Četvrta međunarodna konferencija
o obnovljivim izvorima
električne energije

The 4th International Conference
on Renewable Electrical
Power Sources

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ZBORNIK RADOVA
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FOREWORD

The world population growth reaching over 7 billion people causes the increasing global energy demand, especially electricity demand. Non-renewable energy sources are depletable and environmentally unacceptable (environmentally unfriendly), since they cause various forms of pollution, as well as one of the biggest challenges in the human history – climate change and global warming. In order to mitigate this, the use of fossil fuels must be reduced, and as long as coal, oil and gas are primary energy sources, the world will not make that necessary step forward. Therefore, a significantly higher share of renewable energy sources is required, and these sources are not only renewable, but also much more environmentally acceptable (environmentally friendly).

As a result, it is believed that renewable energy sources will be increasingly used in Europe, which will lead to the reduction of greenhouse gas emissions and less dependence on oil. Searching for such solutions, the European Union set an ambitious goal – Directive 2009/28/EC, which prescribes the reduction of total energy by 20%, the increase of the share of renewable energy in the total energy by 20% and the reduction of greenhouse gas emission by 20%. The European Union has been making large investments in order to reduce carbon emission, achieve competitive prices and protect the environment.

The main goal of the 4th international conference on renewable electricity (electric power) sources is to analyse the comparative advantages and disadvantages of modern solutions in the field of renewable electricity sources used globally and in this country, and to provide the constructive exchange of competent opinions and ideas related to the development and use of these sources.

This international conference is for the fourth time organised by the Society for Renewable Electricity Sources within SMEITS (Serbian Union of Mechanical and Electrical Engineers and Technicians).

Belgrade,
October 2016

PREDGOVOR

Porast broja stanovnika u svetu na preko 7 milijardi uslovljava da svetske potrebe za energijom, posebno električnom, postaju sve veće. Neobnovljivi izvori energije su iscrpivi, nisu ekološki prihvatljivi, jer izazivaju razne oblike zagađenja, kao i jedan od najvećih izazova u ljudskoj istoriji - klimatske promene i globalno zagrevanje. Da bi se to ublažilo korišćenje fosilnih goriva se mora smanjiti, jer dok god su ugalj, nafta i gas primarni energetski izvori, svet neće napraviti taj neophodan korak napred. Zbog toga se zahteva znatno veće učešće obnovljivih izvora energije koji su pored toga što su obnovljivi, i ekološki znatno prihvatljiviji.

Zbog toga se veruje da će se obnovljivi izvori energije u Evropi sve više koristiti, što vodi smanjenju emisije gasova sa efektom staklene bašte i manjoj zavisnosti od nafte. U traganju za takvim rešenjima, Evropska unija je postavila ambiciozan cilj – Direktivu 2009/28/EC koja propisuje da se do 2020. godine ukupna potrošnja energije smanji za 20%, da u ukupnoj potrošnji energije obnovljivi izvori učestvuju sa 20%, kao i da se emisija gasova sa efektom staklene bašte smanji za 20%. Evropska unija ulaže velika sredstva u ostvarenje ciljeva smanjenja emisije ugljenika, postizanja konkurentnih cena i zaštite životne sredine.

Osnovni cilj 4. Međunarodne konferencije o obnovljivim izvorima električne energije jeste da se analiziraju uporedne prednosti i nedostaci savremenih rešenja u oblasti obnovljivih izvora električne energije u svetu i kod nas, i da se obezbedi plodotvorna razmena kompetentnih mišljenja i ideja vezanih za razvoj i primenu ovih izvora.

Ovaj međunarodni skup po četvrti put organizuje Društvo za obnovljive izvore električne energije u okviru Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS).

U Beogradu,
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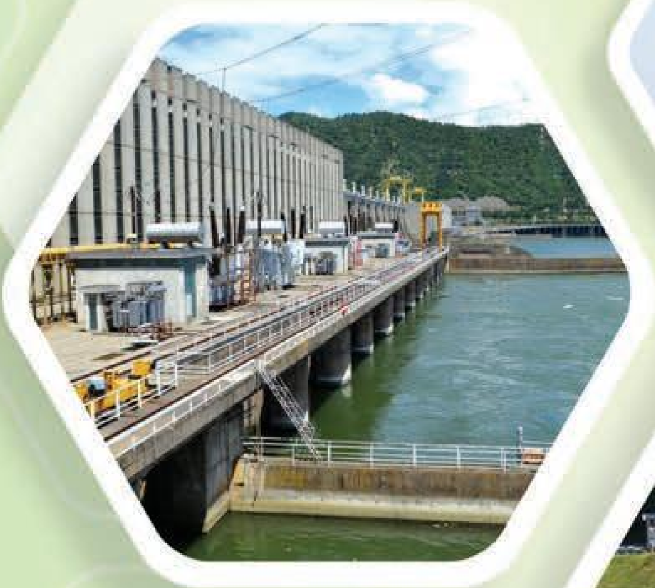

ЕПС

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OPTIMISATION OF GEOMETRY OF HORIZONTAL ROOF OVERHANGS COVERED WITH PHOTOVOLTAIC PANELS

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Овај рад представља опис два примера истраживања везаних за фотонапонске ћелије и резултате оптимизације величине (дубине) надстрешница покривених са фотонапонским панелима за различите комбинације кућа. Све куће имају надстрешнице покривене фотонапонским панелима. Куће су симулиране и оптимизоване коришћењем EnergyPlus-a и Hooke Jeeves алгоритма. Затим су добијене оптималне дубине надстрешница при чему је мимимизиран збир потрошње примарне енергије на грејање и хлађење просторија и уграђене енергије за надстрешнице и фотонапонске ћелије. Резултати показују да дубина надстрешница зависи од њихове оријентације.

Ključne reči: *fotonaponski paneli, nadstrešnice, ugrađena energija, EnergyPlus*

This paper present description of two examples of research related to photovoltaic cells and the results of the optimization of the size of overhangs with photovoltaic panels for different combinations of houses. All the houses have overhangs covered by photovoltaic panels. They are simulated and optimized by using EnergyPlus and Hooke Jeeves algorithm. Then, optimal depths of the overhangs are found. The objective function serves to minimize the primary energy for heating and cooling of the house, and amount of embodied energy in overhangs and photovoltaic panels. Results show that overhangs depth depends on their orientation.

Keywords: *Photovoltaic panels, Overhangs, Embodied Energy, EnergyPlus*

1. INTRODUCTION

Of the total energy consumed by a household consumes in a year, more than three-quarters of the energy is spent on heating, cooling and lighting, while the rest is spent on household electrical appliances (electric equipment). Reducing energy consumption is of great importance not only for the individual, but also globally, as the burning of fossil fuels into the atmosphere emit significant amounts of greenhouse gases, primarily carbon dioxide. It also fossil fuels are a limited resource, which in nature is less and it should be used very cautiously.

By applying the principles of building with passive energy elements which include elements of shading horizontal roof overhangs that is improving the indoor comfort, reduces the consumption of primary energy and hence reduce greenhouse gas emissions. When designing strive to (aspire to) better insulation of the building from outside influences, to reduce energy exchange, on the other hand it is necessary in the best way to utilize energy from the environment in order to achieve even better results. The implementation of these principles in the stage of designing buildings, is the most effective way to achieve good results in reducing the energy required for heating, cooling and lighting.

In the published works that explore the impact of installing roof overhangs on the energy consumption was not investigated how installation roof overhangs influence on the common consumption of energy for heating, cooling and lighting. In this paper, the effect of shadowing by horizontal roof overhangs covered with photovoltaic panels was investigated on the primary energy consumption for heating, cooling and lighting of the residential building throughout the year. Optimization is performed with the simultaneous operation of the program EnergyPlus and GenOpt to optimize the obtained optimal size horizontal roof overhangs placed over all four walls (east, west, north and south). This is performed with respect to the primary energy consumption for heating, cooling and lighting, and at the same time takes into account the energy that is spent for the construction of concrete horizontal roof overhangs (embodied energy) of the appropriate dimensions [1].

2. DESCRIPTION OF A HOUSE

The house (figure 1) had a plane roof. The house was used by one family, and had the living area of 116.64 m^2. The house had 4 air-conditioned rooms (figure 2). Their floor area was 92.88 m^2. The unconditioned building area was 24 m^2 (the area of anterooms and bathrooms that were not air-conditioned).

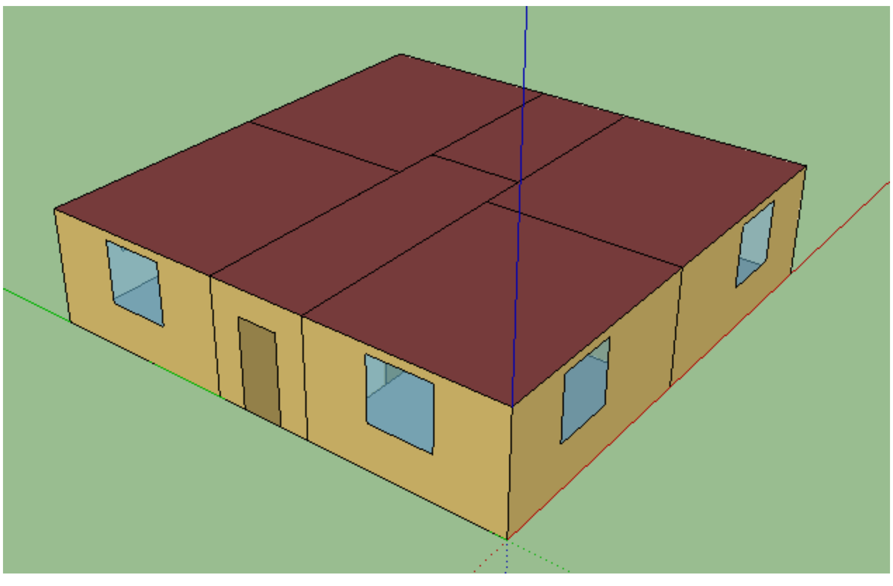

Figure 1 – Model of house

Each air-conditioned room had exterior walls, external windows, interior walls, ceilings, and floors of the same size and composition. In each room, all windows were set to the identical geometrical position relative to the boundaries of room.

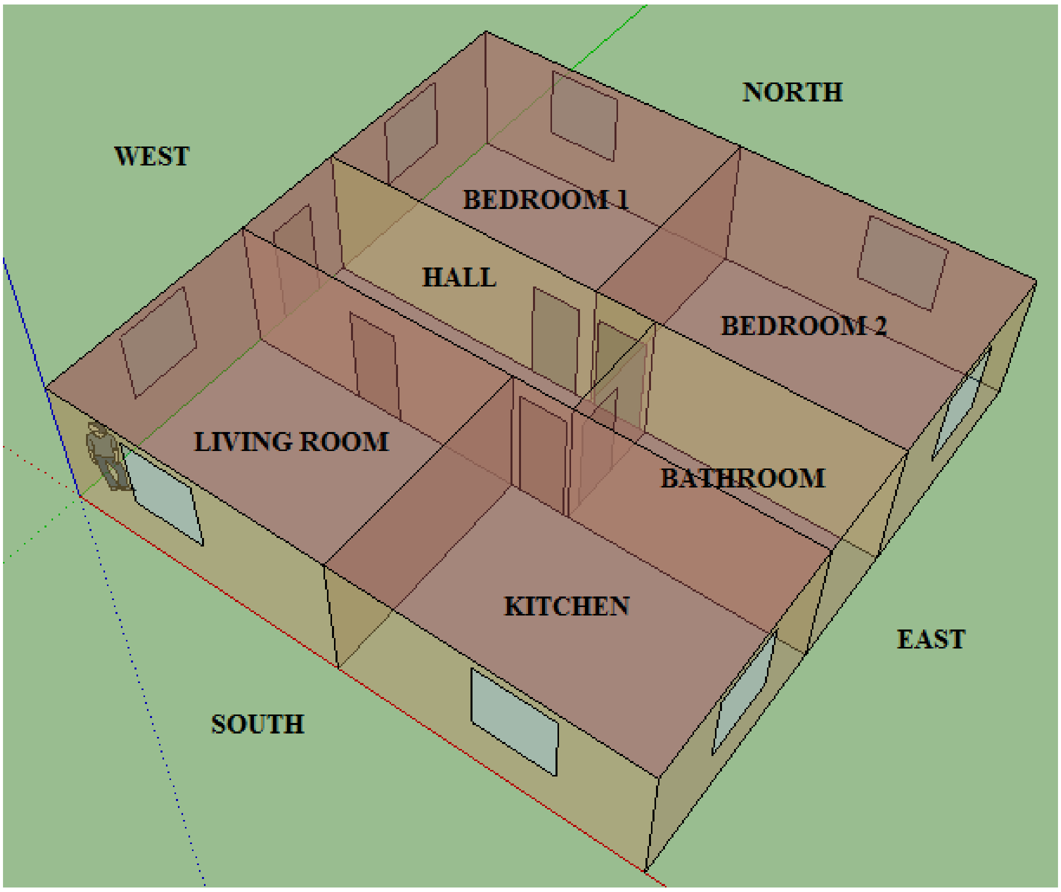

Figure 2 – Room layout

The exterior walls were made (from inside to the outside) by using 0.015 m of lime mortar, 0.19 m of clay block, 0.15 m of polystyrene, and 0.015 m of lime mortar. They had the U-value of 0.24 W/(m^{2}K). The interior walls were made by using 0.015 m of lime mortar, 0.19 m of clay block, and 0.015 m of lime mortar. They had the U-value of 1,53 W/(m^{2}K). The windows were double glazed with the air gap of 13 mm having U-value of 2.72 W/(m^{2}K). The roof was made (from top to bottom) by using 0.04 m of cement screed, 0.08 m of glass wool, 0.16 m of brick, 0.015 m of lime mortar. They had the U-value of 0.4 W/(m^{2}K). The floor was made (from the outside to the inside) by using 0.2 m of sand, 0.15 m of concrete, 0.00015 m of PVC foil, 0.05 m of polystyrene, 0.04 m of cement screed, 0.02 m of carpet. They had the U-value of 0.43 W/(m^{2}K).

The ratio of glass to the surface of the outer wall layer is 13.96%, and the total area of exterior walls is 112.32 m^2 and window area is 15.68 m^2.

3. LOCATION AND CLIMATIC CONDITIONS OF THE OBJECT

Within EnergyPlus software package was used meteorological file SER Belgrade 132720 IWEC.epw describing Meteorological characteristics of Belgrade, Serbia [2]. The average elevation of Belgrade is 99m, and is latitude 44°82N and longitude 20°28E. Belgrade has a moderate continental climate with four seasons of winter, spring, summer and autumn.

4. THE MATHEMATICAL MODEL

To simulate the energy performance of a building EnergyPlus software was used, in which architecture is shaped himself and set all system parameters corresponding to his physical condition (thermal, lighting condition, etc.) and energy exchange with the environment in a given period of time. Finding the optimal size horizontal roof overhangs with photovoltaic panels was made with Hooke Jeeves optimization method with the help of GenOpt, so that the objective function that minimizes the consumption of primary energy for heating, cooling and lighting of the building and when it is taken in the calculation of the energy expended to build a horizontal roof overhangs with photovoltaic panels. The program works by GenOpt is coupled with the two programs EnergyPlus one of them with fixed parameters, and the other with variable parameters in which the optimization is performed. The ".ini" file defined the objective function and all necessary parameters and variables that are required for optimization as well as input, output and configuration files. The command file is given as the pattern of the traits that are necessary for the execution of the optimization algorithm (in this case Hooke Jeeves Algorithm).

To ensure adequate thermal comfort in winter, electric heaters was used. Heating thermostat is used to set the appropriate temperature in winter mode. In summer mode to maintain proper thermal comfort in rooms is used room air conditioners with the appropriate thermostat. Room air conditioners are also supplied with electricity. To maintain an appropriate light level, the combined impact of daylight and electric lighting, using DayLightingControls function (this function is implemented in EnergyPlus), which is available by entering the appropriate parameters set dimmer room in a given time interval [2].

The simulation results are obtained in the output file, and that the optimum horizontal roof overhangs size with photovoltaic panels and power consumption of heating, air conditioning, lighting and total consumed primary energy.

5. ENERGY

5.1 Primary energy consumption

Primary energy consumption of the analyzed object is calculated by the following equation:

$$E_{prim} = (E_{ac}+E_{eh}+E_{eq}+E_{el}-E_{pp})K_{ec} \quad (1)$$

Where the E_{ac} stand for electricity consumption in the indoor air conditioners, E_{eh} - electricity consumption of the electric heating, E_{eq} - electricity consumption for the electric equipment, E_{el} electricity consumption for lighting, E_{pp} - energy produced from photovoltaic panels and K_{ec} - primary energy factor (PEF). This factor is defined as the ratio of total primary energy consumption by energy sources (hydro, coal, oil, hevy oil and natural gas) and the total supplied electricity when not taking into account the imported electricity. For Serbia, the value of manufactured and supplied electricity on average in 2010th and 2011th amounts K_{ec}= 3.04 [3] (this value varies from year to year and depends on the season hydrological situation).

$$K_{ec}=(m_{c1}H_{d1}+m_{c2}H_{d2}+m_{c3}H_{d3})/Eec,f \quad (2)$$

5.2 Embodied energy

Embodied energy for horizontal roof overhangs depends on size and type of material, given in the third equation:

$$E_{emb}=\rho\ \delta\ l\ h\ s_{ec}/f_n \quad (3)$$

The optimization was performed in respect to the length of the exhaust horizontal roof overhangs h, where ρ stand for material density for roof overhangs (concrete, ρ=2150 kg/m^3), l stands for the width of the roof overhangs that relies on the buildings wall (10.8 m), δ thick of roof overhangs (0.18 m), h length of roof overhangs, s_{ec} roof overhangs specific embodied energy (1.924 MJ/kg) [4], f_n roof overhangs lifecycle (20 years).

5.3 The total energy

The total energy is equal to the sum of the primary energy and embodied energy as shown in Equation 4:

$$E_{tot}=E_{prim}+E_{emb} \quad (4)$$

Equation 4 is the objective function.

5.4 The achieved energy savings

Realized savings of primary energy for heating, cooling and lighting is calculated for the house with the roof overhangs set in relation to an object without roof overhangs installed:

$$e_{psav} = 100(E_{p0}- E_{pmin})E_{p0} \quad (5)$$

Where is e_{psav} - achieved primary energy savings in %, E_{pmin} - primary energy consumed in house before installation the roof overhangs, E_{p0} - primary energy consumed in a facility without roof overhangs.

6. RESULTS

6.1. Results before optimization

As already noted, the house most of the energy spent on heating, cooling and interior lighting. House without horizontal roof overhang spent annually 183 kWh/m^{2}a to heating, 101 kWh/m^{2}a to cooling, while interior lighting spent annually 40 kWh/m^{2}a.

The results also show that power consumption can be reduced if the house has a horizontal roof overhangs (depth 1 m) covered with photovoltaic panels. Table 1. shows the results for different combinations.

Table 1 – Results of energy consumption for different combinations

House	[kWh/m^{2}a]		
	Heating	Cooling	Interior lighting
Without overhangs and photovoltaic panels	183,5	101,4	40,5
All four sides	199,5	69,7	42,2
East – West	190,7	84,2	41,1
North – South	191,9	86,8	41,5

6.2 Results of optimization

Optimal depth horizontal roof overhangs covered with photovoltaic panels in different variants are shown in table 2.

Table 2 – Optimal depth horizontal roof overhangs covered with photovoltaic panels

House	Depth			
	East [m]	West [m]	North [m]	South [m]
Without	/	/	/	/
All four	**2.41**	**2.51**	**1.81**	**2.74**
East – West	**2.84**	**2.74**	/	/
North – South	/	/	**2.81**	**2.78**
East	**3**	/	/	/
West	/	**1.31**	/	/
North	/	/	**1.22**	/
South	/	/	/	**1.91**

Houses without horizontal roof overhangs covered with photovoltaic panels consumes the most primary energy (409,1 kWh/m^{2}a), then the total energy is equal to the primary. House with horizontal roof overhangs covered with photovoltaic panels on all four sides spends at least primary (and total) energy (E_{tot}=135.2 kWh/m^{2}a, $E_{p\text{-}rim}$=123.9 kWh/m^{2}a), but then embodied energy consumption is highest (figure 3).

Figure 3 - Energy consumption for different combinations

House with horizontal roof overhangs covered with photovoltaic panels on all four sides products the most energy (77 kWh/m^{2}a). House with horizontal roof overhang covered with photovoltaic panels on east side products more energy than house with horizontal roof overhang covered with photovoltaic panels on west (or south, or north) side, because it is the deepest (table 3).

Figure 4. shows the production of energy for different combinations.

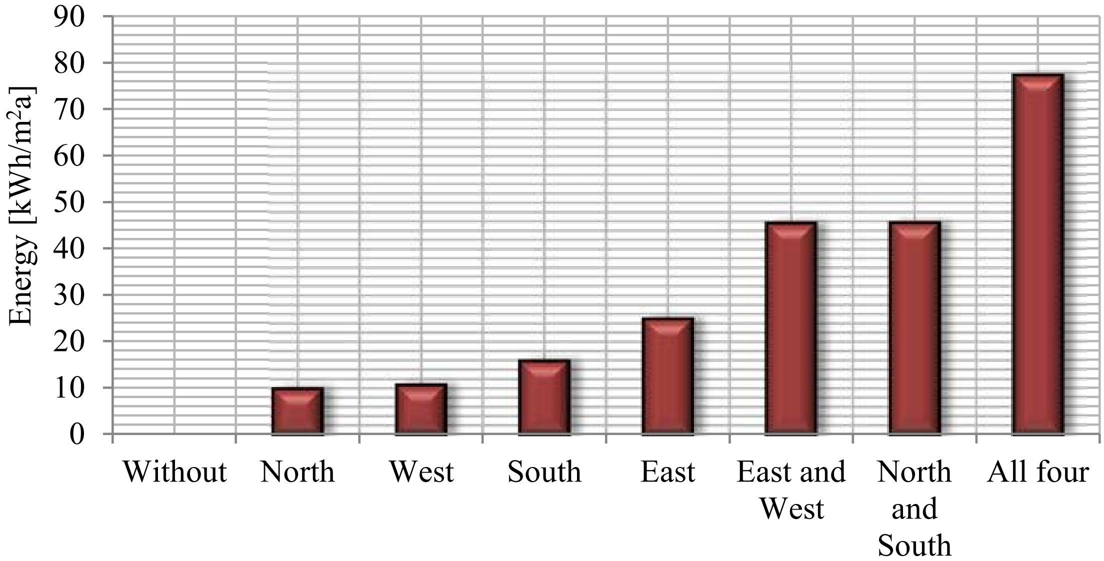

Figure 4 – Production energy from photovoltaic panels

7. ENERGY SAVING

The results show that it is possible to save up to 67% if the house owns horizontal roof overhangs covered with photovoltaic panels on all four sides (figure 5). If the house owns horizontal roof overhangs covered with photovoltaic panels on east and west, when possible savings of up to 45.6%, or 45.7% if the house owns horizontal roof overhangs covered with photovoltaic panels on north and south. If the house owns horizontal roof overhang covered with photovoltaic panels on south side, when possible savings of up to 20.4%.

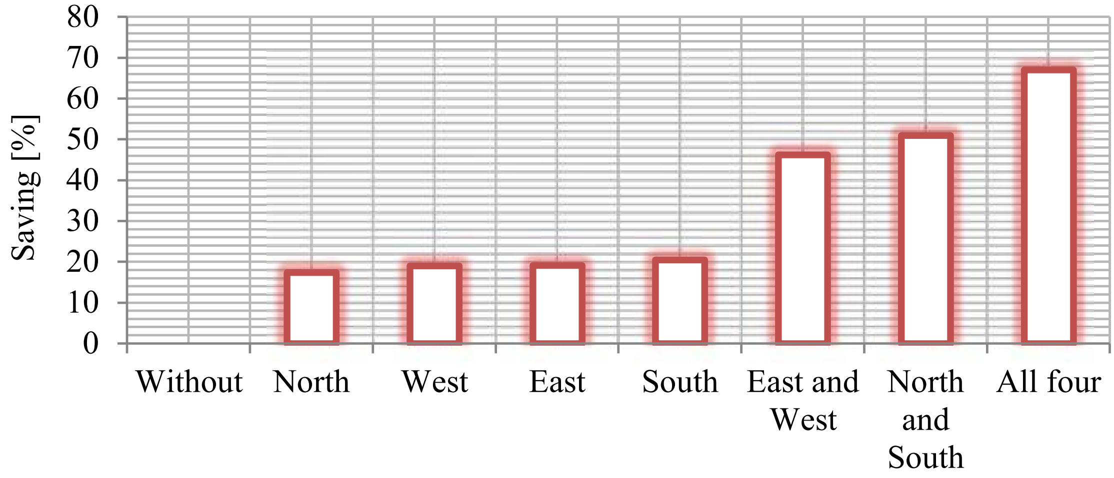

Figure 5 – Energy saving for different combinations

8. CONCLUSION

Installing overhangs optimal depth and photovoltaic panels that cover them completely, has a positive impact on energy saving houses with overhangs and photovoltaic panels in relation to the house without them.

By analyzing the results of optimization can be concluded that in the case of installing horizontal roof overhangs covered with photovoltaic panels on all four sides, the depth of overhang on the south side is 2.74 m, 1.81 m to the north, on the east side 2.41 m, while on the west 2.51 m.

A house that has horizontal roof overhangs covered with photovoltaic panels on the north and south, north overhang is 2.81 m, and the south is 2.78 m.

A house that has horizontal roof overhangs covered with photovoltaic panels on the west and east, west overhang is 2.74 m, and the east is 2.84 m.

If the house has only eastern horizontal roof overhang covered with photovoltaic panels, its optimal depth is the largest (3 m), while the lowest depths of the north (1.22m).

Modern development requires turning to energy efficiency, energy savings, cost effectiveness and renewable energy sources.

Design shading, canopies optimal combination of architecture depth covered with photovoltaic panels, a modern expression and response to issues of energy independence and efficiency of the house, as well as independence from fossil fuels.

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NOMENCLATURE

E_{prim} – annual consumption of primary energy,
E_{ac} – annual electricity consumption of the air conditioners,
E_{eh} – annual electricity consumption of the electric heating,
E_{eq} – annual electricity consumption of the electric equipment,
E_{el} – annual electricity consumption of the electric lightting,
E_{pp} – annual energy produced from photovoltaic panels,
E_{emb} – embodied energy,
E_{tot} – total annual energy,
K_{ec} – primary energy factor (PEF),
h – length of roof overhangs,
ρ – material density for roof overhangs,
l – length of the exhaust horizontal roof overhangs,
δ – thick of roof overhangs,
s_{ec} – specific embodied energy,
f_n – roof overhangs lifecycle,
$e_{psav\%}$ – achieved primary energy savings in %,
E_{pmin} – primary energy consumed in house afther installation the roof overhangs,
E_{p0} – primary energy consumed in house without roof overhangs,
E_{popt} –primary energy consumed in house afther installation the roof overhangs optimal dimensions,
$e_{p\%}$ – reduction of primary energy.

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