Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 6, December 2023, pp. 3238~3246
ISSN: 2302-9285, DOI: 10.11591/eei.v12i6.5357

Indoor light energy harvesting technique to energize a heat sensor using polycrystalline solar panel

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Article Info

Article history:

Received Nov 28, 2022
Revised Mar 24, 2023
Accepted May 25, 2023

Keywords:

Energy harvesting system
Heat sensor
Incandescent light bulb
Polycrystalline
Solar panel

ABSTRACT

This paper presents the effect of using different illumination types between the polycrystalline solar panel and the light sources on energy harvesting performance for indoor low-power applications such as heat sensors. The main advantage of indoor energy harvesting is it makes good use of ambient energy from the environment and converts it directly to electricity for small power devices. In this paper, the maximum power of polycrystalline solar panels for four different light illuminations has been investigated under different distances of light sources from the polycrystalline solar panel. Implementation and test results of the effect of varying the distance and the power produced for different light illuminations are presented which highlights the practical issues and limitations of the system.

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1. INTRODUCTION

Energy harvesting is a process of capturing a variety of ambient energy sources, stored in a period, and then used to power up low-power electronic devices or applications [1], [2]. In other words, the goal of energy harvesting is to transform energy so that it may be used to power electronic equipment. There are many energy harvesting techniques, such as solar energy harvesting, light energy harvesting, wind energy harvesting, and piezoelectric energy harvesting [3]–[5]. Wireless sensor networks (WSN) is a technological device that detects changes in an environment. It is one of the applications of solar energy harvesting since it consumes a small power consumption [6]. This paper focuses on light energy harvesting, harvesting energy from indoor light sources to support the operation of low-power devices and sensors. Energy wastage from some places that use almost 24 hours of light but are not utilized efficiently and not entirely harvested has become the major concern in this paper. This issue should be given more attention because it is related to power consumption [7]. Moreover, [8] shows that dye sensitized solar cells (DSSC) can harvest indoor light. Thus, this paper aims to study and determine the possibility and suitability of energy harvesting from indoor light sources by using polycrystalline silicon solar cells to energize a heat sensor that consumes 0.03 W and compare it with DSSC. Light energy harvesting is applied with the three main components of energy harvesting: power generation, power management, and power storage [9]. Solar panel acts as a transducer and power generation, buck converter for power management, and rechargeable battery for power storage.

The solar panel is manufactured by allowing photons or particles of light to knock electrons free from atoms and produce a flow of direct current (DC) electricity. It is often used to generate electricity from sunlight, but solar panels can also be used to generate electricity under indoor light sources [10]. This is because both sunlight and indoor light sources fall within the range of the visible light of the electromagnetic spectrum (EM). Light is electromagnetic radiation within a certain portion of EM [11]. The part of the spectrum that reaches the Earth from the Sun is called solar radiation, and it ranges from 100 nm to 1 mm. The highest irradiance values are from 400 to 700 nm, which is from visible light, which is why the manufacturer designed and focused on maximizing the absorption of light from the visible region [9].

Monocrystalline solar cells (m-Si) and polycrystalline solar cells (p-Si) cover a wider range of wavelengths from 300-1200 nm, including visible light [12], [13]. However, other thin-film solar cells, such as copper indium gallium selenide (CIGS) and cadmium telluride solar cell (CdTe), also falls under the same region as m-Si and p-Si but with less efficiency [14]. DSSC, amorphous solar cells (a-Si), and gallium arsenide (GaAs) are specifically manufactured to be in visible regions [15].

The incandescent lamp is composed of a glass balloon whereby the filament is heated to high temperatures (2,000 to 3,000 K), and the wavelength falls within the spectrum of the visible region. It is within 300 to 700 nm wavelength and has its peak in the infrared region of light [16]–[19]. Besides, most solar panels absorb wavelength ranges of 400 to 800 nm [20], [21]. Therefore, the results show that the incandescent lamp falls under the same region where the solar panel could extract power from the sunlight, proving that solar panels can also generate electricity under indoor light sources.

A few factors can affect the operation and performance of solar panels with a light source. The factors are the distance of the solar panel to the light source, the light intensity [19], [22], [23], and the amount of bulb wattage [24]. According to Amajama [25], as the distance of solar cells increases from the light source, the voltage, and power of the cell also decreases with the light intensity. Moreover, the author also stated that the current rises steadily and voltage increases sharply with the increase in intensity. The surface will appear dimmer once the light source is moved away from the solar panel that is illuminated by the light source.

2. METHOD

2.1. Related works

Light energy harvesting for low-power consumption devices has been done and studied by a few researchers. The difference between all those researchers is the types of energy harvesters that were used for power generation. They tried to use different types of energy harvesters, also known as power generation, to find out the harvester's potential for light energy harvesting. Table 1 shows the different types of energy harvesters that were used in their research.

Table 1. Related works with other types of energy harvesters

Ref	Title	Power generation/energy harvester
[8]	Indoor light harvesting using dye sensitized solar cell	DSSC
[9]	A study on light energy harvesting from the indoor environment: the autonomous sensor nodes	Amorphous silicon solar cell

2.2. Proposed method

The experiment will use a polycrystalline type of solar panel to capture and harvest light from the light source that produces the optimum results. This type of solar panel is chosen to determine whether the statement claimed by [8] stated that polycrystalline solar panel deployment had been restricted due to its limitation to work under indoor light energy. Thus, this paper will analyze the possibility of using a polycrystalline solar panel to harvest energy from indoor light.

2.2.1. Flowchart

The flow of the experiment is summarized in Figure 1. It begins with constructing the connection of six solar panels connected in both ways, in series to increase its voltage and in parallel to increase its current. Four types of light bulbs will then be tested individually by placing them 15 cm away from the polycrystalline solar panel. The first measurement uses a multimeter to find out the solar panel's open circuit voltage and short circuit current. The solar panel is then connected with a diode and buck converter to a rechargeable battery. A diode is used to avoid reverse current from the rechargeable battery to the solar panel. It will then be connected to a heat sensor that can detect the presence of heat from the fire. The prototype is left 15 cm away from the light source to harvest energy and discover its potential to supply energy to a heat sensor. The functionality of the heat sensor will be tested by lighting up a fire near the sensor. Once it senses the presence of heat coming from the fire, the blue LED light will light up, and a buzzer will produce a sound.

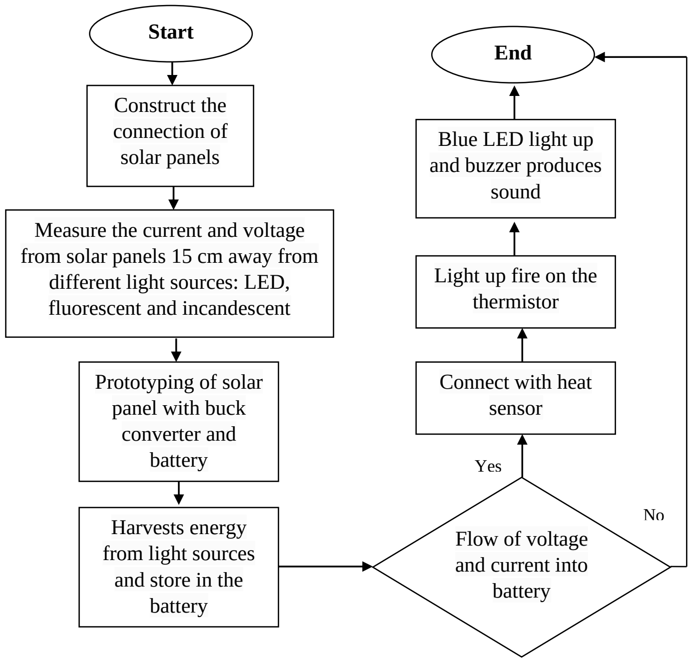

Figure 1. Flowchart of the whole experiment

2.2.2. Block diagram

For the proposed light energy harvesting under indoor light sources, the block diagram is as shown in Figure 2, which comprises the LED, fluorescent light bulb, and incandescent light bulb as the light sources, polycrystalline solar panel as the power generation, LM2596 buck converter as the power management, 3.5 V lithium-ion rechargeable battery as the power storage and lastly heat sensor as the load.

Figure 2. Block diagram of light energy harvesting for a heat sensor

2.2.3. Light harvesting from indoor to energise a heat sensor

The basic idea of this experiment is to design an energy harvesting system from indoor light radiation using a solar panel for a sensor. Thus, Figure 3 shows the proposed experiment of light energy harvesting to energize a heat sensor. Based on Figure 3, there are ten components used in this proposed experiment. No. 1 stated in the figure represents three types of light sources that will be used in this experiment as an energy source for a battery and it is placed 15 cm away from the polycrystalline solar panel. No. 2 is a polycrystalline solar panel that acts as a transducer to harvest the light from the light source. No. 3 is a diode that is used to prevent reverse current from the battery to the solar panel. No. 4 is a buck converter used to reduce the voltage from the solar panel to the battery. No. 5 is a rechargeable battery that acts as an energy storage and power supply for the fire sensor. No. 6 is a 2N2222 transistor that is used to no. 7 is a thermistor that changes with temperature variations. An increase in temperature makes the resistance decrease. No. 8 is a blue LED light that will light up once it senses the presence of heat from the fire. No. 9 is a buzzer that will produce a buzzing sound once it detects the presence of heat from the fire. Lastly, no. 10 is a 1 kΩ resistor.

2.2.4. Proposed schematic diagram of total light energy harvesting to energize a heat sensor

Figure 4 is the proposed schematic diagram of total light energy harvesting to energize a heat sensor. The figure illustrates all the main components that are needed in energy harvesting. There are polycrystalline solar panels for power generation, buck converters for power management, rechargeable battery for power storage, and heat sensor as load.

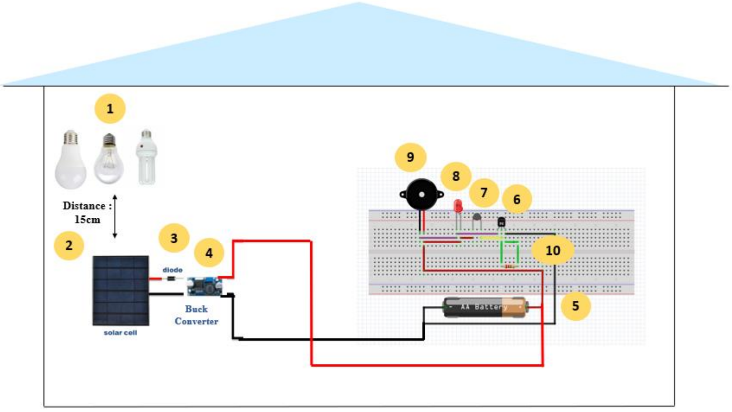

Figure 3. The proposed connection diagram of light energy harvesting to energize a heat sensor

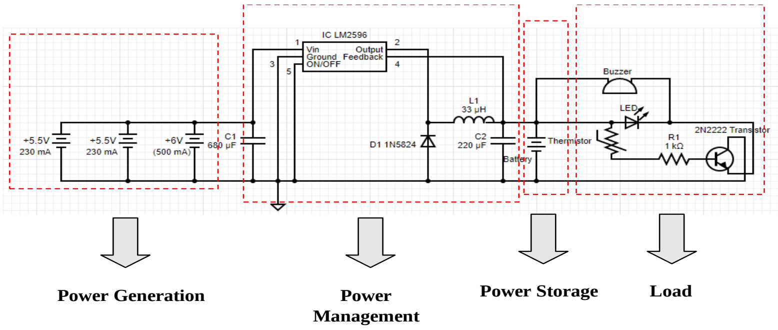

Figure 4. Proposed schematic diagram of total light energy harvesting to energize a heat sensor

2.2.5 Experiment setup

The proposed approach is conducted by experimenting with 4 different light bulbs as the light source. Table 2 presents the experimental setup with all the light bulbs conducted individually with the polycrystalline solar panel 15 cm away from them. The voltage and current flow from the rechargeable battery to the heat sensor are measured using a multimeter. The functionality and suitability of polycrystalline solar panels with the 4 different light bulbs were tested by lighting up a fire near the heat sensor.

Table 2. Related works with other types of energy harvesters

Experiment	Type of bulb	Experimental setup
Experiment 1	 24 W LED light bulb	
Experiment 2	 23 W fluorescent light bulb	
Experiment 3	 60 W incandescent light bulb	
Experiment 4	 100 W incandescent light bulb	

3. RESULTS AND DISCUSSION

In based on Tables 3(a) and (b) and 4(a) and (b), the highest power produced from buck converter to battery is 89.43 mW which is the 100 W incandescent light bulb, followed by a 60 W incandescent light bulb at 50.75 mW, an LED light bulb at 5.09 mW, and lastly fluorescent light bulb at 4.34 mW. Next, when the battery was connected to a heat sensor circuit, a fire was ignited near the sensor, and the blue LED and buzzer gave no response when these three light sources were used, namely, LED light bulb and fluorescent, and 60 W incandescent light bulb.

However, the blue LED lights up and the buzzer produces a sound when a 100 W incandescent light bulb is used, indicating that the sensor senses the presence of fire. It was proven by the results shown in the Tables 3 and 4. Both batteries produced zero power when a LED and fluorescent light bulb were used. This is because there is no current flow from the battery to the heat sensor. However, when a 60 W incandescent bulb was used, power was generated from it, but it was still not enough to energize the heat sensor. The 100 W incandescent light bulb is most suitable to be used as it produces an ample amount of current flow, which is at 52.43 mA or 0.05 W. The power produced is higher than the amount of power needed for the operation of the heat sensor. Thus, it concludes that it has the maximum light harvesting compared to other light sources. This is because the incandescent light bulb is the most suitable type of light bulb to be used with polycrystalline solar panels compared to LED and fluorescent light bulbs.

Incandescent light bulb has a wavelength that falls within a spectrum of 300 to 7000 nm, which is in the range of a visible region [16], [17], [26]. It falls under the same region where the polycrystalline solar panel could extract power from natural light, which is sunlight [26]. LED and fluorescent light bulbs were not as efficient with silicon cells since the power generation is getting lesser as it goes through three conversions; i) from solar panel to a buck converter, ii) buck converter to the battery, and iii) battery to heat sensor. However, these two types of light bulbs can still be used to charge solar-powered devices if the voltage supplied is slightly higher than the battery voltage and there is the current generated. The only problem is that it might take a long time to charge the devices fully.

Table 3a. Results obtained for 24 W incandescent light bulbs

Time	24 W								
	V_1	I_1 (mA)	P_1 (mW)	V_2	I_2 (mW)	P_2 (mW)	V_3	I_3 (mA)	P_3 (mW)
11:30	3.61	7.13	25.74	3.51	1.36	4.77	3.41	0	0
11:35	3.69	7.10	26.20	3.52	1.45	5.10	3.43	0	0
11:40	3.68	7.09	26.09	3.52	1.44	5.07	3.44	0	0
11:45	3.70	7.31	27.05	3.53	1.46	5.15	3.41	0	0
11:50	3.69	7.30	26.94	3.52	1.45	5.10	3.43	0	0
11:55	3.69	7.29	26.90	3.53	1.45	5.12	3.43	0	0
12:00	3.69	7.30	26.94	3.53	1.45	5.12	3.43	0	0
12:05	3.71	7.40	27.45	3.53	1.44	5.08	3.43	0	0
12:10	3.71	7.26	26.93	3.52	1.45	5.10	3.44	0	0
12:15	3.72	7.22	26.86	3.52	1.46	5.14	3.43	0	0
12:20	3.72	7.32	27.23	3.52	1.46	5.14	3.43	0	0
12:25	3.71	7.29	27.05	3.53	1.45	5.12	3.43	0	0
12:30	3.72	7.32	27.23	3.53	1.46	5.15	3.41	0	0
Average	3.70	7.26	26.82	3.52	1.44	5.09	3.43	0	0

Table 3b. Results obtained for 23 W incandescent light bulbs

Time	23 W							
	I_1 (mA)	P_1 (mW)	V_2	I_2 (mW)	P_2 (mW)	V_3	I_3 (mA)	P_3 (mW)
11:30	5.68	20.50	3.57	1.16	4.14	3.45	0	0
11:35	5.69	20.60	3.56	1.18	4.20	3.43	0	0
11:40	5.71	20.67	3.57	1.21	4.32	3.43	0	0
11:45	5.72	20.76	3.57	1.24	4.43	3.43	0	0
11:50	5.73	20.80	3.57	1.19	4.25	3.43	0	0
11:55	5.73	20.74	3.56	1.22	4.34	3.42	0	0
12:00	5.74	20.89	3.57	1.22	4.36	3.44	0	0
12:05	5.74	20.84	3.57	1.24	4.43	3.43	0	0
12:10	5.74	20.89	3.56	1.24	4.41	3.44	0	0
12:15	5.75	2.93	3.56	1.22	4.34	3.43	0	0
12:20	5.75	20.87	3.56	1.24	4.41	3.44	0	0
12:25	5.73	20.86	3.57	1.21	4.32	3.43	0	0
12:30	5.74	20.89	3.57	1.24	4.43	3.43	0	0
Average	5.73	19.40	3.57	1.22	4.34	3.43	0	0

Table 4a. Results obtained for 60 W incandescent light bulb

Time	60 W								
	V_1	I_1 (mA)	P_1 (mW)	V_2	I_2 (mW)	P_2 (mW)	V_3	I_3 (mA)	P_3 (mW)
11:30	4.73	23.75	112.34	3.55	11.46	40.68	3.50	4.25	14.88
11:35	4.75	23.52	111.72	3.52	11.52	40.55	3.49	4.25	14.83
11:40	4.74	23.55	111.63	3.52	11.49	40.44	3.48	4.22	14.69
11:45	4.74	23.62	111.96	3.52	11.49	40.45	3.49	4.23	14.76
11:50	4.75	23.79	113.00	3.55	11.51	40.86	3.48	4.23	14.72
11:55	4.75	23.71	112.62	3.55	11.52	40.90	3.50	4.25	14.88
12:00	4.75	23.86	113.34	3.55	11.53	40.93	3.50	4.23	14.81
12:05	4.74	23.71	112.39	3.55	11.50	40.83	3.49	4.25	14.83
12:10	4.74	23.68	112.24	5.54	11.49	40.67	3.49	4.24	14.80
12:15	4.74	23.75	112.58	5.54	11.52	40.78	3.49	4.26	14.87
12:20	4.74	24.02	113.85	3.55	11.51	40.86	3.50	4.26	14.91
12:25	4.73	23.96	113.33	3.55	11.49	40.79	3.50	4.25	14.88
12:30	4.73	23.85	111.81	3.55	11.54	40.97	3.50	4.24	14.84
Average	4.74	23.75	112.52	3.85	11.51	40.75	3.49	4.24	14.82

Table 4b. Results obtained for 100 W incandescent light bulbs

Time	100 W							
	I_1 (mA)	P_1 (mW)	V_2	I_2 (mW)	P_2 (mW)	V_3	I_3 (mA)	P_3 (mW)
11:30	36.72	184.70	4.20	22.58	94.84	3.50	15.02	52.57
11:35	36.17	181.21	3.92	22.82	89.45	3.50	15.02	52.57
11:40	35.97	180.93	3.93	22.63	88.94	3.49	14.96	52.21
11:45	36.17	181.57	3.92	22.96	90.00	3.49	14.99	52.32
11:50	36.23	181.87	3.92	22.13	86.75	3.50	15.02	52.57
11:55	36.50	182.87	3.92	22.69	88.94	3.49	15.02	52.42
12:00	36.39	183.04	3.93	22.13	86.97	3.48	15.02	52.27
12:05	36.52	183.33	3.92	22.82	89.45	3.49	14.98	52.28
12:10	36.41	182.78	3.92	22.88	89.69	3.50	15.04	52.64
12:15	36.28	181.76	3.93	22.72	89.29	3.49	15.01	52.38
12:20	36.25	181.98	3.95	22.67	89.55	3.50	14.98	52.43
12:25	36.43	183.24	3.93	22.78	89.53	3.50	14.98	52.43
12:30	36.39	183.04	3.94	22.65	89.24	3.49	15.05	52.52
Average	36.34	182.49	3.95	22.65	89.43	3.49	15.01	52.43

The amount of wattage used was also one of the reasons that affected the output power [24]. That is the reason why a 60 W incandescent light bulb does not have the ability to supply power to the heat sensor, even though the type of light source is suitable for the polycrystalline solar panel. Furthermore, solar cells require a certain level of brightness to generate useful amounts of electricity. The 100 W incandescent light bulb has the highest brightness among others, which is 1650 lux on average. Figure 5 shows the experiment conducted to test the possibility of light energy harvesting to energize a heat sensor using a 100 W incandescent light bulb. The blue LED light-up and buzzer produce sound, proving that it is possible to use indoor light harvesting to energize a heat sensor that requires a small amount of power.

Figure 5. Total connection of light energy harvesting to energize heat sensor under 100 W incandescent bulb

The 100 W incandescent light bulb is suitable to be used for energy harvesting. However, it has more disadvantages than advantages to it. The reason for that is it is energy inefficient. It converts less than 5% of the energy it uses as visible light and the remaining 95% of energy is lost as heat. Moreover, it also has a short lifetime, around 1000 hours, due to higher filament temperature. Thus, it does not fit a heat sensor because it may cause confusion and false alarm to the sensor that is meant to detect the presence of heat. Table 5 summarizes the details of the types of energy harvester, light source, and power storage in this experiment, the amount of power flow to the load, light intensity, and efficiency.

Table 5. The list of equipment and parameters used in this experiment

Equipment	Parameter
Energy harvester	Polycrystalline solar panel
Light source	100 W incandescent light bulb
Power storage	3.5 V lithium light bulb
Power to the heat sensor	0.05243 mW
Light intensity	1650 lux
Efficiency	0.0894%

This paper is compared with the previous paper [8] that used DSSC which is a different energy harvester to find out the potentiality of it to be harvested under indoor light conditions by varying the distance between solar cells and the 24 W LED light bulb. Figure 6 illustrates the voltage in the open circuit (V_{oc}) and the distance between the DSSC in [8] and the proposed polycrystalline solar panel. It shows that the polycrystalline solar panel has a slightly higher voltage compared to the voltage for DSSC. This indicates that the polycrystalline solar panel that was used in this project has the potential to be harvested. This proposed technique has been tested under indoor light conditions and shows the importance of the distance between solar cells and the light sources to produce a better output.

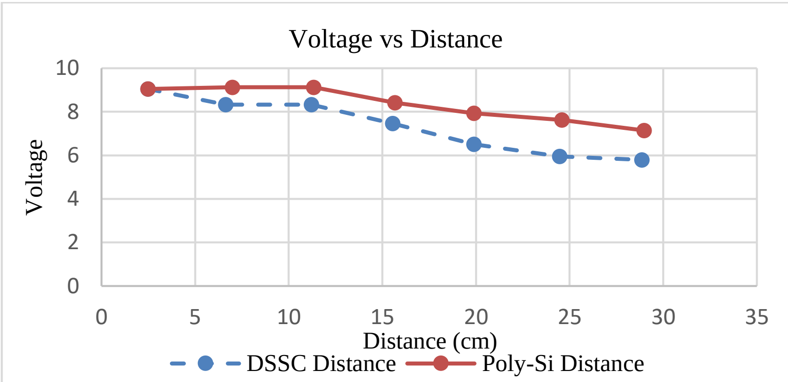

Figure 6. Plotted graph of V_{oc} of polycrystalline and DSSC

4. CONCLUSION

Energy harvesting is a good process where it makes good use of ambient energy from the environment and converts it directly to electricity for small-powered devices. This experiment has proven that it is possible to use energy from indoor light sources to energize a heat sensor using polycrystalline solar panels. The V_{oc} has also been compared with DSSC and polycrystalline shows higher V_{oc} than DSSC. The possibility of using indoor light radiation for energy harvesting using the polycrystalline solar panel was proven, and all 4 light sources used in this experiment were able to produce power when it was placed 15 cm away from the light source. The design of an energy harvesting system for energizing heat sensors using polycrystalline solar panels also has been done where only 100 W incandescent light bulbs have the potential to supply power to the heat sensor.

ACKNOWLEDGEMENTS

This work was partially supported by Petronas Research Sdn. Bhd. under research grant SPP22-124-0124.

REFERENCES

[1] U. Guler, M. S. E. Sendi, and M. Ghovanloo, "A dual-mode passive rectifier for wide-range input power flow," *2017 IEEE 60th International Midwest Symposium on Circuits and Systems (MWSCAS)*, Boston, MA, USA, 2017, pp. 1376-1379, doi: 10.1109/MWSCAS.2017.8053188.

[2] I. de la Parra, M. Muñoz, E. Lorenzo, M. García, J. Marcos, and F. Martínez-Moreno, "PV performance modelling: A review in the light of quality assurance for large PV plants," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 780–797, Oct. 2017, doi: 10.1016/J.RSER.2017.04.080.

[3] A. S. A. Badawi *et al.*, "Evaluation of wind power for electrical energy generation in the mediterranean coast of Palestine for 14 years," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 4, pp. 2212–2219, 2019, doi: 10.11591/ijece.v9i4.pp2212-2219.

[4] K. V. Selvan and M. S. Mohamed Ali, "Micro-scale energy harvesting devices: Review of methodological performances in the last decade," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 1035–1047, Feb. 2016, doi: 10.1016/J.RSER.2015.10.046.

[5] F. Akhtar and M. H. Rehmani, "Energy replenishment using renewable and traditional energy resources for sustainable wireless sensor networks: A review," *Renewable and Sustainable Energy Reviews*, vol. 45, pp. 769–784, May 2015, doi: 10.1016/J.RSER.2015.02.021.

[6] S. Senivasan, M. Drieberg, B. S. M. Singh, P. Sebastian, and L. H. Hiung, "An MPPT micro solar energy harvester for wireless sensor networks," *2017 IEEE 13th International Colloquium on Signal Processing & its Applications (CSPA)*, Penang, Malaysia, 2017, pp. 159-163, doi: 10.1109/CSPA.2017.8064943.

[7] A. Abdullah, S. H. Yusoff, S. A. Zaini, N. S. Midi, and S. Y. Mohamad, "Energy efficient smart street light for smart city using sensors and controller," *Bulletin of Electrical Engineering and Informatics*, vol. 8, no. 2, pp. 558–568, Jun. 2019, doi: 10.11591/EEI.V8I2.1527.

[8] P. Poulose and P. Sreejaya, "Indoor Light Harvesting Using Dye Sensitized Solar Cell," *2018 International CET Conference on Control, Communication, and Computing (IC4)*, Thiruvananthapuram, India, 2018, pp. 152-156, doi: 10.1109/CETIC4.2018.8530924.

[9] A. Chirap, V. Popa, E. Coca, and D. A. Potorac, "A study on light energy harvesting from indoor environment: The autonomous sensor nodes," *2014 International Conference on Development and Application Systems (DAS)*, Suceava, Romania, 2014, pp. 127-131, doi: 10.1109/DAAS.2014.6842441.

[10] M. Kokkonen *et al.*, "Advanced research trends in dye-sensitized solar cells," *Journal of Materials Chemistry*, vol. 9, no. 17, pp. 10527–10545, May 2021, doi: 10.1039/D1TA00690H.

[11] S. Keshari, R. Gupta, and R. Bhargava, "Realization of Visible Light Communication approach with Power LED and Solar panel," *2019 International Conference on Computing, Power and Communication Technologies (GUCON)*, New Delhi, India, 2019, pp. 953-958.

[12] M. A. Abd El Gany, M. F. M. Hassan, M. D. Asham, and U. M. N El Demerdash, "Experimental Investigation of Silicon and Dye Sensitized Solar Cells Based on Wavelength Dependence," *Journal of Basic and Environmental Sciences*, vol. 5, pp. 123–133, 2018.

[13] N. Kawaguchi, G. Okada, Y. Futami, D. Nakauchi, T. Kato, and T. Yanagida, "Scintillation and dosimetric properties of monocrystalline and polycrystalline Li2B4O7," *Sensors and Materials*, vol. 32, no. 4, pp. 1419–1426, 2020, doi: 10.18494/SAM.2020.2752.

[14] M. A. Green, Y. Hishikawa, E. D. Dunlop, D. H. Levi, J. Hohl-Ebinger, and A. W. Y. Ho-Baillie, "Solar cell efficiency tables (version 52)," *Progress in Photovoltaics: Research and Applications*, vol. 26, no. 7, pp. 427–436, Jul. 2018, doi: 10.1002/PIP.3040.

[15] J. Li *et al.*, "A Brief Review of High Efficiency III-V Solar Cells for Space Application," *Frontiers in Physics*, vol. 8, p. 657, Feb. 2021, doi: 10.3389/FPHY.2020.631925/BIBTEX.

[16] S. Yu, Y. Xu, C. Liang, W. Lou, and L. Peng, "Spectral bands of incandescent lamp leading to variable productivity of purple bacteria biomass and microbial protein: Full is better than segmented," *Science of The Total Environment*, vol. 823, p. 153736, Jun. 2022, doi: 10.1016/J.SCITOTENV.2022.153736.

[17] V. Turon, Z. Anxionnaz-Minvielle, and J. C. Willison, "Replacing incandescent lamps with an LED panel for hydrogen production by photofermentation: Visible and NIR wavelength requirements," *International Journal of Hydrogen Energy*, vol. 43, no. 16, pp. 7784–7794, Apr. 2018, doi: 10.1016/J.IJHYDENE.2018.03.019.

[18] H. A. Kazem and M. T. Chaichan, "The impact of using solar colored filters to cover the PV panel on its outcomes," *Scholars Bulletin*, pp. 464-469, 2016, doi: 10.21276/sb.2016.2.7.5.

[19] C. Yang, R. P. Xue, X. Li, X. Q. Zhang, and Z. Y. Wu, "Power performance of solar energy harvesting system under typical indoor light sources," *Renew Energy*, vol. 161, pp. 836–845, 2020, doi: 10.1016/J.RENENE.2020.06.088.

[20] G. Sahin, "Effect of wavelength on the electrical parameters of a vertical parallel junction silicon solar cell illuminated by its rear side in frequency domain," *Results in Physics*, vol. 6, pp. 107–111, 2016, doi: 10.1016/j.rinp.2016.02.003.

[21] E. M. Tennyson *et al.*, "Photovoltage Tomography in Polycrystalline Solar Cells," *ACS Energy Letters*, vol. 1, no. 5, pp. 899–905, Nov. 2016, doi: 10.1021/ACSENERGYLETT.6B00331.

[22] X. Li *et al.*, "Measuring conversion efficiency of solar vapor generation," *Joule*, vol. 3, no. 8, pp. 1798-1803, 2019, doi: 10.1016/j.joule.2019.06.009.

[23] C. Jia and Q. Liu, "Analysis of solar cells in different situations," Thesis, Department of Electrical Engineering, Blekinge Tekniska Högskola, Karlskrona, Sweden, 2015.

[24] A. W. Zulu and G. Kashweka, "The Influence of Artificial Light and Shading on Photovoltaic Solar Panels," *International Journal of Energy Engineering*, vol. 3, no. 1, pp. 15-20, 2013, doi: 10.5923/j.ijee.20130301.03.

[25] J. Amajama, "Effect of Solar Illuminance (or Intensity) on Solar (Photovoltaic) cell's output and the use of Converging lenses and X or Gamma rays to enhance output performance," *International Journal of Engineering Research and General Science*, vol. 4, no. 4, 2016.

[26] Carlos, "Can Solar Panels Work with Artificial Light?," 2021.https://ecotality.com/can-solar-panels-work-with-artificial-light/. Access date: Aug 16, 2022.

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