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10th International Conference

ICQME 2016

(Quality, Management, Environment, Education, Engineering)

PROCEEDINGS

TEMPUS JP 543662

Editor: Prof. Zdravko Krivokapić, PhD

Petrovac, Montenegro
28th – 30th September 2016

TEMPUS JP 543662

Krivokapić, Z. (editor): *Proceedings of the 10th International Conference "Quality, Management, Environment, Education, Engineering" (ICQME 2016)*; Petrovac, Montenegro; 28th–30th September 2016. Podgorica (Montenegro): Center for Quality, Faculty of Mechanical Engineering, University of Montenegro 2016. - 349 pp. ISBN 978-9940-527-49-5.

Publisher: Center for Quality, Faculty of Mechanical Engineering,
University of Montenegro,
81000 Podgorica, Montenegro

For publisher: Prof. Zdravko Krivokapić, PhD, Director of the Center for Quality

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Approved by:
Decision no. 1/9/2016 from 01-09-2016 from Center for Quality, Podgorica (Montenegro)

Circulation: 150 exemplars

Printed by: Artgrafika
Nikšić, Montenegro

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P R E F A C E

It is our pleasure to invite you, on behalf of the Organizational Committee, to the 10^{th} International ICQME Conference that will be held in Petrovac between 28^{th} and 30^{th} September, 2016.
The idea of Conference has first come to life when a need was felt to have the eleweenth traditional National Conference on Quality Management System (SQM) with the international participation evolve into an international conference, with an extension of thematic areas to be covered.
National Conference on Quality Management System (SQM) with the international participation has been gathering prominent experts from the field of quality over the last twelve years. In addition to the local, Montenegrin experts, the participation lists included a number of well-known scientists and experts from France, Spain, Canada, Portugal, Italy, Greek, Poland, Denmark, Slovakia, Slovenia, Serbia, Bosnia and Herzegovina, Croatia, so some of the vital issues of quality, management, engineering, education, and environmental protection will be discussed at 10^{th} International ICQME Conference, and the participants from both the university and the commercial fields will take part, contributing to a more productive exchange of ideas and experiences.
The conference intends to shed further light on the complex and potentially conflicting choices that firms take, in order to acquire, exchange, and create knowledge in order to improve its performance. This theme relates to quite a wide variety of aspects relating to the increasing complexity (e.g. economic, management, engineering, sociology) of systems for knowledge creation and innovation. This complexity implies a more intensive and more frequent need to embrace as well as to connect both internal and external source of knowledge in the search for new technological achievements. ICQME became a part of Quality Festival, a manifestation that takes place in Montenegro, Bosnia and Herzegovina and Serbia.

In Podgorica,
September 2016

ON BEHALF OF THE ORGANIZING COMMITTEE

Prof. Zdravko Krivokapić, PhD **Prof. Milan Perović, PhD**

TEMPUS JP 543662

C O N T E N T S

Danijela Nikolić[1]
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Jasmina Skerlić[3]

SERBIAN ZNEB AND PNEB - OPTIMIZATION OF ENERGY CONSUMPTION

Abstract: *Today, significant part of the total energy consumption is related to the building, so research and development of methods for improving energy efficiency in buildings are very important. In this paper it is investigated the Serbian residential building with photovoltaic panels and solar collectors on the roof in order to achieve the concept of ZNEB (zero net energy building) and PNEB (positive net energy building). The building with district space heating is analyzed. Energy optimization (including embodied energy) was performed with the major aim to determine the optimal area of the PV array and solar collector area on the roof. The residential buildings with variable thermal insulation thickness, variable electric energy consumption and variable domestic hot water consumption are investigated. 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 and solar collectors system. With these optimal sizes, the concept ZNEB and PNEB can be achieved.*

Keywords: *ZNEB; PNEB, Photovoltaic; Solar collector; Optimization.*

1. INTRODUCTION

In recent years, question of energy security and stability has become the cardinal question of the entire world economy, economic and social system. EU in addition to its high level of development and evolution of its own relationship to the energy efficiency and energy security, are also faced with a problem of reducing the global warming due to the growing use of fossil fuels. In the energy sector, the most important mechanisms for the fight against climate change are generally known - increasing energy efficiency and the introduction of renewable energy sources in the production, transmission, distribution and satisfying energy needs.

Renewable energy sources are inexhaustible energy sources and have an important role in reducing emission of carbon dioxide into the atmosphere. In the future, solar energy will be very important as a form of clean and renewable energy, especially because of the prevention of the serious consequences of global warming. Solar energy can be directly transform into electricity by PV array, or can be transformed in heat energy in solar collectors. On that way, solar energy may be used for heating, cooling, lighting and electric equipment in the buildings.

In Serbia, the building sector consumes more 40 - 50% of the total used energy [1]. An intention of our country to become a member of EU obliges us to reduce the energy consumption by 20% and to obtain 20% of total energy from renewable energy by 2020 [2]. To achieve these goals, some advanced energy concepts for built environment should be applied such as a zero-net energy building (ZNEB) and a positive-net energy building (PNEB).

Many of scientists defined ZNEB, PNEB, and NNEB in the past decade [3, 4]. By definition, ZNEB produces all energy it consumes during year, PNEB produces more energy than it consumes during year, and NNEB produces less energy than it consumes during the year [5, 6].

In this paper, energy consumption is analyzed for a residential building with PV array and solar collectors installed on the roof - Figure 1 [7]. Residential building with district heating system is

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located in Kragujevac, Serbia. From solar energy, the building generates heat energy by the solar collectors. Generated heat energy is used for domestic hot water (DHW) heating. Also, from solar energy, building produces electrical energy by the PV array on its roof. Electricity generated by the PV array is limited with 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 needs for electrical energy, then the rest of PV generated electricity will be fed-in the electricity grid.

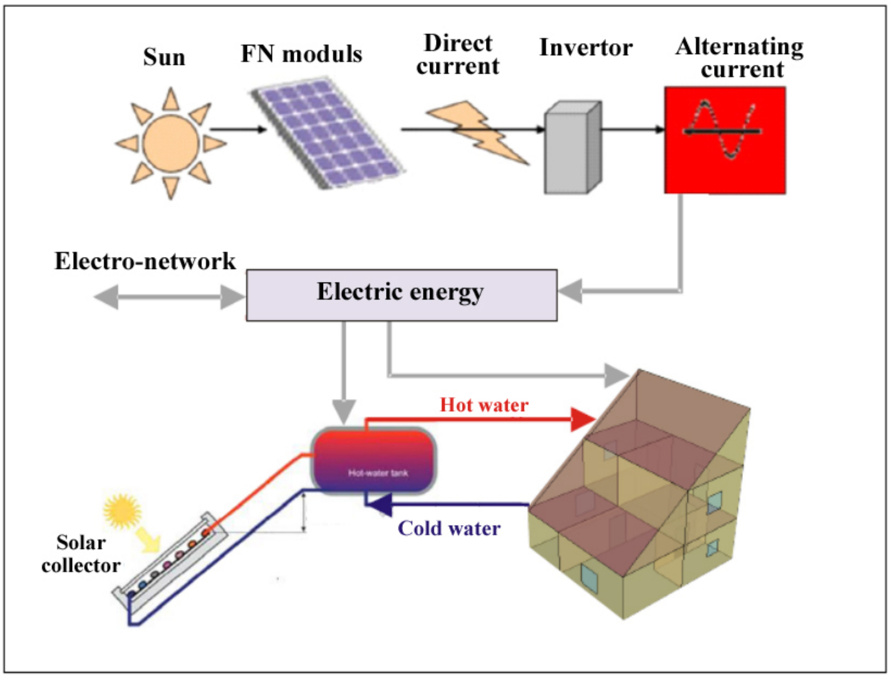

Figure 1. Positive-Net Energy Building with PV array and solar collectors

The major objective of this investigation is to determine the optimal sizes of PV panels and solar collectors on the roof, in order to minimize achieve zero-net energy building or positive net-energy building. Buildings are analyzed for variable thermal insulation thickness, variable electric energy consumption and variable domestic hot water consumption.

In this paper, the EnergyPlus, Open Studio plug-in in Google SketchUp, Hooke-Jeeves algorithm, and Genopt were used to achieve this objectives.

2. SIMULATION SOFTWARES AND CLIMATE

2.1. Simulation softwares

EnergyPlus software may be used for simulation of energy and mass flows in the buildings. In this study, the version 8.1.0 was used. EnergyPlus is made available by the Lawrence Berkley Laboratory in USA and it has been tested using the IEA HVAC BESTEST E100-E200 series of tests. For PV electricity generation, EnergyPlus uses the different component, like PV array and inverter [2].

Open Studio plug-in in Google SketchUp software - Google SketchUp is a free 3D software tool that combines a tool-set with an intelligent drawing system. 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. The software allows to the user to create, edit and view EnergyPlus input files within SketchUp [8].

GenOpt is an optimization program for the minimization of cost function evaluated by an external simulation program. GenOpt serves for optimization problems where the cost function is computationally expensive and its derivatives are not available or may not even exist. It can be coupled to any simulation program that reads its input from text files and writes its output to text files. GenOpt is written in Java so that it is platform independent. It has a library with adaptive Hooke-Jeeves algorithm [8].

2.2.Climate

The analyzed building is located at Kragujevac, Serbia. Kragujevac lays in Balkan Peninsula. Its average height is 209 m above sea-level. The latitude of Kragujevac is 44.1^0N, and the longitude is 20.55^0E. The time zone is GMT+1.0 h. The summers are worm and humid with temperatures as high as 37^0C. The winters are cold with snow and temperatures as low as - 19^0C. The EnergyPlus uses weather data from its own database file.

3. MATHEMATICAL MODEL

3.1. EnergyPlus model for modeled building

The modeled residential building is shown in Figure 2 [9]. The building has the south-oriented roof with a slope of 37.5^0 and 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 is 80.6 m^2. Building is thermally insulated by polystyrene. 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 PV system is 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 [10, 11].

Electricity is consumed for lighting, domestic hot water (DHW), and appliances (E_{EL*}). In the case of district heating, the main part of electricity was consumed by appliances. District heating energy is marked with E_{DH}.

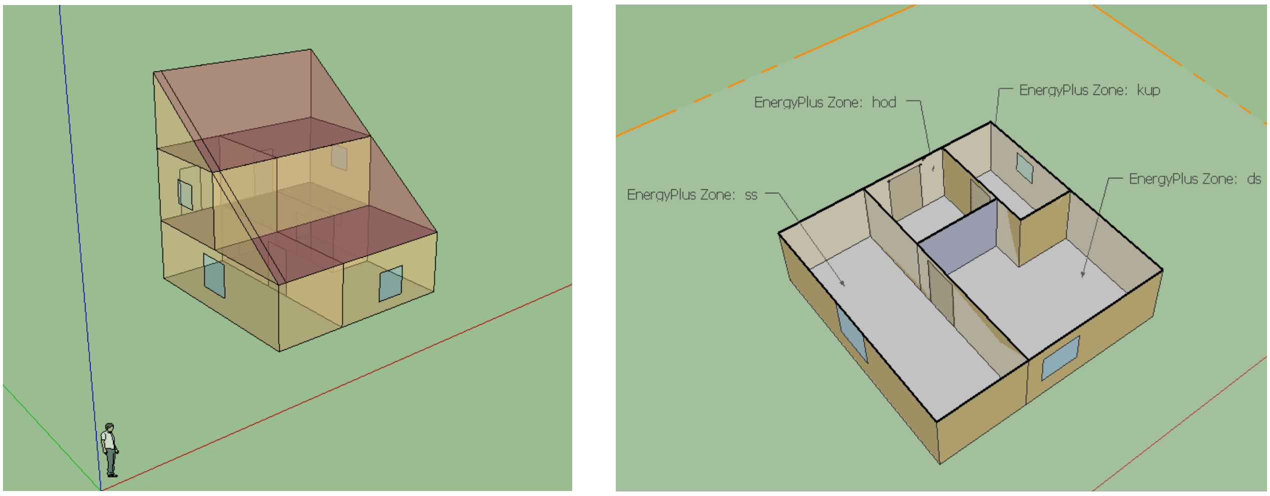

Figure 2. Modeled residential building

3.2. Optimization procedure

Mathematical optimization was performed according to the buildings energy needs. This optimization had the major goal to determine the optimal size of PV array and solar collector, which will yield the minimal primary energy consumption of the building. The primary energy saving (E_{PRIM}) consists of the primary energy covered by energy generated by PVs (E_{PV}) and energy generated by solar collectors (E_{COLL}), embodied energy in the PV array ($E_{em,PV}$), embodied energy in the solar collectors ($E_{em,COLL}$) and embodied energy of the thermal insulation ($E_{em,ISO}$) [8]. For the optimization, the following objective function was used [7]

$$E_{PRIM} = R_{EL}\left(E_{PV} + E_{COLL}\right) - C_m\left[\left(E_{em,PV} + E_{em,COLL}\right)C_{inst}\right] - C_{m1}E_{em,ISO}$$

where: E_{PRIM} – the yearly avoided operative primary energy consumption due to operation of the PV array and solar collectors (J); R_{EL} = 3.04 - primary conversion multiplier [71]; E_{PV} – yearly electrical energy generated by PV array (J); E_{COLL} – yearly heat energy generated by solar collectors (J); $E_{em, PV}$ – PV array embodied energy (J); $E_{em, COLL}$ – solar collectors embodied energy (J); $C_m=1/LC$; where LC is life cycle of PV and solar collectors, in years, $C_{m1}=1/LC_{ISO}$; where LC_{ISO} is life cycle of thermal isolations, in years, $E_{em, ISO}$ – insulation embodied energy (J) and C_{inst} – coefficient of instalation and maitenance of solar systems during their life cycle (-) [12]. The primary energy of total building consumption is

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

where E_{DH} stands for the yearly total electricity consumption by building (J); p_{DH}=2.03 stands for the primary conversion multiplier for district heating energy consumption in a building [1]. 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 [10, 11] 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) and the average PV life time is 30 years. Sanchez [13] 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 %). 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 [14].

4. RESULTS AND DISCUSION

4.1. Different thermal insulation thickness

To achieve the PNEB, the thermal insulation thickness was varied for the residential building with district space heating (DH). Three cases were investigated - buildings with 0.05 m, 0.10 m, 0.15 m and 0.2 m of thermal insulation thickness. Table 1 represents the total building energy consumption (E_{CONS}) and primary energy of E_{CONS} ($E_{primary, CONS}$).

Table 1. Electricity consumption, space heating energy, and building energy consumption

	Thermal insulation thickness			
	0.05 m	0.1 m	0.15 m	0.2 m
E_{EL*} - Electricity consumption	30.82 GJ	30.82 GJ	30.82 GJ	30,82 GJ
E_{DH} - Space district heating energy	42.24 GJ	39.36 GJ	38.06 GJ	37,31 GJ
E_{CONS} - Total energy consumption	73.06 GJ	70.18 GJ	68.88 GJ	68,13 GJ
$E_{primary,CONS}$ - Primary energy of total energy consumption	179.44 GJ	173.60 GJ	170.94 GJ	169,43 GJ

Figure 3 represent energy consumption, generated energy and avoided primary energy for buildings with district space heating system and different thermal insulation thickness.

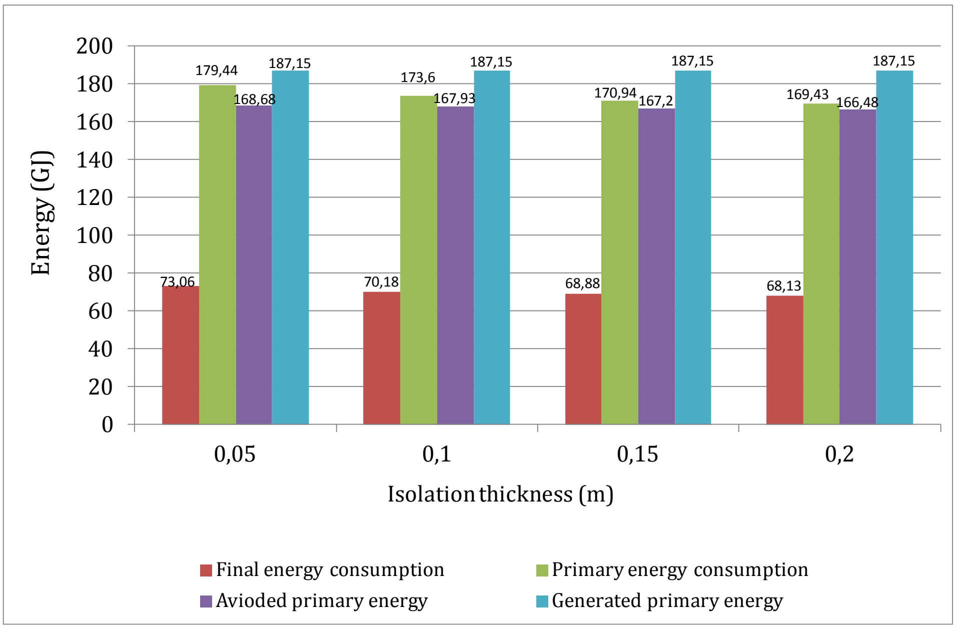

Figure 3. Energy consumption, generated energy, fraction of PV panels and avoided operative primary energy consumption of the buildings with different isolation thickness

The obtained results shows that fraction of PV array on the roof was 91.88 % in all cases, i.e. area of PV array was 74.1 m^2 while the rest of 6.5 m^2 of the roof are was covered with solar collectors – Table 2.

All the buildings with district heating systems are PNEB (building type approach with taking in account the embodied energy), while they are NNEB according to the approach with the embodied energy. Avoided primary energy decreases with the increasing of thermal insulation thickness.

Table 2. Energy consumption, generated energy, fraction of PV panels and avoided primary energy consumption of the buildings (Yearly values)

	Isolation thickness			
	0.05 m	0.1 m	0,15 m	0.2 m
Fraction of PV panels on the roof (%)	91.88	91.88	91.88	91.88
Total generated electricity by PV (GJ)	48.81	48.81	48.81	48.81
Total generated heat energy (GJ)	12.75	12.75	12.75	12.75
Primary energy of generated energy (GJ)	187.15	187.15	187.15	187.15
E_{PRIM} – avoided primary energy (GJ)	168.65	167.93	167.20	166.48
Embodied energy in solar systems (GJ)	17.78	17.78	17.78	17.78
Embodied energy in therm. insulation (GJ)	0.72	1.44	2.17	2.89
Total primary energy consumption (GJ)	179.44	173.6	170.94	169.43
Building type (without emb. energy)	PNEB	PNEB	PNEB	PNEB
Building type (with embodied energy)	NNEB	NNEB	NNEB	NNEB

4.2. Different hot water consumption

Buildings with different hot water consumption were analyzed - 8 m^3, 11.5 m^3 (referent case), 19 m^3 and 27 m^3 (monthly). Each building had the thermal insulation thickness of 0.15 m.

With the increasing of hot water consumption, the electricity required for its heating increasing too, and there is a small increase in the consumption of electricity required for the operation of electrical devices. All this resulted in different electricity consumption - Table 3. This table shows the energy needed for heating the building by using the district heating system and the annually total primary energy consumption. Obtained results showed that with the increase of the hot water consumption, the consumption of final or primary energy increasing too.

Table 3 – Final and primary energy consumption in buildings, for different hot water consumption

Electricty consumption (GJ)	Hot water consumption (m^3)			
	8	11.5 - Ref	19	27
Lighting	1.02	1.02	1.02	1.02
Electrical devices	6.90	6.91	6.95	6.98
Water heating	19.08	22.89	32.53	42.31
SUM	27.00	30.82	40.50	50.31
District heating	37.52			
Final energy consumption	65.06	68.88	78.56	88.37
Primary energy consumption	159.33	170.94	200.37	230.19

For different of hot water consumption in the building with gas heating system, compared to the lowest consumption of 8m^3, increasing of primary energy consumption for hot water consumptions of 11.5 m^3, 19 m^3 and 27 m^3 is 11.61 GJ (7.3%) 41,04 GJ (25.8 %) and 70.86 GJ (44.5 %), respectively. The reason for such a large increase in primary energy consumption is that with the increase of hot water consumption significantly increases total final energy consumption, which has a large coefficient of conversion to primary energy. Figure 4 provides an overview of energy parameters in case of district heating building.

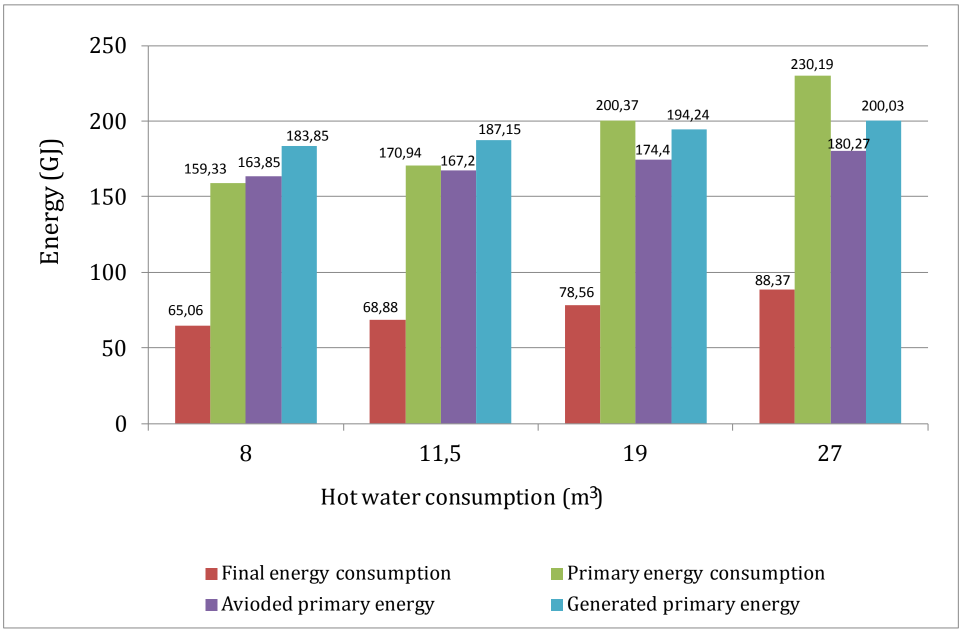

Figure 4. Energy consumption, generated primary energy and avoided primary energy for buildings with different hot water consumption and district heating system (Yearly values)

Results obtained by the optimization for building with district heating system and different hot water consumption are given in Table 4. Building with the lowest hot water consumption was PNEB, building with the referent hot water consumption was PNEB without embodied energy (NNEB with embodied energy approach), and the buildings with higher hot water consumption were NNEB according to the both approach.

Table 4. Energy consumption, generated energy, fraction of PV panels and avoided primary energy consumption of the buildings (Yearly values)

	Hot water consumption (m^3)			
	8	11,5 –Ref	19	27
Fraction of PV panels on the roof (%)	93,13	91,88	89,38	87,5
Total generated electricity by PV (GJ)	49,47	48,81	47,48	46,48
Total generated heat energy (GJ)	11,01	12,75	16,41	19,31
Primary energy of generated energy (GJ)	183,86	187,15	194,24	200,03
E_{PRIM} – avoided primary energy (GJ)	163,86	167,20	174,4	180,27
Embodied energy in solar systems (GJ)	17,83	17,78	17,67	17,59
Embodied energy in therm. insulation (GJ)	2,17	2,17	2,17	2,17
Total primary energy consumption (GJ)	159,33	170,94	200,37	230,19
Building type (without emb. energy)	**PNEB**	**PNEB**	**NNEB**	**NNEB**
Building type (with embodied energy)	**PNEB**	**NNEB**	**NNEB**	**NNEB**

Fraction of PV panels on the roof decreases with increase of the hot water consumption, while the fraction of solar collectors on the roof increases. For hot water consumption of 8 m3, fraction of PV panels on the roof is 93.13% (area of PV array is 75.1 m^2 while the other 5.5 m^2 of the roof are covered with solar collectors). For hot water consumption of 11.5 m3, 19 m3 and 27 m3, fraction of the PV panels on the roof is 91.88%, 89.38% and 87.5% respectively (Figure 5).

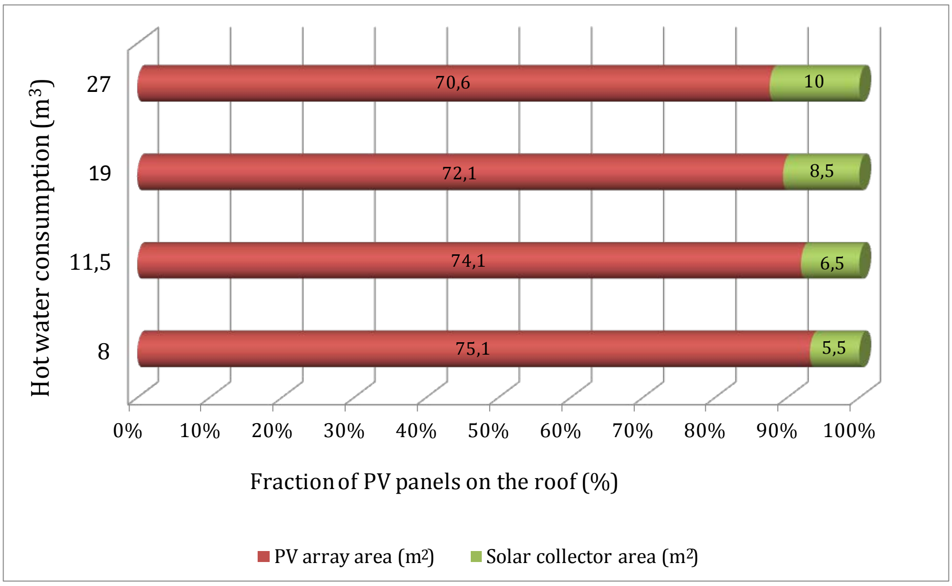

Figure 5. Area ratios of PV panels and solar collectors for different hot water consumptions

CONCLUSION

The major aim of this investigation was optimization to determine the optimal area of PV array and solar collectors on the roof, due to achieving the concept of positive net-energy building. All the considered buildings had the district heating system.

For different thermal insulation thickness, all the buildings were PNEB without a consideration of the embodied energy in solar installations and thermal insulation, and NNEB with a consideration of the embodied energy.

In the cases of different hot water consumption, fraction of PV area on the roof decreases with increase of the hot water consumption, while the fraction of solar collectors increases. Building with the lowest hot water consumption was PNEB, building with the referent hot water consumption was PNEB without embodied energy and NNEB with embodied energy approach. Buildings with higher hot water consumption were NNEB according to the both approach.

Obtained results showed that concept of PNEB can be achieved in the case of buildings with district heating system, when the buildings have their own systems of renewable energy.

ACKNOWLEDGEMENT

This paper is a result of three projects: TR33015, III 42006, and COST action TU1205-BISTS. The projects TR33015, and III 42006 are financed by the Ministry of Education, Science, and Technological Development of Republic of Serbia. The COST action TU1205-BISTS is supported by EU. The authors thank to the all institutions for their financial support.

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Национална библиотека Црне Горе, Цетиње

ISBN 978-9940-527-49-5
COBISS.CG-ID 31423504