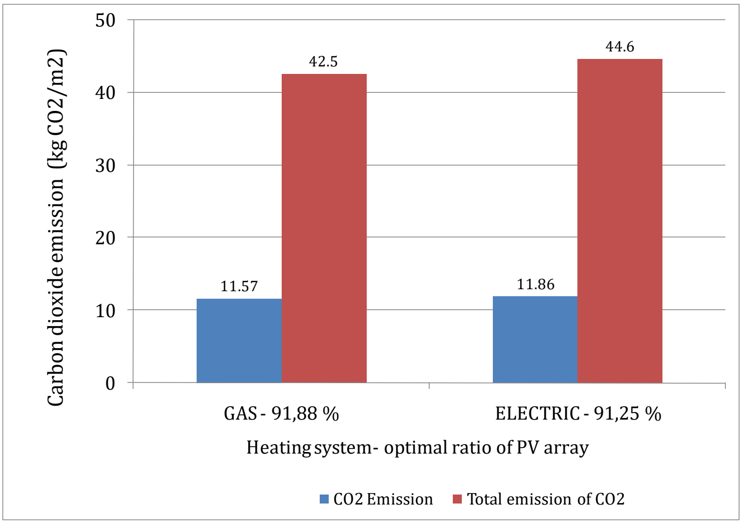

Figure 3. *Emission and total emission of CO_2 for energy optimized building with different heating systems and 12 % of PV cell efficiency*

With the PV cell efficiency of 14 % and 16 %, in all buildings, regardless of the heating system, optimal ratio of PV array on the roof is 92.5 % (PV array area of 74.6 m^2, and solar collectors area of 6 m^2) and 93.13 % (PV array area of 75.1 m^2, and solar collectors area of 5.5 m^2), respectively.

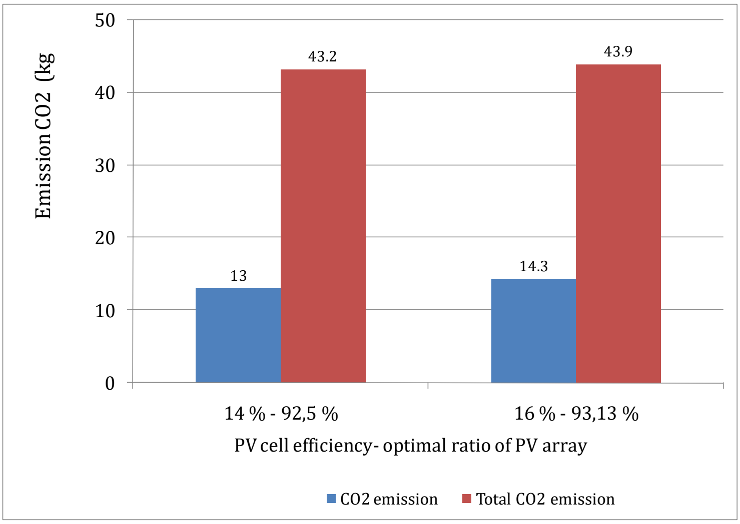

Figure 4. *Emission and total emission of CO_2 for energy optimized building with different heating systems and different PV cell efficiency (14 % and 16 %)*

In the case of PV cell efficiency of 14 %, the annual carbon dioxide emission of solar systems is 13 kg CO_2/m^2 of solar installation, while the total amount of CO_2 emissions of solar systems is 43.2 kg CO_2/m^2 of solar installation.

In the case of PV cell efficiency of 16 %, the annual carbon dioxide emission of solar systems is 14.3 kg CO_2/m^2 of solar installation, while the total amount of CO_2 emissions of solar systems is 43.9 kg CO_2/m^2 of solar installation (Figure 4).

Emission payback time for analyzed buildings with 14 % PV cell efficiency, regardless of the heating system, is 2.3 years. For 16 % PV cell efficiency, the emission payback time is 2.1 years, also regardless of the heating system. With the increase of PV cell efficiency, the emission payback time decreasing due to the increase in the amount of generated electricity.

6 CONCLUSION

The major aim of this investigation was analyzing environmental impact of solar systems (PV panels and solar collectors) through energy optimization on serbian building. With energy optimization, the optimal size of solar systems is determined, and after that, the carbon dioxide emission and total CO_2 emission is calculated. Investigated buildings has gas space heating and electric space heating.

Primary energy consumption is significantly less for the building with gas heating system.

With the increase of PV cell efficiency, the emission payback time decreasing due to the increase in the amount of generated electricity.

ACKNOWLEDGMENT

This paper is a result of the project TR33015 which is financed by the Ministry of Education, Science and Technological Development of Republic of Serbia. The authors thank to this institution for its financial support.

NOMENCLATURE

S carbon dioxide emission, kg/GJ

EMPB emission payback time, -

Subscripts and superscripts

CO_2 carbon dioxide
emb embodied
KOLL solar collector
PV photovoltaic (PV)
TOT total

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