ADBU-Journal of Engineering Technology

SIMULATION AND ANALYSIS OF GREEN HOUSE BASED AGRI-VOLTAIC SYSTEM USING ENERGY 3D SOFTWARE

Sandip Bordoloi[1]

[1] Girijananda Chowdhury Institute of Management and Technology,
Guwahati, Assam, India,
sandip_aei@gimt-guwahati.ac.in

Abstract*: Solar energy is useful not only for agriculture but also for generating electricity which has been widely tapped around the world replacing conventional non-renewable energy. The demand for food and energy is increasing at a fast rate and their security has become the prime issue. The sun provides the necessary energy to crops and vegetations to carry out photosynthesis so that plants can grow and bear fruits and vegetables. Agriculture and energy production using PV cells can be used together to form Agri-Voltaic system, which is capable of producing non-conventional energy as well as agricultural products. Agricultural products can be grown in small green houses. These green houses can be installed with solar panel. The performance of green house on roof-integrated with crystalline photovoltaic (PV) system installed located at Guwahati, Assam in North-East India using Energy 3D software have been used here for analysis.

***Keywords*: PV cell, Agri-voltaic, Green house, Agriculture.**

(Article history: Received: 11th January 2021 and accepted 23rd May 2021)

I. INTRODUCTION

With growing concerns about greenhouse gas emissions, the security of conventional energy supplies, and the environmental safety of conventional energy production techniques, renewable energy systems are becoming increasingly important and are receiving a great deal of political attention. In particular, photovoltaic (PV) and concentrated solar power (CSP) systems for the conversion of solar energy into electricity have been found to be technologically robust, scalable, and geographically dispersed and possess enormous potential as sustainable energy sources. A solar electric or photovoltaic (PV) system can reliably produce electricity at home or office. These small or distributed solar systems are often installed by home or business owners to offset their electricity costs [1].

In Germany, the researchers and solar energy pioneers Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems in Freiburg, and Armin Zastrow published a first theoretical study in 1982 showing that there is enough radiation underneath elevated PV arrays to permit cultivation of many different crops. The result of this first theoretical assessment was that for a combined solar PV and agriculture system 2/3 of solar radiation would still be available for plant growth even if the arrangement of solar modules was optimized for solar power generation. Further it was also proved that this radiation distributes almost uniformly over the day so that homogeneous plant growth could be realized. The preliminary conclusion was that this amount of radiation would be sufficient to grow a variety of crops such as rye, barley, oats and sugar beets as well as maintaining livestock underneath the PV system [2].

The concept of using both agricultural land and PV arrays defines the solar cells for dual –use or agri-voltaic system as - The simultaneous use of the same area of land for photovoltaic and agricultural production (which includes aquaculture also).

A broader look into this perspective defines the objectives and benefits of the solar dual-use or agrivoltaic system: A form of land-use in which solar power generation and agricultural or aquacultural production are deliberately combined on the same land plot to reduce land-use conflicts and to achieve socio-economic benefits compared to the single-use of both applications, and b) power savings (self consumption of the generated solar energy) and/or power sales [2].

The solar dual-use or agri-voltaic system has different design concepts which depends on different crop yields or production of electricity. The general concepts will be mainly categorized in

1. “Full” solar dual-use concepts that apply an equal focus on agricultural production and solar energy generation or even prioritize agriculture over energy generation.
2. “Add-on” concepts that prioritize solar energy generation (mostly to generate revenues from Feed-in-Tariffs) with an add-on agricultural component.
3. Solar PV greenhouses.
4. Dual use concepts for aquaculture.

A specific form of solar dual-use that has been applied in different world regions already is the integration of solar energy technologies (mainly solar PV but also solar thermal technologies) into the environmental control systems (cooling, heating, lighting etc.) of greenhouses. Here, different PV technologies have been applied ranging from traditional silicon-cell based modules to flexible cell concepts, and different types of semi-transparent module concepts that allow a higher transition of sunlight to the plants.

Larger solar PV greenhouse applications have been installed in China but also in other regions of the world. In general, the experience with those projects shows that the integration of solar PV and solar thermal (ST) technologies in greenhouses can be very beneficial in terms of energy and cost saving, and in the reduction of the environmental impacts of greenhouse production (water demand, CO2 emissions etc.)[2]. Key challenges are specific crop management, the selection of the most suitable crops and the use of most beneficial solar PV technologies such as semi-transparent cells/ modules to reduce impacts on plant growth [3].

This paper focusses on the agri-voltaic system used in Solar green houses. Two types of green house with rooftop PV array have been designed using Energy 3D software [4]. These two green houses can serve different objectives. While the greenhouse with shed roof can be installed for agricultural products for the market, the green house with gambrel roof can be designed as a small structure which can be constructed in a small space in a inside the boundary of a house. The advantage of having an agri-voltaic green house is that it serve three purposes- growing of agricultural products, generation of electricity and rain water harvesting. The amount of light to be allowed inside the green houses depends on the type of vegetable/ agricultural products that is to be planted/ grown inside the green house. The following agricultural products that can be grown in a green house – tomatoes, Strawberries, Squash, Beans and peas, Broccoli, Leafy greens—spinach, kale, arugula and micro greens, Herbs, Artichoke etc.

II. DESIGN OF AGRI-VOLTAIC BASED GREEN HOUSE

For this work, two Greenhouses with shed roof and gambrel roof have been designed using the software Energy 3D. One green house has two structures adjacent to each other, while the other greenhouse is a stand-alone structure. The agri-voltaic green house with shed roof and gambrel roof has been designated as GH1 and GH2 respectively.

The design of the front view of the greenhouse with shed type roof has two structure designated as structure 1 and 2 respectively which is shown in fig.1

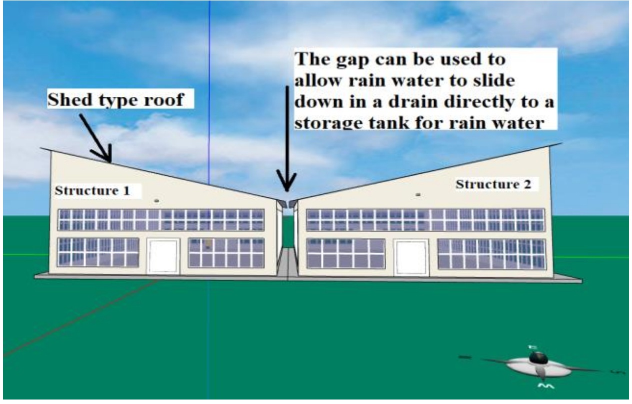

Fig.1: Front view of the design of the two structure made in Energy 3D software

The top view of the two structures (1 & 2) in Fig.2 shows the position of the roof window and the PV panels, while Fig.3 shows the side-view of structure 1 (From North-south direction). Since the two structures are alike, the side-view of structure 2 will be same as that of structure 1 and the analysis is will be repetitive

.

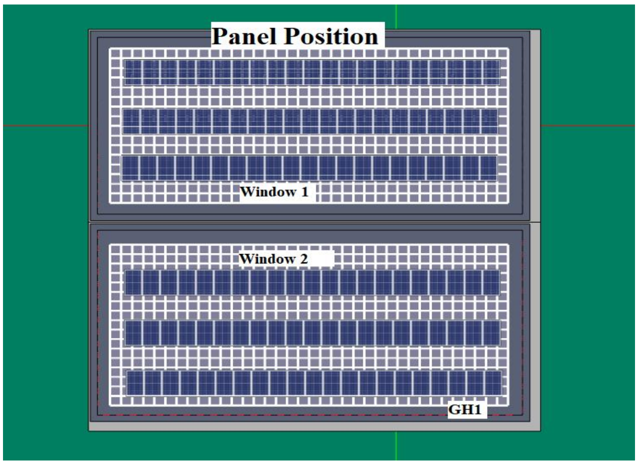

Fig.2: Top View of the two *structure* made in Energy 3D software

The side view of structure 1 (from North-south direction) is shown in fig.3.

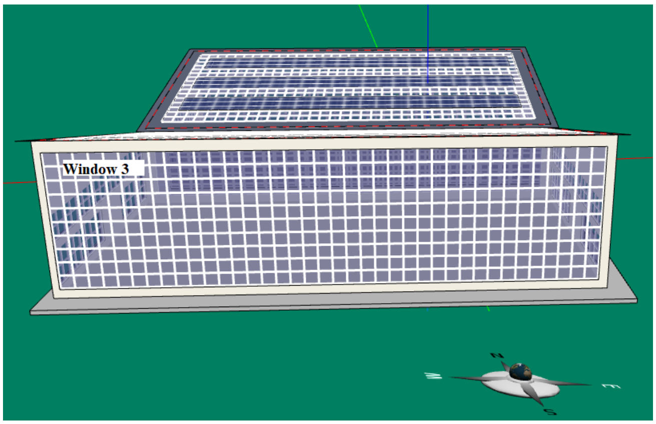

Fig.3: Side view of the *structure 1* from North-South direction

The front view and top view of the agri-voltaic green house with gambrel roof is shown in fig.4 and 5 (from North-south direction) respectively.

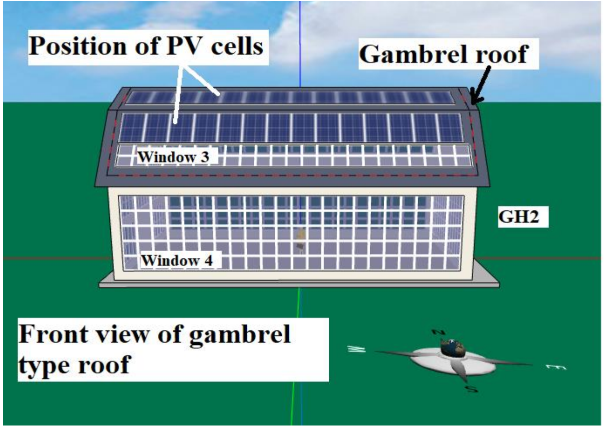

Fig.4: Front view of gambrel roof type green roof

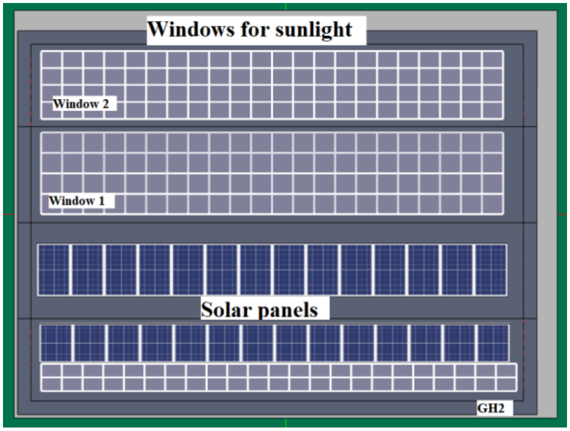

Fig.5: Top view of gambrel roof type green roof

The front view of the agri-voltaic green house with gambrel roof shows transparent window which allows solar energy inside the house from the North-south or south-north direction. In this work, the windows are made of transparent glass material, to allow maximum light to pass through. However, translucent/ semi-permeable material can be used to allow partial light to pass through.

These two agro voltaic green-houses are analyzed based on the amount of solar energy transcending on the structure, the transparent windows as well as on the solar PV arrays that are installed on the roof of the two agro voltaic green-houses. All the analysis has been carried out using the analysis tool of Energy 3D software. The first part of the analysis is based on the solar illumination/ radiation passing through transparent medium i.e. through glass, while the second part of the analysis will focus on the power analysis of the solar panels installed on the roof-tops.

III. SOLAR POWER ANALYSIS

For the purpose of analysis, the region selected in the software is Guwahati, Assam, India, which has latitude of 26. The Month and year selected for the analysis is January 2021 and the time selected is 12.00 noon. No shading conditions from other trees or buildings considered for the analysis. The analysis has been carried out for one year i.e. from the month of January to December 2021. Fig. 6 shows the variation of sunshine hours in Guwahati from the month of January to December. Fig.7 shows the annual variation of temperature (highest and lowest) in air and 0.5m deep in the ground. It is to be mentioned that the environmental data like temperature shown may vary with actual data.

The solar power and power analysis have been carried out first for the two structures of GH1 and then for GH2. Fig.8 shows the variation of solar power and heat gain at the roof for structure 1 & 2 respectively in the unit of kWh as illustrated in table 1.

TABLE I. HEAT GAIN AND SOLAR POWER GENERTION

Structure	Solar power (kWh)	Heat gain (kWh)
1 (270.2 m^2)	135270.48	11037.80
2 (258.5 m^2)	161712.9	10630.24

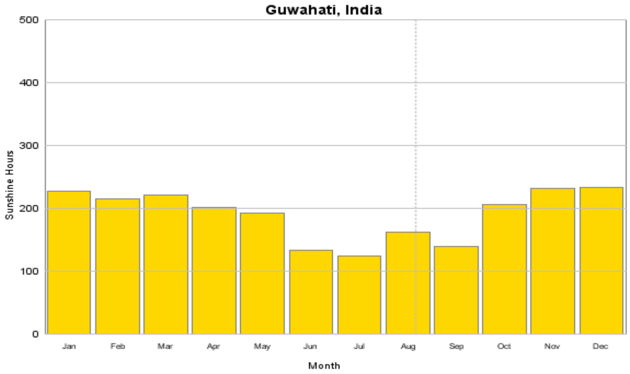

Fig.6: Top view of gambrel roof type green roof

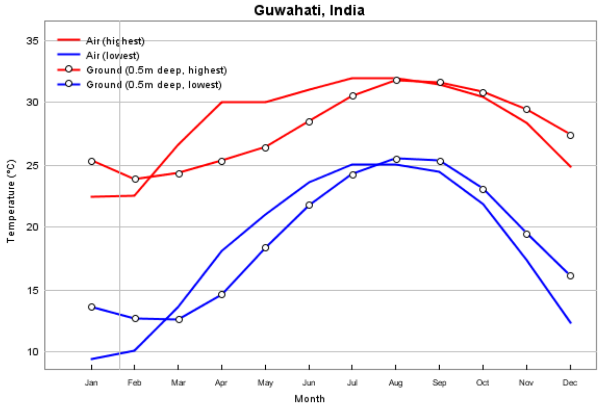

Fig.7: annual variation of temperature (highest and lowest) in air and 0.5m deep in the ground

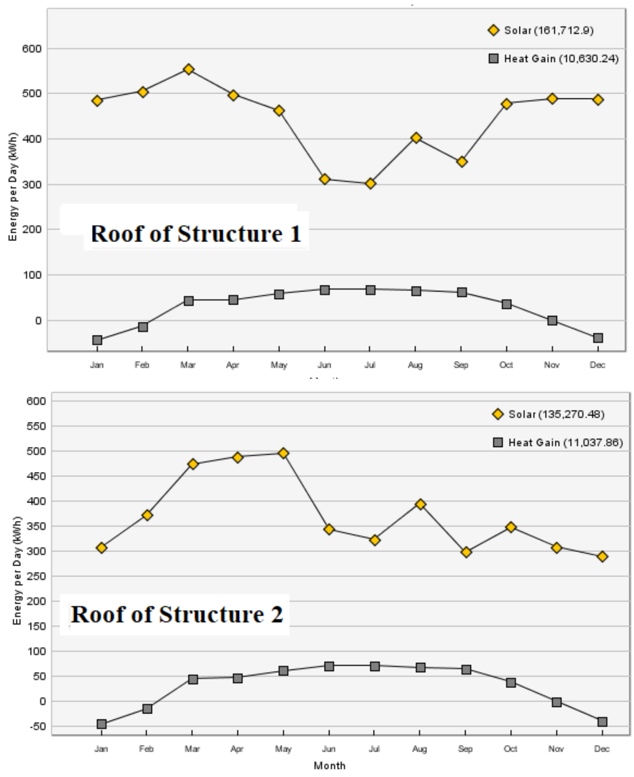

Fig.8: Variation of heat gain and solar power for structure 1 & 2

There are also two windows (3 & 4) which are made in structure 1 & 2 (Shown in fig.3 for structure 1). The variation of solar power and heat gain in the side window for structure 1 & 2 respectively in the unit of kWh as illustrated in table 2 and shown in fig.9.

TABLE II. HEAT GAIN AND SOLAR POWER GENERTION

Structure	Solar power (kWh)	Heat gain (kWh)
1(270.2 m^2)	69834.99	6670.11
2 (258.5 m^2)	29632.25	6670.11

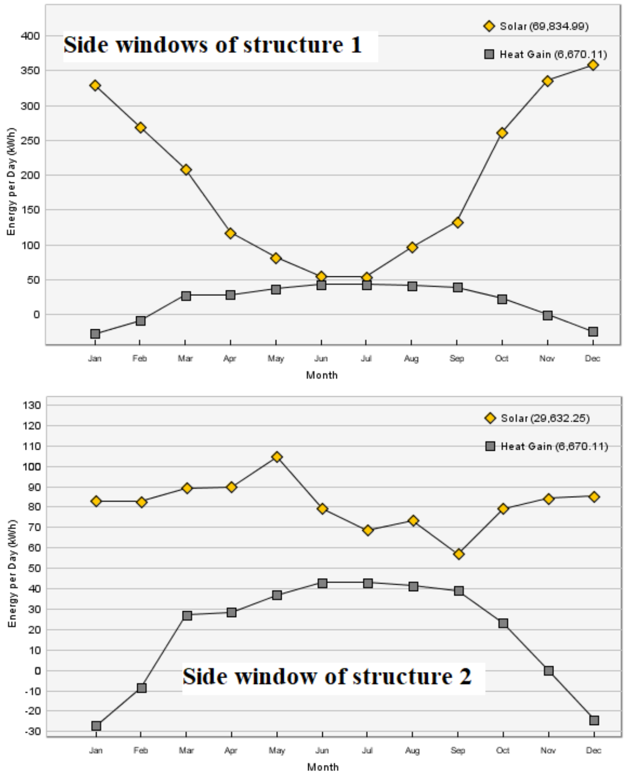

Fig.8: Variation of heat gain and solar power for side window of structure 1 & 2

For GH2, the analysis has been carried out in a similar fashion. Fig. 9 shows the variation of solar power and heat gain of window 1 and 2 (as shown in fig.5) and window 3 and 4 (as shown in fig.4) respectively. The data have been shown in Table 3.

TABLE III. HEAT GAIN AND SOLAR POWER GENERTION

Window	Solar power (kWh)	Heat gain (kWh)
1	0	1690.57
2	0	1935.78
3	0	798.49
4	0	2121.5

Table 3 shows that the solar power generated for GH2 is very small and hence considered to be zero. On the other hand, heat absorption has occurred due to the glass material, which are as shown.

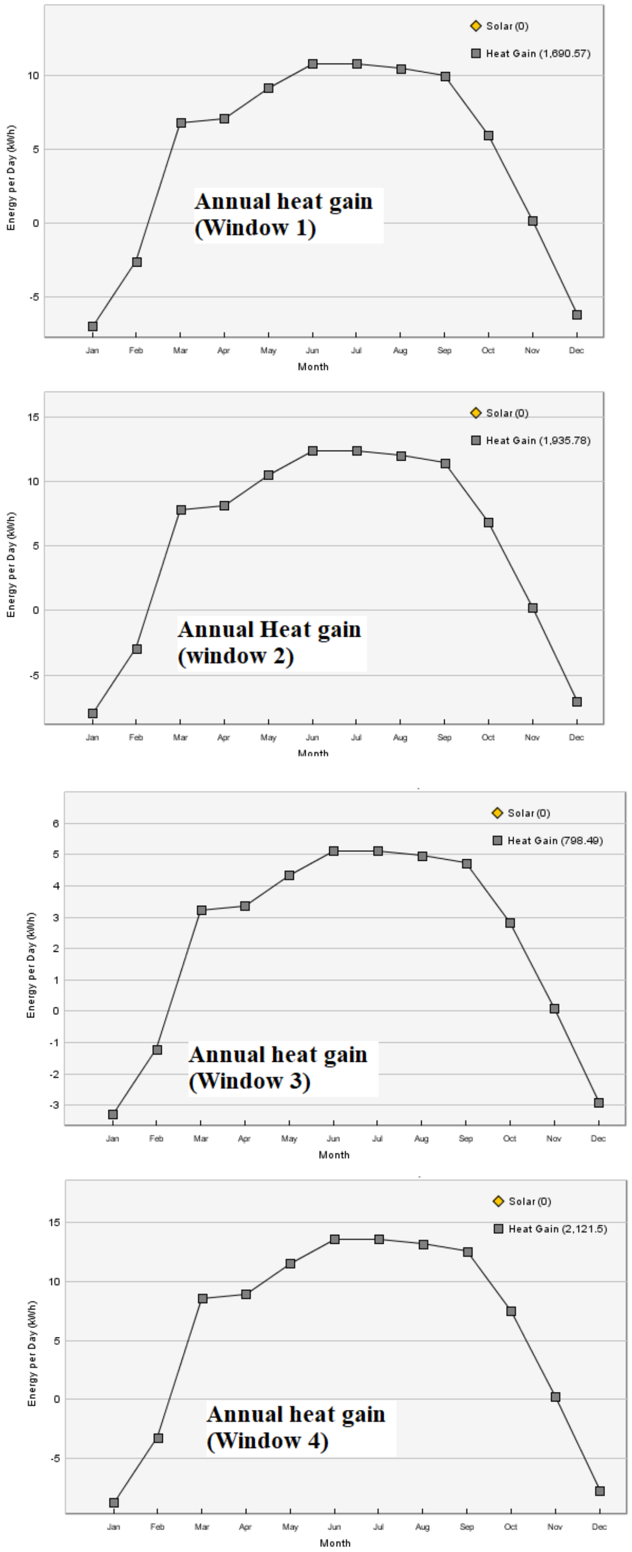

Fig.9: Variation of Heat gain (kWh) for different windows in GH2

There are also two windows which are made GH2. The variation of solar power and heat gain in the side window in the unit of kWh as illustrated in table 4 and shown in fig.10.

TABLE IV. HEAT GAIN AND SOLAR POWER GENERTION

Side Window	Solar power (kWh)	Heat gain (kWh)
1 (N-S)	0	1690.57
2 (S-N)	0	1935.78

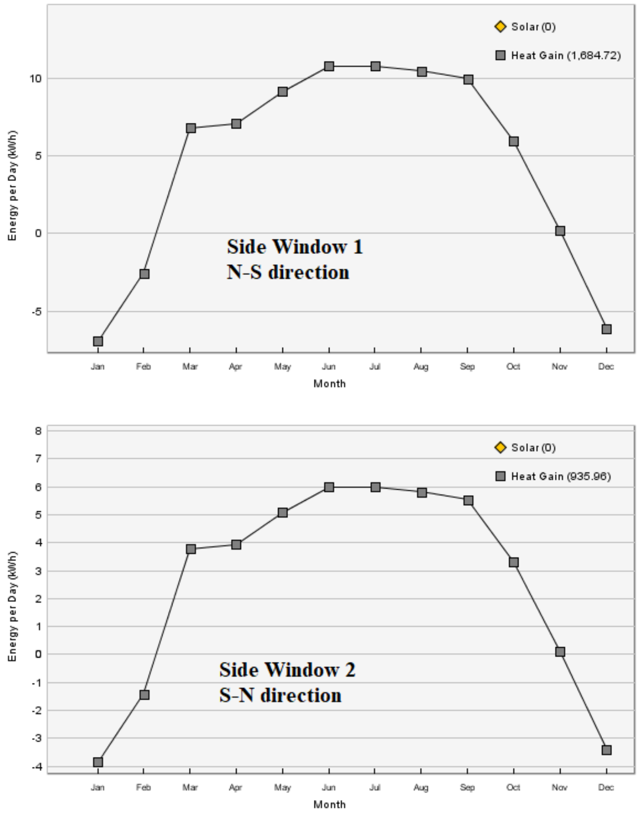

Fig.10: Variation of Heat gain (kWh) for side windows in GH2

The heat gain obtained from the simulation shows that amount of heat passing through the glass materials. These heat are trapped inside the green house which can be used for cultivation of selected agricultural products.

After the analysis of the solar power and heat gain, the power generated from solar panels installed on GH1 and Gh2 are shown in figure 11 and 12 respectively.

IV. SOLAR PANEL POWER ANALYSIS

The analysis of power generated from solar panels at GH1 and GH2 is carried out in this section. For the solar panels of GH1 (structure 1 + structure 2) and GH2, simulation results for the solar panels are shown in table 5. The graph for the power generated (annual) from the solar panels is shown in fig. 13 and 14. The graph shows the variation of the power generated per day for 12 months.

TABLE V. HEAT GAIN AND SOLAR POWER GENERTION

Green-house	Annual Solar panel yield (kWh)	Annual Electricity generated (kWh)
GH1	39293.77	39718.13
GH2	9816.06	9816.06

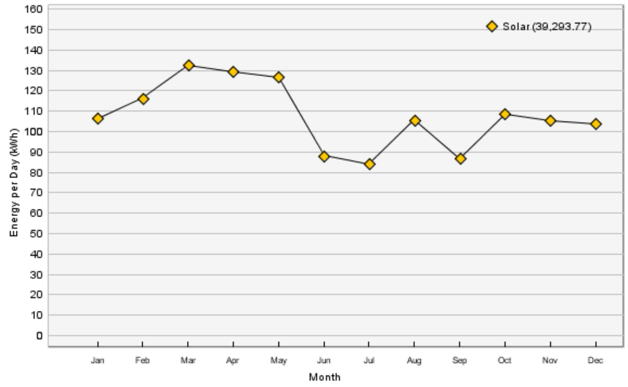

Fig.13: Power generated (annual) from the solar panels in GH1

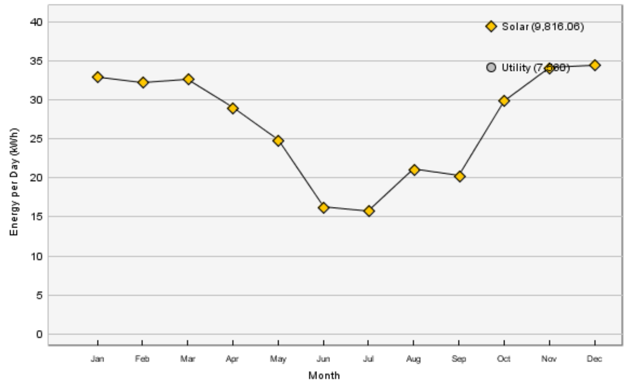

Fig.14: Power generated (annual) from the solar panels in GH2

The energy density of the solar panels of GH1 (structure 1 + structure 2) and GH2 is shown in Fig. 15 and 16 respectively.

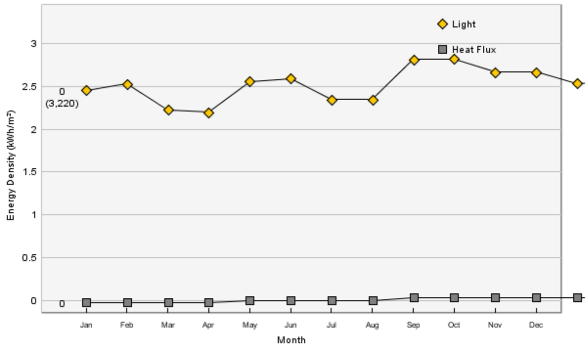

Fig.15: Energy density (annual) from the solar panels in GH1

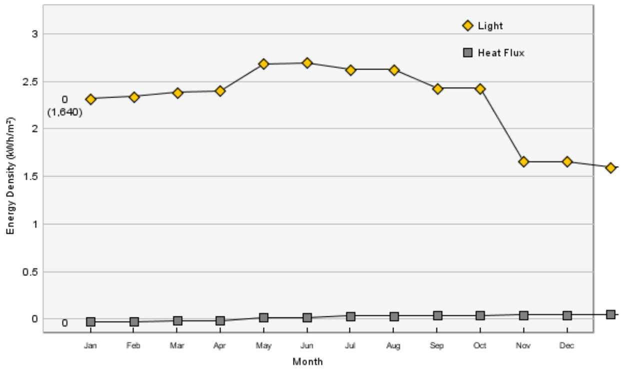

Fig.16: Energy density (annual) from the solar panels in GH2

V. RAIN WATER HARVESTING

The agri-voltaic green houses can be designed for rain water harvesting by designing a channel at the slope of the roof. Fig. 1 shows such an arrangement where rain water coming down the slopes of shed roof of structure 1 and 2 falls down into a channel, which can be connected to an underground tank to store rain water. In GH2, a closed conduit can be attached with the slope portion of the gambrel roof. The rain water will slide down the roof and fall on the conduit which will then carry the water to an underground tank.

VI. CONCLUSION

The data from simulation work can be summarized in the form of a table for GH1 and GH2. Table 6 and 7 shows the data for the proposed agri-voltaic green houses.

TABLE VI. DATA TABLE FOR GH1

Parameter	**Structure 1**	**Structure 2**
Area (m^2)	270.2	258.5
Solar power (kWh) total of all windows	231547.89	164902.73
Heat gain (kWh) – total of all windows	17300.35	17707.91
Number of solar panels	63	63
Annual solar panel yield (kWh)	39293.77	
Annual Electricity generated (kWh)	39718.13	
Rain water Harvesting	can be incorporated	

TABLE VII. DATA TABLE FOR GH1

Parameter	**Value**
Area (m^2)	152.2
Solar power (kWh) total of all windows	0
Heat gain (kWh) – total of all windows	6546.34
Number of solar panels	28
Annual solar panel yield (kWh)	9816.06
Annual Electricity generated (kWh)	9816.06
Rain water Harvesting	can be incorporated

Table 6 and 7 clearly shows the prospect of agri-voltaic based greenhouse in Assam. From the simulation results made for two designs of green houses with- shed type roof and gambrel roof, it has been found that there is a huge potential for trapping heat energy using green house effect for heating water, using the electricity from solar panels to run agricultural machines (like pumps) or using rain water harvesting to store rain water. Further analysis in this area has a huge scope which can be later implemented in practical field.

References

[1] https://www.energy.gov/energysaver/buying-and-making-electricity/using-solar-electricity-home.

[2] http://rainer-brohm.de/wp-content/uploads/2019/02/Dual-use-approaches-for-solar-energy-and-food-production-international-experience_en.pdf

[3] R. Chamara and C. Beneragama, "Agrivoltaic systems and its potential to optimize agricultural land use for energy production in Sri Lanka: A Review," Journal of Solar Energy Research Vol 5 No 2 Spring (2020) 417-431

[4] https://energy.concord.org/energy3d/

AUTHOR PROFILE

Dr. Sandip Bordoloi is an Associate Professor in the Department of Electrical Engineering, Girijananda Chowdhury Institute of Management and Technology, Azara Guwahati, Assam. He has ten years of teaching and Research experience. His specialization is in Sensors, sensor system and Instrumentation. He has guided many under graduate and post graduate students and is a project supervisor under Assam Science and Technology University and currently guiding PhD students. He has published many research papers and has three sponsored projects under his name. He has also organized many academic and non-academic programs as coordinators at the Institute and National level