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Research Paper

Partial Energy Harvesting Study of Solar Energy in a Microworld by Artificial Illumination

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Abstract

Renewable energy is of significant focus in modern times as the world climate change attracts attention. The study explores the energy harvest and the energy remaining in a solar energy harvesting cage in terms of light intensity and developed voltage. A miniature solar cage has been modelled and built for the study. The dynamic nature of weather posed a challenge in studying the impact on the availability of illumination inside the cage. Therefore, a controlled environment, by artificial lighting, has been adopted. Owing to the minimal presence of background or indirect light, a significant reduction of illumination has been observed for a low level of illumination inside the cage. This reduction can be translated to sustainable energy harvesting and the minimum energy needed for plant growth.

Keywords: Solar cage; Renewable energy; Energy harvesting impact; Sustainable energy harvesting; Artificial illumination, Solar cells.

1. Introduction

The demand for clean energy has become more urgent each year as mentioned in [1]. As one clean energy resource, the solar energy harvesting is prevalent and cost effective. There are various means to harvest incoming solar radiation. In recent years, solar panels have been used to capture sunlight. Capture and conversion of light by solar panels might represent "artificial" harvesters. In addition, the "natural" harvesters of incoming solar energy are plants and other photosynthetic organisms. The integration of solar farms with agricultural production has been reported [2-5]. Therefore, an optimal strategy to maximize capture of solar energy might be to use a combination of solar panels and plants. This optimal strategy leads to sustainable energy harvesting to balance food production and energy harvesting. This study focuses on the background of this combined harvesting.

Electrical output of photovoltaic cells, solar cells, depend on the illumination level [6]. The efficiency of them has improved over time [7]. The illumination level depends on the geographic location, and seasons. Studies [8-10] have been performed to experimentally investigate the remaining energy after harvesting by solar cages. However,

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the limitations of the experiments are the season and illumination levels. Weather changes as well as the illumination level. Even on the same day the illumination level changes. Therefore, it is challenging to predict the remaining energy for a specific illumination level inside the cage. To overcome the challenge, control setting has been set up and used to test illumination level for non-varying sources of light. Initial results in controlled environment have been reported in [11].

The structure considered in the study has 5 panels. It has been referred to as a solar cage [8]. Since it has a different temperature and illumination compared to the outside natural environment, it has been termed as a microworld. Finally, the microworld is planned to be utilized to explore the energy available for the plantation.

The harvesting of solar energy depends on the types of solar cells. The efficiency of photovoltaic, PV, cells also depends on the inclination angle of the panels [12, 13]. The solar panel structure in this study is horizontal. Therefore, the efficiency of conversion is not considered; however, the structure can demonstrate the energy fluctuations inside in terms of illumination. Artificial sources of lighting are utilized to study the remaining energy inside the solar cage.

2. Structure of solar cage and setup

The solar cage model used in this study is presented in Figure 1. The built structure is shown in Figure 2. The solar panels were built by PV cells. The PV cell dimensions are 1 inch by 1.5 inches. The 5-panel structure was built by soldering the connections between the cells.

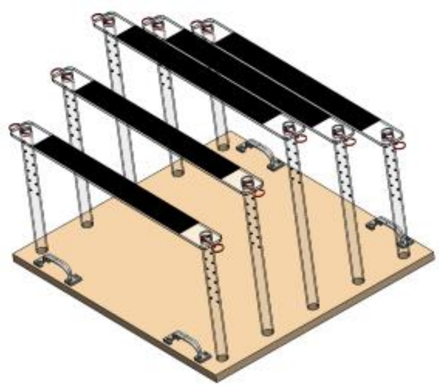

Figure 1. Flexible vertical model, in which the black horizontal areas are customized connected PV cell. The panels can be removed if needed [9].

Figure 2. 5-panel structure with adjustable height. The measuring panel sits on the ground for experiments. The 5 panels are placed at the top level in the figure.

Compared to the other solar cage in [8], the built cage has flexibility in the model. The panel heights can be adjusted to study the variation of energy for various orientations. The horizontal area of the cage is 3723.75 cm2, and the total effective area of power generating panels is 387.27 cm2.
In this structure, 23 PV cells were soldered to make one panel. The panels are supported by vertical plastic hollow pipes. The whole structure stands on a wooden plank which helps convenient movement during experiments.

2.1. Orientation of cage

The study intends to explore the variation of intensity. Four types of orientation of the cage have been studied. There are Top Dome, Bottom Dome, Large Dome and Flat; the geometric shapes are shown in Figure 3. The orientations offer the opportunity to study the remaining energy inside for the same structure with height adjustments. Top Dome and Bottom Dome in the figure represent highest and lowest cage structure.

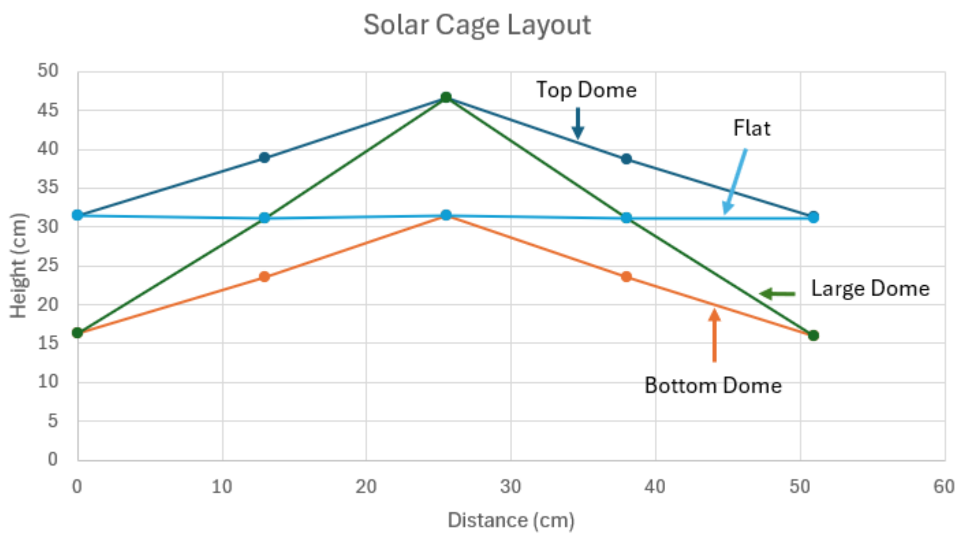

Figure 3. Visual presentation of the four orientations [14].

2.2. Control environment setup

The experimental data of the remaining illumination have the limitation of ever-changing weather conditions. It was changing over the course of prior experiments during both summer and winter [8, 9, 10]. To obtain consistent data, illumination can be made constant in a controlled setting. To test various illumination conditions, a control environment is set up. The following figure shows the setup. The illumination was changed by voltage variation by using a variac.

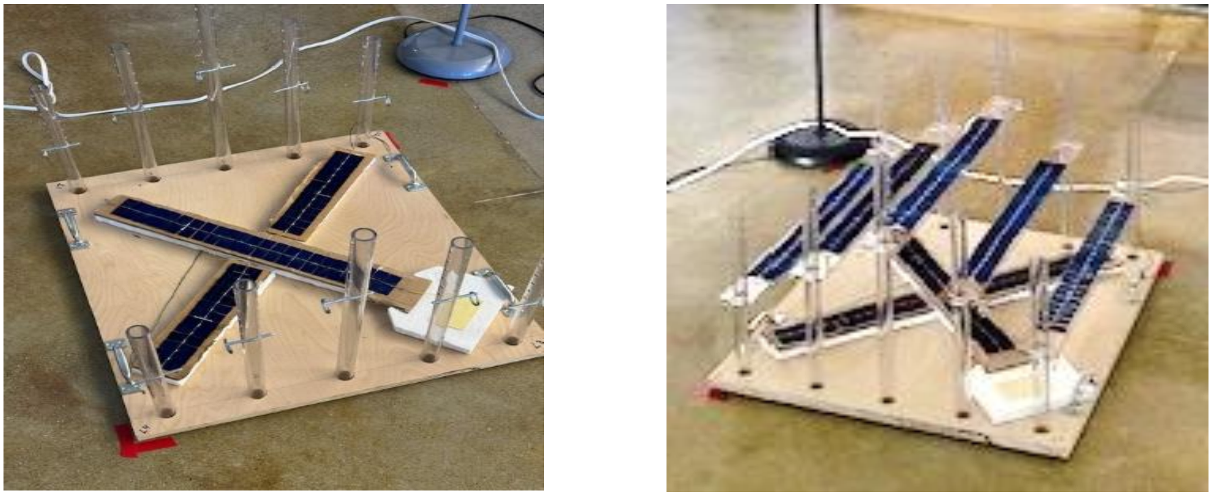

Figure 4. Solar cage and measuring pane structure. (a) The figure shows only the measuring panel on the base; (b) The solar cage is placed on the floor; the measuring panel lies on the base of the cage.

3. Results

As artificial light sources, LED bulbs were used. They were placed on lamp posts. In the experiments, 4 LED bulbs were used to produce near uniform intensity on the cage. It is shown in Figure 5. The bulbs have a power of 100 Watt. The average distance between posts is 45.75 inches and the average height of the bulbs from the ground is 51.75 inches.

Figure 5. The figure shows the placement of the measuring panel while it was being calibrated. The four LED lights were used to provide near uniform intensity on the panel.

As shown in Figure 6, the illumination was not varied significantly for voltages above 100V. Therefore, experiments were conducted for the voltages 40V to 100 V controlled by the variac.

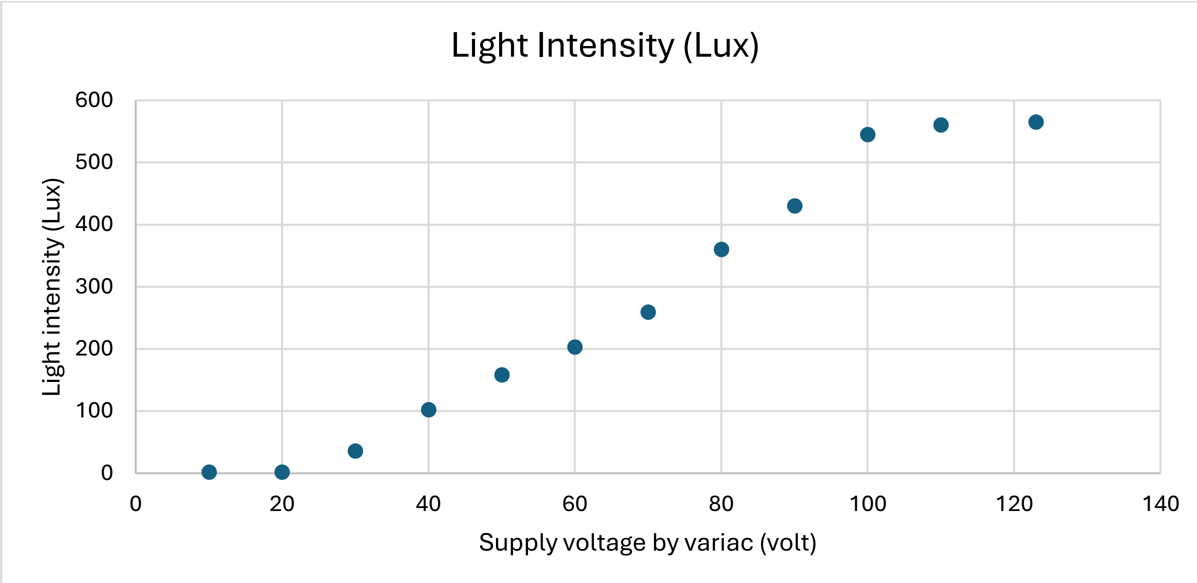

Figure 6. Light intensity on the base without the cage for variac voltages in control setting. There was background diffused lighting from surroundings which was included in the illumination.

Tables 1 and 2 show the voltage reduction by the cages for two different illumination levels. For the data in Table 1, the same lighting condition produces 8.91 V in the measuring panel alone. Measuring panel voltages, MPV, are presented for regulator voltages in Tables 3, and 4. For the data in Table 2, the same lighting condition produces 9.55 V in the measuring panel. The data in both tables above are consistent regarding the reduction of intensity inside the cage.

Table 1. Measuring panel voltage for supply voltage 40 V.

Orientation	Top	Big	Flat	Bottom
MPV (Volt)	8.15	7.98	8.00	7.86

Table 2. Measuring panel voltage for supply voltage 60 V.

Orientation	Top	Big	Flat	Bottom
MPV (Volt)	8.63	8.4	8.34	8.0

Detail data are provided for the following illumination. For the following data in Table 3, the measuring panel was calibrated. The calibration curve is shown in Figure 7. The calibration curve is utilized to convert the measuring panel voltage to equivalent illumination inside the cage.

In the control environment, the flat shape has the largest reduction of intensity where the illumination was provided from the top. The indirect light and diffused light were minimum in the setting. The indirect and diffused lighting can modify the percentage intensity reduction which is shown in [9]. The equivalent lux for the MP voltage in Table 3 is calculated using the calibration curve. Finally, illumination reduction inside the cage for the four orientations has been computed and presented in Table 4. In this artificial environment, the highest reduction was observed for Flat orientation.

Table 3. Panel and Measuring panel voltage for supply of regulator Voltage of 100 V.

Panel	Top Dome panel voltage	Big Dome panel voltage	Flat panel voltage	Bottom Dome panel voltage
1	5.40	5.46	5.69	6.07
2	8.16	7.67	8.05	7.99
3	7.16	7.23	6.85	6.95
4	6.98	6.74	6.80	6.76
5	8.45	8.15	8.49	8.27
MPV	15.05	15.24	14.59	14.81

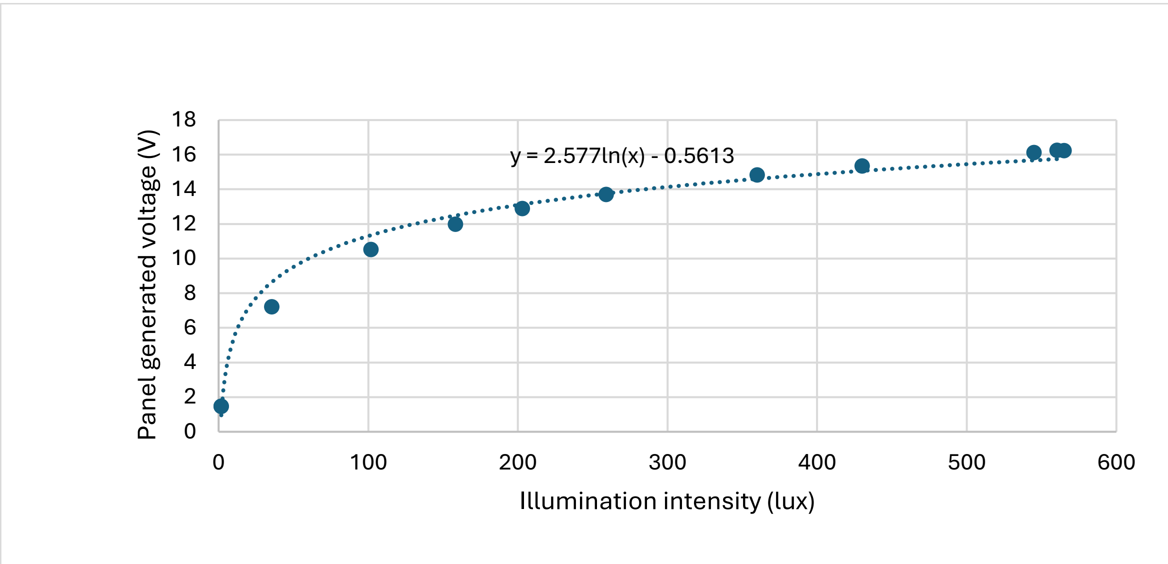

Figure 7. Calibration of the measuring panel.

Table 4. Illumination reduction inside the cage for the data in Table 3.

Orientation	Top	Big	Flat	Bottom
MPV equivalent lux	427.28	459.97	357.43	389.28
% illumination reduction	21.60	15.60	34.42	28.57

In the control setting, the light sources were arranged to provide near uniform illumination which is observed in data of Table 3. However, some anomaly still exists. For example, for the panel 1 of the four orientations are 5.4, 5.46, 5.69 and 6.09 volts. These voltages have equivalent illumination intensity. This is equivalent to the time around noon where the sun is above the structure and source of uniform illumination. The reduction of illumination in experiments was found to be 14% in reference [9] around noon; this is much smaller than the highest reduction in control environment.

When this light intensity inside the cage is considered for plant growth, use of light by plants under solar cages can be measured at three scales. 1) Short-term (< 1 sec) capture of light and use of this energy to drive photosynthesis can be measured with chlorophyll fluorescence [15, 16]. 2) Medium-term (minutes) measures of light use by plants can be assessed with photosynthetic gas exchange [17, 18]. 3) Long-term (weeks to months) measures of light use by plants can be assessed with measures of growth.

In the present context, if plants are growing in 2500 to 7500 lux, this is around 2.5 to 7.5 percent of full sunlight, similar to understory plants in a temperate deciduous forest [19], similar to many habitats in Michigan. In terms of percentage reduction of intensity in the artificial setting, it appears to be sufficient; however, it would require experiment to validate the proposition of plan growth inside a cage.

4. Conclusion

The study focuses on the intensity available in the control setting for the solar cage. The experimental data showed illumination variation; however, in this set up, illumination reduction was even more extreme. The rationale is that there was minimal reflection from the surroundings; in real setting, there are indirect or reflected lights from the ground and plants. The test results showed the reduction limit of 34.42% for the particular structure. Under the control setting, the extreme reduction of illumination is possible. Therefore, it can show the lower bound of the energy available for the cage. The experiments in the field will have more indirect or reflected lights from surrounding elements which will increase the level of illumination that will potentially assist the plant growth more. This work will provide a new level of understanding regarding how light conditions are influenced by artificial energy sources for structural variations. Simultaneously, these results could potentially inform harvesting of a renewable energy source. Future studies will determine the extent to which solar energy is shared between solar panels and plants.

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Conflicts of Interest: The authors declare no conflicts of interest.

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