SimTerm 2019

Energy – Efficiency – Ecology

PROCEEDINGS

19th International Conference on
Thermal Science and Engineering of Serbia

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Contents

Energy Analysis of Solar Greenhouse with Photovoltaic System and Heat Pump

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Abstract: Greenhouses have significant importance in the field of agriculture and horticulture. A special type of greenhouse is solar greenhouse, which is designed to collect solar energy during sunny days and to store heat for use at night or during periods without the Sun. In this paper it is investigated a solar greenhouse with photovoltaic panels. For greenhouse heating in the winter period and cooling in the summer period, a ground source heat pump was used. Solar greenhouse is simulated in EnergyPlus environment, while Open Studio plug-in in Google SketchUp was used for greenhouse design. Energy analysis was performed with the major aim to minimize greenhouse energy consumption, and to achieve solar greenhouse with net-zero energy consumption. Cases of different solar greenhouse orientations, different photovoltaic slope and different photovoltaic cell efficiency were considered. The simulation results showed that total energy consumption for heating and cooling of the greenhouse can be significantly reduced by using the optimal parameters (orientation and photovoltaic slope angle). Also, by changing the photovoltaics area and by using photovoltaics with higher cell efficiency, a concept of net-zero energy solar greenhouses can be achieved.

Keywords: Solar greenhouse, Photovoltaic, Heat pump, Energy consumption.

1. Introduction

The rapid population increase over the last two centuries has caused a major economic development, which influenced more energy consumption in the world. In recent years, question of energy security and stability has become the cardinal question of the entire world economy, economic and social system. The whole world today is 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.

Agriculture has relatively small share in total final energy consumption in both, industrialized and developing countries. Modern agriculture requires energy use at all stages of agricultural production: water management, irrigation, cultivation, harvesting and also farm machinery. In OECD countries around 3-5% of total final energy consumption is used directly in the agriculture sector, while in developing countries that range is 4-8% of total final commercial energy use [1]. According to the European energy statistics the total final energy consumption of the 27 EU countries of the sector "agriculture/forestry" was given as 1,071 PJ, which is corresponding to 2.2 % of the total final energy consumption in the European Union [2].

Greenhouses are widely used today all over the world, for indoor cultivation of vegetables, flowers, trees and other agricultural plants. They give better quality of plants and protect them from natural environmental effects such as wind or rain. At the other side, greenhouse is giving the ability for out of season growing. This type of agriculture is described as ‘’protected agriculture’’ since it provides mechanical protections against outdoor climatic conditions [3]. Greenhouses are designed to provide control and maintain the amount of solar radiation, indoor air temperature, relative humidity and carbon dioxide levels in the aerial environment [4]. Significant amount of energy is necessary to greenhouse produce process and distribute the crops and plants and energy saving is an important issue for greenhouse farming. Application of solar energy in greenhouses could be of great importance, because it can reduce CO_2 emission and heating costs.

Solar greenhouse is a special type of greenhouse, which is designed not only to collect solar energy during sunny days but also to store heat for use at night or during cloudy periods. Overheating during the day can be prevented using natural or mechanical ventilation for cooling. Ventilation also regulates the relative air humidity [5]. Solar greenhouse uses solar energy with passive or active systems. Passive solar greenhouses are a cost-efficient way for farmers to extend the growing season. Solar heating may be supplemented with some auxiliary heating system to protect plants against extreme cold. Active solar greenhouses use supplemental energy to move solar heated air or water from storage or collection areas to other regions of the greenhouse, or to produce electricity by photovoltaics [6]. Various systems, including steam, hot water radiation system or hot air heater system can be used for greenhouse heating, but it is considered that the ground source heat pump system is a favorable option for greenhouse since it can provide both heating and cooling energy [7]. In recent years, a large number of scientists have been studying various designs of greenhouses that have used solar energy and geothermal energy.

Solar energy usage in commercial greenhouses to electricity supply for the cooling and mechanical ventilation is an economic, sustainable solution. Solar photovoltaic array at greenhouses was the subject of many scientific papers and studies. Hassanien at al. [8] gave a review of the solar energy applications technologies in the environmental control systems of greenhouses (cooling, heating and lighting), generated energy of photovoltaic and the use of photovoltaics for water pumping for irrigation. They also showed economic analyses of this technology. Fatnassia at al. [9] analyzed two arrangements of photovoltaic panels array (straight-line and checkerboard) in two different prototypes of greenhouses with Computational Fluid Dynamic model. The study shows that compared to the straight-line arrangement, the checkerboard photovoltaic panel setup improved the balance of the spatial distribution of sunlight received in the greenhouse. Wang at al. [10] in their paper represent an integration of solar technology to modern greenhouse in China. They shown that China's modern solar greenhouses with photovoltaic (PV) has payback period of less than 9 years. Trypanagnostopoulos at al. [11] considered how PV installation influenced to the plant shading in the greenhouse. Photovoltaics were the fixed one, with panels placed on south facing greenhouse roof and two sun tracking modes. Allardyce at al. [12], Hassanien at al. [13] and Roslan at al. [14] describe the greenhouse with building integrated photovoltaics and their limitations. They have paid attention to the semi-transparent PV with Dye-Sensitized solar Cells, (DSSC) as alternative greenhouse glazing that offers advantages including enhanced thermal stabilization and improved yields. Influence of solar greenhouse shape to thermal performances analyzed Mobtaker at al. in their paper [15]. Yano and Cossu [16] investigate PV electricity generation in solar greenhouses, PV shading effects on plants and important aspects of greenhouse cultivation. Gao at al. in [17] considered energy performance of greenhouse with sun-tracking photovoltaics and concluded that quasi-perpendicular sun tracking improves the annual energy generation for 7.40 % compared to the closed position.

Using a different heat pumps system in greenhouse enables large energy savings for heating and cooling. Yang at al. [18] investigated heat pump system that used surplus air thermal energy and underground water thermal energy as heat sources for greenhouse. Significant energy saving was achieved by using two of this type of heat pump. Yang and Rhee evaluated a surplus air heat pump system for greenhouse cooling and heating in Korea [19], and determined maximum energy savings of 76.3 % daily and 25.7 % monthly. Benli in his paper [20] gave the comparison between a horizontal source and vertical source heat pump systems for a greenhouse heating in the mild climate in Elaziğ, Turkey. The results showed that the utilization of the ground-source heat pump is suitable for greenhouse heating in this region. Noorollahi at al. carried out numerical modeling and economic analysis of greenhouse with a ground source heat pump in Iran [21]. Gas burning heating system and an evaporative cooling system are considered to supply the greenhouse energy, and they were compared with the GSHP system. The conclusion is that, due to the high price of electricity and heat pump units and low price of natural gas in Iran, using GSHPs for greenhouses in Iran is not cost-effective. Hassanien at al. [22] investigate the performance of using evacuated tube solar collector as a solar water heater assisted an electric heat pump for greenhouse heating in China. This integration provide more than 35% of the total required heat for greenhouse. Awani at al. [23] analyzed two cases of greenhouses: one with heat pump (water/air) which was coupled with flat plate collector and the other with a vertical heat exchanger in order to obtain a comfortable climate in the winter in the greenhouses. Good results are obtained comparing with others similar results in research area. Russo at al. [24] carried out environmental analysis of the efficiency of a Photovoltaic-Geothermal Heat Pump integrated system as a greenhouse heating system, compared to a conventional hot air generator using liquefied petroleum gas. The estimated payback-time for energy and for carbon emissions were 1 year and 2.25 years, respectively.

By installing more renewable energy technologies simultaneously in a solar greenhouse, the concept of nearly-zero greenhouses can be realized easily. Yildirim and Bilir [25] presented the evaluation of a hybrid system for a nearly zero energy greenhouse in the Mediterranean climate. A hybrid system consisted of grid connected photovoltaics which generate sufficient electrical energy for lighting and assist a ground source heat pump. In this way, a nearly zero energy greenhouse concept is foreseen for three different agricultural products. Yearly coverage ratio values were between 86.8% and 104.5%. Sun at al. in [26] analyzed the possibilities for improving the traditional greenhouse to new low-cost near-zero-energy solar greenhouse in China. The main technical measures include internal and external insulation envelope using reflective aluminum knitting film; the ecological water circulation system for solar heat storage and collection, and geothermal energy utilization. It was concluded that the new solar greenhouse without artificial heating can achieve nearly zero net energy concept.

By reviewing the literature, it was found that there are no researches in the field of greenhouses with the use of renewable energy sources in the Serbia, which was a great challenge for investigation in this field. This particular fact is supported by the increasing energy consumption and energy saving opportunities with the use of renewable energy sources. The city of Kragujevac belongs to the Sumadija region, which has the great opportunities for agriculture production, especially due to good climate conditions. In order to improve agricultural production, the number of greenhouses has increased in the recent years. At the other side, a large amount of energy can be saved by using a photovoltaic system and a geothermal pump in a solar greenhouse, as shown by the results of this research. By setting a sufficiently large photovoltaic system it is possible to even realize the concept of zero energy solar greenhouse concept.

This paper represents energy analyses of solar greenhouse located in Kragujevac, Serbia. A ground source heat pump is implemented for heating in the winter period and cooling in the summer period, while grid connected photovoltaics generate the electricity. When photovoltaic array produce more electricity than greenhouse needs, the rest of PV generated electricity will be fed-in the electricity grid. When the PV system don`t satisfy the greenhouse needs for electrical energy, then the electricity will be used from the electricity grid. Energy analysis was performed with the major aim to minimize greenhouse energy consumption, and to achieve solar greenhouse with zero net energy consumption. Solar greenhouse is simulated in EnergyPlus environment, while Open Studio plug-in in Google SketchUp was used for design of the greenhouse with implemented systems. Cases of different solar greenhouse orientations, different photovoltaic slope and different photovoltaic cell efficiency were considered. In a case of higher cell efficiency of PV array, nearly zero energy solar greenhouse concept can be achieved.

2. Model of analyzed solar greenhouse

Solar greenhouse, which is analyzed in this paper, is located in the city of Kragujevac, which lays in the Balkan Peninsula in the state of Serbia, around 120 km south of its capital city of Belgrade. Its average height above the sea is 209 m. The latitude of Kragujevac is 44.1^{0}N, the longitude is 20.55 ^{0}E and the time zone is GMT+1.0 h. Kragujevac has a moderate continental climate, with worm and humid summers with temperatures as high as 37 ^{0}C. The winters are cool, with snow and with temperatures as low as -19 ^{0}C [27]. The EnergyPlus software uses weather data from its own data base with weather files.

2.1. Solar greenhouse architecture

The investigated solar greenhouse is shown in Figure 1 and it is south-oriented. Greenhouse has a rectangular shape (20x8 m), with a total area of 160 m^2.

The vertical side walls (east and west) are in the form of an irregular quadruple. The small quadruple south wall (20x0.5 m) is connected with the southern roof which has a slop angle of 40°. At a height of 4.86 m (ridge of greenhouse), the southern roof cuts the northern wall, which has a slope of 60° and it is all the way to the ground. South roof has dimensions 20x6.78 m with total area of 135.6 m^2, of which 126.88 m^2 are windows - there are 60 identical windows with dimensions 2.18x0.97 m. The northern roof has dimensions 20x5.61 m with total area of 112.2 m^2. Two doors (2x2.5 m) are located on the side walls – east and west.

The greenhouse is made from modular elements that enable quick assembly, and the used materials are stable and have lower heat conduction. Greenhouse frame is made of aluminum and it forms its shape. The northern wall, the south wall and the side walls together with the doors are made of non massive sandwich structures that are easily mounted on an aluminum frame. The sandwich structure consists of two layers of aluminum sheet (thickness of 2 mm), with polyurethane foam (100 mm thickness) among them. These structures are available on the market and they have good thermal properties with heat transfer coefficient of the 0.269 W/m^2K.

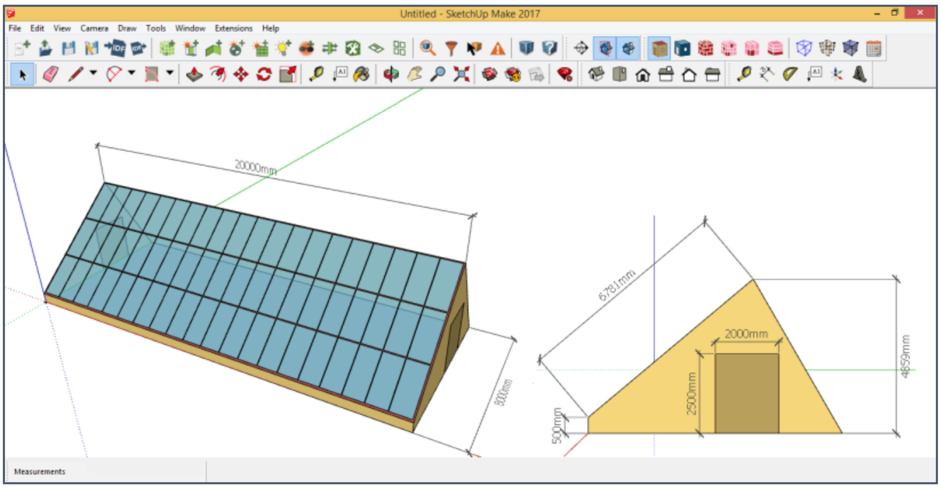

Figure 1. <Solar greenhouse model in Google Sketch-Up>

The windows on the southern roof are double glazed with high-transparent glass of 4 mm thickness and they are positioned at a distance of 13 mm (distances are fill with air space). The coefficient of solar transmission of glass at a normal incident angle is 0.9, solar heat gain coefficient (SHGC) is 0.859 and the U-value is 1.45 W/m^2K. Double glazing prevents condensation and reduces heat losses.

Software EnergyPlus has no developed module for plant implementation, but it has the ability to simulate vegetation on the roofs. In this case, vegetative layer was used on the floor surface to calculate the share of energy absorbed and emitted by the plants.

The schedule provided that in the greenhouse various activities are performed by two people, 5 hours a day per day. The software takes into account people presence and the heat emission which is about 120 W per person.

The air in the greenhouse became aggressive, too humid, full of gases, and it is necessary to replace it with fresh air. By ventilation, these characteristics are altered to match the needs of cultivated crops. Natural ventilation by opening doors and windows is foreseen in the months when the greenhouse is overheated, from April 15th to October 15th. This can significantly save the cooling energy.

2.2. Photovoltaic array

Photovoltaic (PV) array is installed on the ridge of the greenhouse. The dimension of the surface on which the photovoltaic modules are sited is 20x4 m with total area of 80 m^2, while PV cell efficiency was 12 %. This area continues to the southern slope of the greenhouse roof, and this position does not make a shade to the greenhouse (Figure 2). The angle that this surface forms with the horizontal plane ranges from 0-90°.

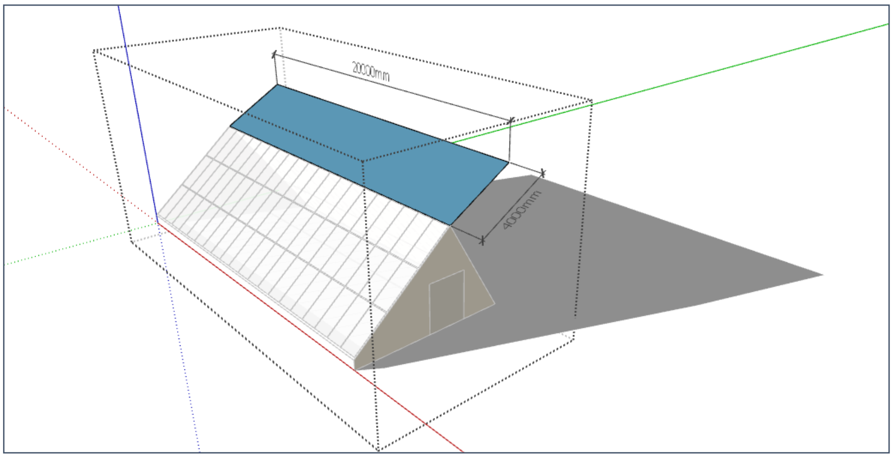

Figure 2. < External surface of the greenhouse model for the installation of photovoltaics>

The PV system consists of the PV array and an inverter. It is an on-grid system. The operation of the PV array is simulated by using EnergyPlus software. The main assumption is that when the PV system operates, generated electricity would be immediately consumed. The surplus electricity is sold to the electricity grid. PV panel is represented by the mathematical model of Generator:Photovoltaic:Simple from EnergyPlus [28], which describes a simple model of PV that may be useful for early phase design analysis. The Generator: Photovoltaic:Simple object represents the simplest model to predict photovoltaic energy production. In this model, the user specifies the efficiency with which the PV array converts the incident solar radiation to electricity. (In the other models, this efficiency is an output of the model.) The full geometric model for solar radiation is used, including sky models, shading, and reflections, to determine the incident solar resource.

2.3. Ground source heat pump

In this paper, a unique heating and cooling system was used, using a geothermal heat pump, which in the scientific research proved to be the most cost-effective. Ground source heat pump indirectly uses geothermal energy and has high efficiency.

Figure 3 schematically describes the heat pump loop. The working fluid on the Source side of the loop is water mixed with 15% glycol. Water circulates with circulation pump and thus transfers heat. In the winter period, heat is drawn from the earth, which has a constant temperature of about 14 ˚C [19]. The working fluid in the earth evaporates and the vapor goes to the compressor station. The steam under pressure raises its temperature and with the tendency to surrender its heat, enters the heat exchanger where it cools and condenses. The condensate, which is still under pressure, encounters the expansion valve in order to reduce the pressure, which creates the conditions for the liquid to evaporate again. In this state, the liquid re-enters the exchanger in the ground and absorbs the heat required to evaporate, thereby closing this circuit and repeating it until the pump operating mode changes [29].

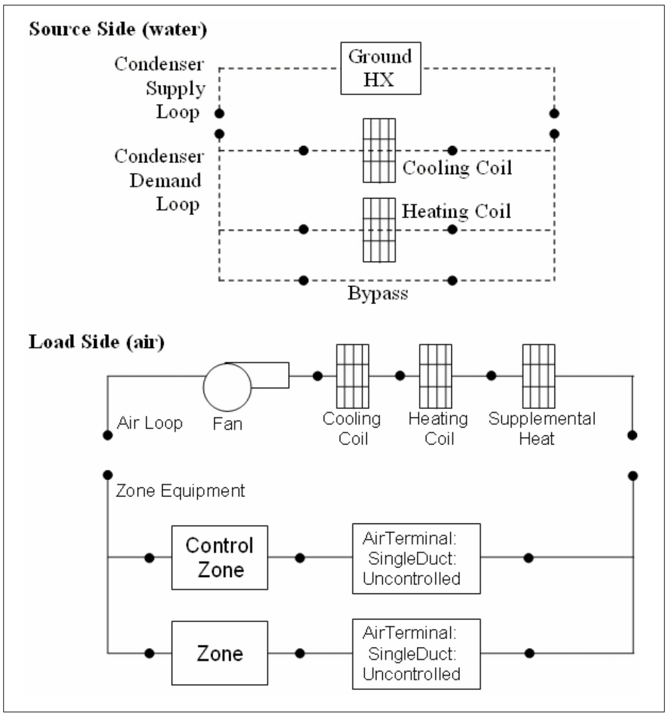

Figure 3. < Source Side and Load Side Configuration of Water To Air Heat Pump [29]>

The Load side of the system uses air as a working fluid, which receives heat from the water in the heat exchanger and, through the channel system with the fan, enters into thermal zone. In addition, this loop has an additional heater that uses electricity (in this case) and it is activated as needed when the temperature of the air supplied by the heat pump does not meet the needs of the thermal zone. In front of the heat exchanger there is a mixer in which the external air enters and refreshes the air transported in the thermal zone, while at the exit from the thermal zone, part of the air is released into the environment.

The heat pump changes the mode between cooling and heating depending on the zone's need using a thermostat and return valve. EnergyPlus defines two heat exchangers (heating and cooling) to approach the operation of a single heat exchanger that can operate in the heating or cooling mode. The 25 W circulation pump conducts a constant fluid flow rate of 0.0033 m^3/s. Vertical ground heat exchanger consists of U tubes with length of 76.2 m, diameter 6.35 cm and heat conductivity coefficient 0.391 W/mK. The heat exchanger, which delivers heat to the consumers, has nominal capacity of 25 kW and an auxiliary heater of 32 kW [29].

Heating is needed during the cold season and can increase the growth of summer plants with keeping the temperature of the greenhouse above the ambient temperature. In the winter period, heat is drawn from the ground, which has a constant temperature of 14℃. During the summer temperatures in the greenhouse reach over 50℃, which plants can`t stand, so it is necessary to cool the air. Natural ventilation in that case is not enough, and then other conventional cooling devices must be used.

Air temperatures in the greenhouse are defined in relation to the needs for cultivation of different cultures in different periods. The heating or cooling mode in EnergyPlus software is regulated by adjusting the thermostats. The following schedule was adopted:

- heating mode: in the period from November 1st to April 1st, air temperature 16 ^{0}C (from 07-17 h) and 10 ^{0}C (from 17-07 h);
- cooling mode: from April 1st to November 1st, air temperature 28 ^{0}C (from 07-19 h) and 10 ^{0}C (from 19-07 h);

3. Results and discussion

3.1. Different solar greenhouse orientation

Solar greenhouse with photovoltaic array (slope 40^o) is simulated for four different orientations (Figure 4): northwest-southeast 20^o from east-west orientation (NW-SE 20^o), east-west (E-W), northeast-southwest 20^o from-west east orientation (NE-SW 20^o) and northeast-southwest 40° from E-W orientation (NE-SW 40^o).

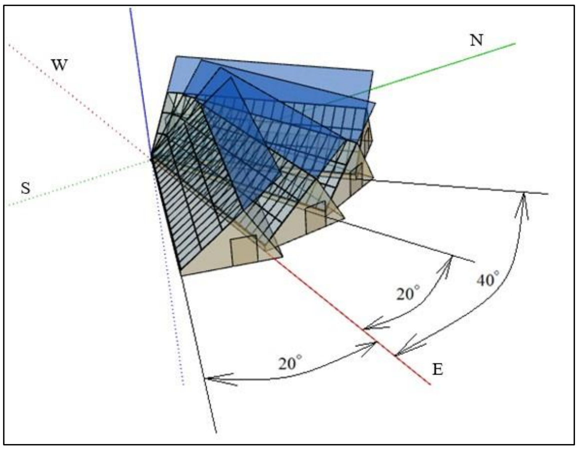

Figure 4. < Different orientation of solar greenhouse with photovoltaics (slope 40^o)>

The simulation results show that total energy consumption of greenhouse is changing with greenhouse orientation. Differences in total energy consumption are not great, but any energy saving is significant. Total energy consumption of greenhouse with northwest-southeast 20^o, east-west, northeast-southwest 20^o and northeast-southwest 40^o are 50.53 GJ, 50.2 GJ, 49.94 GJ and 49.69 GJ, respectively (Tab. 1). All simulations were done for a period of one year. According to these results, if the turning of greenhouses from south to north is observed, total energy consumption is reduced, so the most optimal orientation is the northeast-southwest 40^o. The greenhouse oriented to the west consumes the most energy for cooling compared to the other orientations, while it does not have the least energy consumption for heating. In the summer, the east-west oriented greenhouse is the most open to receiving solar energy, and therefore it takes a lot of energy for cooling. On the other hand, in the winter, solar radiation reduces the heating energy consumption. The only reason why the northeast-southwest 40^o oriented greenhouse (closest to the north) has the lowest energy consumption is due to the ratio of the required energy for heating and cooling, which is somewhat higher in favor of cooling (Fig. 5). This orientation is more opened to the east, where the Sun is coming out, and in the afternoon, the western wall creates a shadow that almost does not exist at the east-west orientation.

Table 1. <Total energy consumption, heating energy, cooling energy, generated and net-energu consumption in solar greenhouse wuth photovoltaics and different orientation>

Orientation	Total energy consumption (GJ)	Heating energy (GJ)	Cooling energy (GJ)	Generated energy (GJ)	Net-energy consumption (GJ)
NW-SE 20˚	50.53	10.62	12.09	25.76	24.77
E-W	50.2	10.42	11.95	25.91	24.29
NE-SW 20˚	49.94	10.48	11.64	25.5	24.40
NE-SW 40˚	49.69	10.76	11.11	24.57	25.12

Total generated energy for greenhouse with northwest-southeast 20^o, east-west, northeast-southwest 20^o and northeast-southwest 40^o are 25.76 GJ, 25.91 GJ, 25.5 GJ and 24.57 GJ, respectively. It is clear that most electricity is produced when photovoltaic array is turned to the east – west. Net-energy consumption is in all analyzed cases about 50 % from total energy consumption (Fig. 6). Generated electricity is used to supply the heat pump. By subtracting generated energy from the total energy consumption for four orientations it can be concluded that the lowest net-energy consumption is obtained for east-west oriented greenhouse.

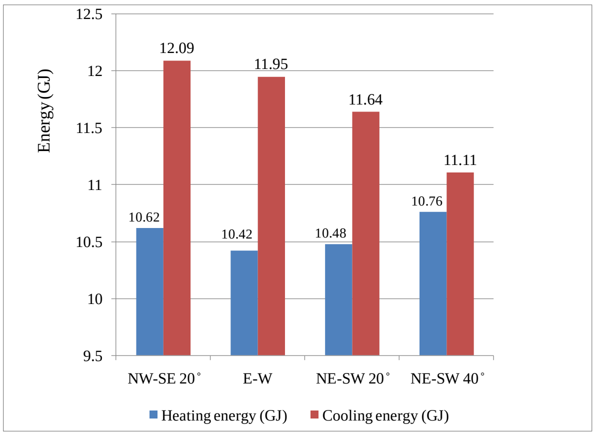

Figure 5. <Heating and cooling energy consumption in solar greenhouse with photovoltaics and different orientation>

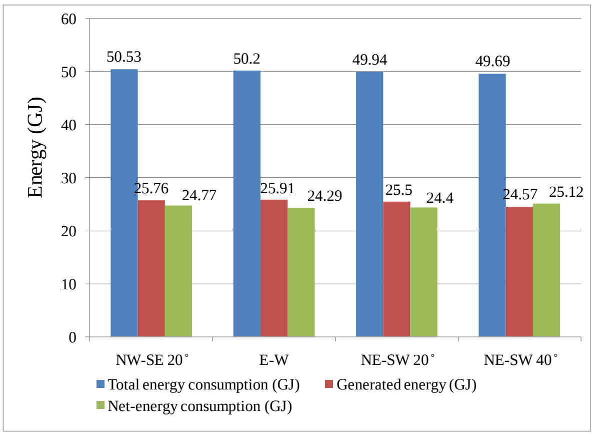

Figure 6. <Total energy consumption, generated electricity and net-energy consumption in solar greenhouse with PV array and different orientation>

3.2. Different slope angle of PV array

Electricity generation depends of photovoltaic slope. It is necessary to set PV panels in the optimum slope angle, where the photovoltaic cells will have the greatest involvement of the solar radiation. The model of photovoltaics with slope angle of 40^o (previous simulations) is rotated, so photovoltaic modules with a slope of 0˚(horizontal modules), 20˚, 30˚and 90˚(vertical modules) are simulated (Fig 7).

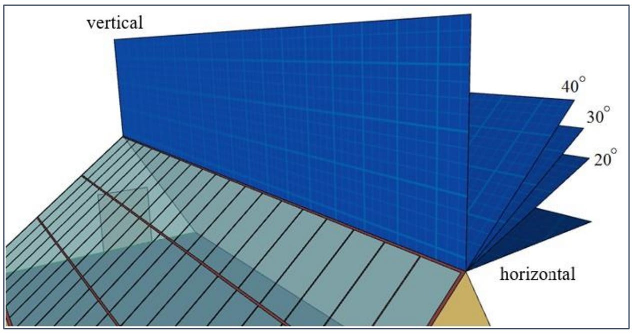

Figure 7. < Different slope angle of photovoltaics>

The greenhouse during the rotation of the module has the same orientation all the time - east-west. By simulating the photovoltaic modules from these four slopes, results were obtained for comparison of the produced electricity with the already known result of the module with a slope of 40˚. When the FN modules have a horizontal position, 22.92 GJ of electricity is produced, 20.56 GJ of electricity is produced when the slope is 20˚, 26 GJ is produced at slope of 30˚, and at vertical position of PV array generates 17.33 GJ electricity

(Table 2, Fig. 8). According to these results, it can be concluded that the most optimal slope of photovoltaics is 30 °.

Table 2. <Total energy consumption, heating energy, cooling energy, generated and net-energu consumption in solar greenhouse wuth photovoltaics and different orientation>

Slope angle (°)	Generated electricity(GJ)	Generated electricity/total energy consumption (%)
0	22.92	45.68
20	25.56	50.92
30	26.03	51.85
40	25.91	51.62
90	17.33	34.61

Horizontal PV modules satisfy 45.68 % of the total energy consumption, photovoltaic modules with a slope of 20˚, 30˚and 40˚meet 50.92 %, 51.85 % and 51.62 % of energy needs, while vertical modules satisfy 34.61% of total energy consumption.

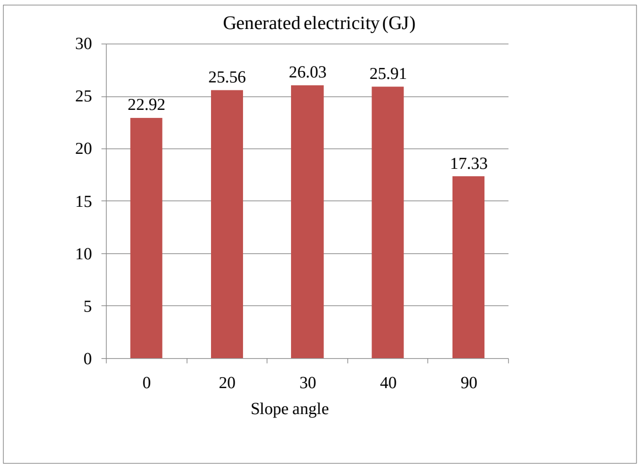

Figure 8. <Generated electricity in solar greenhouse with different photovoltaic slope>

3.3. Different photovoltaic cell efficiency

Photovoltaic cell efficiency directly influences to the electricity generation in PV array. Previous simulation was done with PV cell efficiency of 12 %, because these modules are cheapest and the most widespread on the market, but they are not always the best solution. In this investigation, cell efficiency of 14 % and 16 % are considered.

Simulation of greenhouse with optimal orientation (east-west) and optimal slope (30°) of photovoltaic array shows that the total electricity generation with PV cells efficiency of η=14% is 30.37 GJ and with PV cells efficiency of η=16% it is 34.71 GJ (Table 3 and Fig. 8), which is significantly higher than the generated energy of 26.03 GJ with PV cells efficiency of 12%. With the increase the PV cell efficiency, net-energy consumption is significantly reduced: 19.83 GJ for PV cells efficiency of 14 % and 15.49 GJ for PV cells efficiency of 16%, compared to total greenhouse energy consumption of 50.2 GJ.

Table 3. <Generated energy, net-energy consumption and satisfaction of greenhouse energy needs in solar greenhouse with optimal parameters and different PV cell efficiency>

PV cell efficiency (%)	Total energy consumption (GJ)	Generated energy (GJ)	Net-energy consumption (GJ)	Generated electricity/total energy consumption (%)
12	50.2	26.03	24.17	51.85
14	50.2	30.37	19.83	60.5
16	50.2	34.71	15.49	69.14

Electricity generated with PV cell efficiency of 14% meets 60.5% of greenhouse energy needs, while PV cell efficiency of 16 % satisfies 69.14% of total energy consumption in the greenhouse (Figure 9, Table 3).

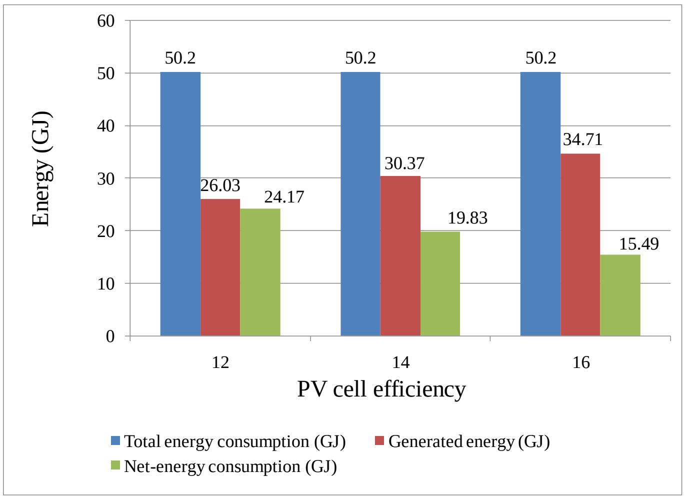

Figure 9. <Total energy consumption, generated electricity and net-energy consumption in solar greenhouse with PV array and different PV cell efficiency>

3.4. Net-zero energy solar greenhouse

Solar greenhouse of net-zero energy consumption is solar greenhouse whose systems use renewable energy sources to produce as much energy as the total energy consumption of solar greenhouse.

The obtained simulation results of the solar greenhouse with PV array total area of 80 m^2 show that this capacity is insufficient to produce enough energy to meet the energy needs of analyzed solar greenhouse. The maximum electricity generation is 69.42 % of the total energy consumption, and according to this relationship, the area of the PV array should be 116 m^2 for the production of electricity equal to the total energy consumption. According to the previous statement, the model of implemented photovoltaics was modified in the SkechUp program by increasing the external surface width by 1.8 m (Figure 10). This increasing in photovoltaics width resulted with electricity generation in amount which is just a little more than total energy consumption of solar greenhouse with defined optimal parameters.

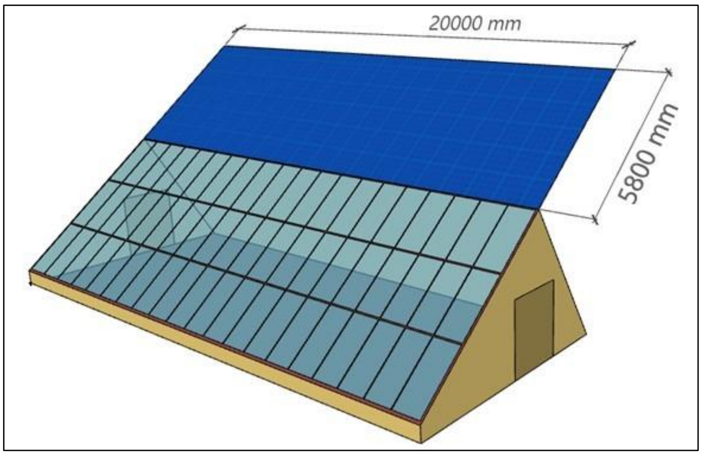

Figure 10. <Model of solar greenhouse with photovoltaic area of 116 m^2>

By simulating east-west oriented solar greenhouse with PV modules of total area of 116 m^2, with slope angle of 30^o and photovoltaic cell efficiency of 16 %, it can be concluded that the net-energy consumption is -0.13 GJ, *i.e.* generated electricity is more than total energy consumption (Table 4). Energy production reaches 100.26 % of total energy consumption.

Table 4. <Total energy consumption, generated energy, net-energy consumption and satisfaction of greenhouse energy needs in solar greenhouse with different PV area and optimal parameters>

	Total energy consumption (GJ)	Generated electricity (GJ)	Net-energy consumption (GJ)	Generated electricity/total energy consumption (%)
Greehhouse with PV area 80 m^2	50.2 GJ	34.71	15.49	69.14
Greehhouse with PV area 116 m^2	50.2 GJ	50.33	-0.13	100.26

Conclusion

The basic idea of this investigation was to determine the orientation and slope angle of PV array, at the simulated solar greenhouse model in EnergyPlus software, which enable the greatest possible electricity generation, and, achieving net-zero energy consumption in the greenhouse.

First, by comparing the results of energy consumption for heating and cooling in solar greenhouses with ground source heat pump and the electricity generation with PV (80 m^2) for four different orientations, the east - west orientation was obtained as the best solution, according to the generated electricity. For the east - west orientation, the slope angle of the PV array of 30 ^{o} was adopted as slope angle with maximal generated electricity. For these values of the orientation and slope angle of solar greenhouse, and the cell efficiency of the photovoltaics of 12 %, solar greenhouse had a total energy consumption of 50.2 GJ and net-energy consumption of 24.17 GJ.

The values of generated electricity for PV cell efficiency of 14 % and 16 % were analyzed too. The net greenhouse energy consumption for the adopted efficiency of 16% was reduced by 35.91 % compared to the efficiency of 12 % and it was 15.49 GJ.

The aim of this research also was to achieve the concept of net-zero energy consumption in the solar greenhouse. Therefore, it was necessary to increase the surface of the PV array to 116 m^2, while retaining the other parameters (orientation and slope) and cellular efficiency of the PV module of 16%, which resulted in a net energy consumption of - 0.13 GJ.

Economically, photovoltaic system besides the heat pump requires large investments [10, 11, 25] with a long payment period. With energy savings and increasing of agricultural yields, with the worldwide downward trend in the price of photovoltaic and other renewable technologies, it is expected an increasing application of RES in the field of agriculture.

Bearing in mind the high consumption of fossil energy and the increasing problem of global warming, in the future, humanity must nevertheless turn to the renewable energy sources. Solar energy is certainly a very attractive solution for the generation of energy because the sun is an inexhaustible source of energy and solar conversion extremely clean way of obtaining energy.

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Ovex inzenjering d.o.o. postoji i uspešno posluje na tržištu Srbije od 1991. godine. Preduzeće se bavi inženjeringom, konsaltingom i trgovinom u oblasti tretmana i kondicioniranja vode. Primarni cilj je preduzeća je zadovoljenje potreba za kvalitetom vode u raznim oblastima industrije kako sa stanovišta tehnologije tako i sa stanovišta isporuke opreme i kompleksnih hemijskih sredstava, poštanja u rad, održavanja i praćenja postignutog kvaliteta kod svih svojih potrošača.

Zahvaljujući visoko obrazovanom i obučenom kadru, Ovex inzenjering uspeva da zadolji i najzahtevnije vodorashladne, parne i vrelovodne kotlovske sisteme. Svoju kompetentnost i opredeljenost kvalitetu smo dokazali u dugogodišnjem poslovanju i našim referencama.

Inovacioni centar naprednih tehnologija, ICNT, formiran je na inicijativu grupe redovnih profesora sa Elektronskog fakulteta i Mašinskog fakulteta Univerziteta u Nišu. Shodno tome, nastao je kao rezultat dugogodišnje akumulacije znanja iz različitih oblasti od kojih se izdvajaju Informaciono-komunikacione tehnologije, telekomunikacije, elektronika, energetika, mehatronika, energetska efikasnost i obnovljivi izvori energije.

Osnivanje ICNT podržala je i kompetentna grupa naučnih istraživača i eksperata iz Niškog regiona. Osnovni zadatak ICNT jeste da prati uticaj nauke i tehnologije na ukupni razvoj savremenog društva, da razvija inovativne proizvode i usluge i da pomaže transfer znanja i difuziju novih tehnologija u industriju. Mi sebe vidimo kao sastavni deo Evropskog istraživačkog prostora, ERA (European Research Area) i spremni smo da aktivno učestvujemo u realizaciji međunarodnih, regionalnih, nacionalnih i lokalnih inovacionih i naučnoistraživačkih projekata.

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