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Design and implementation of AEM10941 based solar energy system harvester for domestic lighting as a sustainable lighting solution for rural areas

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Lack of access to reliable and affordable electricity in Mbo'o community and the reliance on kerosene lamps for lighting has impacted various aspects of daily life in the area such as education, health, safety and economic productivity. Yields rural exodus and poverty. The aim of this research is to address the challenge of inadequate lighting in the Mbo'o community by developing a sustainable and affordable solution using the AEM10941 solar lamp and thus improving the quality of life for community members and reducing environmental impacts. The methodology involved utilizing the AEM10941 and connecting it with an ATMEGA328pu, switch and LED to construct the lamp. This included configuring the AEM10941, designing the printed circuit board for the lighting and control circuits, and then crafting the lamp casing. The lamp was designed to operate in two modes including indoor and outdoor/security modes. Performance evaluation tests revealed that the AEM10941 effectively charges the battery to full capacity within three hours. Additionally, in indoor mode, a single charge can sustain up to 10 h of lighting, demonstrating the lamp's efficiency and reliability in providing prolonged illumination. At full brightness, the lamp produced an illuminance of 1436 lx. the AEM10941 based solar lamps performance characteristics including illumination intensity, runtime and charging time are in accordance with the standards values and even above. This sustainable way of lighting is the convenient solution to improve the general living standard of the Mbo'o community. The key contribution of this work is the development of a sustainable, affordable and versatile solar lamp tailored to the specific needs of the Mbo'o community. This work provides an innovative solution to address the community's reliance on kerosene lamps, thereby potentially reducing emissions while improving safety and quality of life.

Keywords AEM10941 device, ATMEGA328pu chip, Solar lamp, Sustainable lighting solution, Mbo'o community

Abbreviations

CAD	Computer-aided design
ENHV	Enable high voltage
ENLV	Enable low voltage
IC	Integrated circuit
LDO	Low drop out
LED	Light emitting diode
LVOUT	Low voltage output
MPP	Maximum power point
MPPT	Maximum power point tracking

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PCB	Printed circuit board
PIR	Passive infra-red
PRIM	Primary battery
SSA	Sub-Saharan Africa

Access to energy is traditionally one of the central aspects of economic and social development[1–3]. It is also closely connected to the emergent issue of energy justice[4] concerning the right of all people to have access to energy services and related social benefits, regardless of whether they live in more or less developed countries.

Unfortunately, approximately 1.2 billion people (constituting 17% of the global population) do not have access to electricity, with the vast majority in the Asia–Pacific region and Sub-Saharan Africa (SSA)[5–7]. In SSA, the electrification rate is only about 32–35% and this translates into about 635 million people living without electricity. Consequently, the current low rates of electrification in many African countries has been identified as the most pressing obstacle to economic growth, more important than access to finance, red tape or corruption[5].

From as early as the 1990s, various interventions were initiated with the aim of improving electricity access and renewable energy programme delivery. These include the Power Sector Reform Programme aiming to provide energy sector regulatory and institutional reforms that could make various African countries to improve the financial and technical efficiency of their utilities and the Clean Development Mechanism aiming to facilitate climate change mitigation whilst promoting sustainable development and the enhanced deployment of renewable energy technologies in developing countries[8–13]) to cite a few. Other important actions include the operations of Power Africa, the Sustainable Energy for All (SE4All) Initiative and the China South-South Climate Cooperation Fund.

No matter the above-mentioned initiatives, a significant number of countries in SSA are not improving electricity access at a pace that is compatible with universal energy access in 2030[14–16]. In Cameroon, despite significant improvements in access to electricity over the last few decades, about 80–90% of the population do not currently have access to electricity even today[17], particularly in rural areas, where 60% of the total population live.

The Mbo'o community in the coastal part of Cameroon is one of these rural areas where kerosene lamps are the only means to bring minimal lighting services into the homes in the early mornings and evenings. In regards of our investigations, people (79.03%) in the Mbo'o community use kerosene lamps as the only means of lighting. The other energy resources including generator, battery-powered torches and solar lighting are not used systematically but alternately or concomitantly with kerosene lamps. This has a direct impact, in particular rural exodus and poverty. The location, distance from the central network, geographical conditions and road accessibility isolate them from urban areas, and therefore villages in the Mbo'o community such as and not limited to Nsanke, Mama, Ebang-Mama, Etabang, Mbokambo, Ekah, Ebakong and Nlolak, cannot be connected to the public distribution network within the foreseeable future. Thus, the adoption of appropriate contextualized technologies is essential not only for sustainable lighting but also for sustainable development of the Mbo'o community. One such technology is solar panels, which can effectively harness solar radiation and convert it into electricity. Considering the coastal location of the Mbo'o community in Cameroon, situated approximately between latitudes 4° and 5° north and longitudes 9° and 10° east, solar panels can effectively receive solar radiation and convert it into electricity due to several factors related to the geographic conditions of the area.

Firstly, being near the equator at a relatively low latitude enhances solar inclination, resulting in more direct sunlight and higher solar irradiance levels throughout the year. The community experiences longer daylight hours, contributing to increased solar energy potential for power generation. Additionally, the coastal location provides relatively clear skies and minimal atmospheric interference, further optimizing solar radiation absorption by the panels. Moreover, the coastal region benefits from a tropical climate characterized by consistent sunlight exposure and minimal seasonal variations, ensuring stable solar energy production year-round. These favorable geographic conditions, including its coastal location with low latitudinal and longitudinal coordinates, which enhance solar inclination and irradiance levels, ultimately maximizing the effectiveness of solar energy conversion into electricity.

The AEM10941-based solar energy system[18] emerges as a promising technology. The AEM10941-based solar energy system from e-peas semiconductors is a new chip that has recently been introduced to the market. The choice of this device is due to the fact that it offers fast activation and features a buck converter that ensures high efficiency. In fact, serving as a solar harvesting technology, it offers a sustainable and cost-effective power source for electronic devices, enabling them to operate independently of physical interventions. By harnessing energy from the sun, this system ensures long-term operability. Moreover, it efficiently charges batteries using solar energy, promoting environmental friendliness and cost-effectiveness. Its compact size and low-power consumption make it well-suited for portable applications such as solar lamps. Furthermore, its integration with microcontrollers enables versatile control and customization, enhancing its adaptability to various lighting needs. In this respect, it has been used by several authors[19,20] as energy harvesting system to enhance charge circuitry for indoor photovoltaic energy harvesting with fast activation and high efficiency. Following the same line, the present study consists of developing a solar lamp using the AEM10941 device. This lamp will consist of a feature that will allow the user to switch between the modes in which the lamp can be used. These modes include the indoor and the outdoor (security) modes. The AEM10941 based solar energy system can help to bring electricity in the Mbo'o community thereby improving their quality of life and stimulating their economic growth[21]. In fact, the comparison of different aspects of the AEM10941 based solar energy system with traditional fuel-based lighting have shown that it will not only improves the quality of lighting, but also the general living standard of the inhabitants in the Mbo'o community.

The subsequent sections chronologically present the following: methodology of the research; results and interpretations, discussions of the findings, advantages and conclusion.

Methodology

In order to achieve the present study, the methodology includes system design, AEM10941 implementation process, performance and cost evaluation of the device.

System architecture

The solar lamp consists of 4 main components: the solar panel, the AEM10941 power management module, the IC-controlled switching and the LED lighting module.

- The solar panel captures solar energy and converts it into electrical energy.
- The AEM10941 module acts as the power management unit, regulating the charging of the battery and controlling the power distribution to the LED lighting module.
- The microcontroller ATMEGA328PU integrated circuit (IC), is powered through the output port of the AEM10941. The potentiometer, PIR sensor, pushbutton, transistor, and LED are all wired accordingly to the ATMEGA;
- The push button is wired as a pull-down push button. The ATMEGA328PU IC counts the number of times the button is pressed. The initial count of the button is "0". In this state, the user can adjust the brightness of the lamp using the potentiometer. When the button is pressed, the ATMEGA328PU IC counts it as a button count of "1". This causes the lamp to automatically switch from potentiometer control mode to PIR sensor mode, which turns on the LED upon detecting motion. When the button is pressed again, the ATMEGA328PU IC counts that as a "2" and automatically switches back to potentiometer control mode. This then resets the counter of the ATMEGA328PU IC back to "0".
- Due to the limited output current of the ATMEGA328PU IC, which is set at 20 mA, the brightness of the LED cannot be maximized. To address this, a BJT transistor is included in the circuit design. The output port of the ATMEGA328PU IC is connected to the base of the transistor, while the LED's terminals are placed between the main voltage supply and the collector terminal of the transistor, allowing for greater control of the LED's brightness.

The system architecture for the solar lamp circuit is summarized by the block diagram presented in Fig. 1.

AEM10941 configuration

For this research work, we used the AEM10941 mini board. To ensure the optimal functioning of the device, proper configuration of the AEM10941 is imperative (Fig. 2). The AEM10941 datasheet provides configurations for the user based on the type of storage element the user intends to use. These configurations comprise MPP

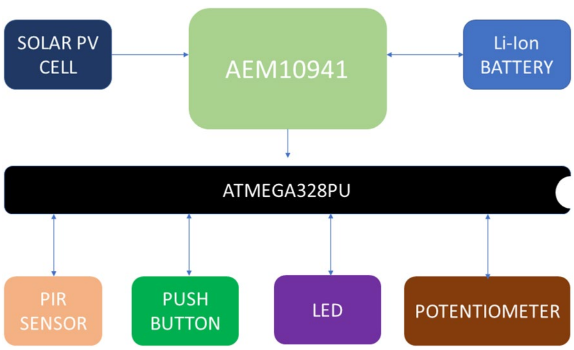

Figure 1. The AEM10941 based solar energy system architecture.

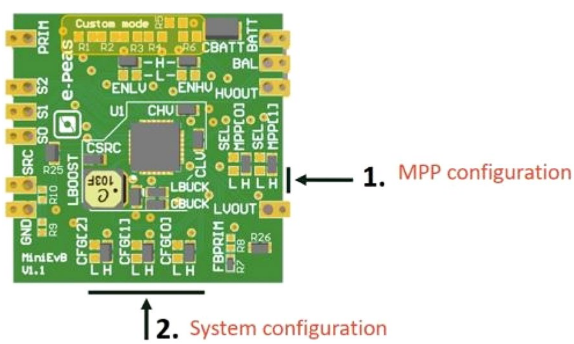

Figure 2. MPP and system configurations on AEM10941.

configuration, LDO output configuration, system configuration, cold start configuration, and final connections. Table 1 provides a summary of the MPP and system configurations that can be implemented for the AEM10941 based solar energy system. The LDO, cold start, and primary battery configurations were pre-configured and did not require any further adjustments. The ENHV and ENLV pins of the LDO were enabled by soldering appropriate resistors.

Referring to Table 1, the MPPT ratio can be selected by soldering a surface mount resistor that corresponds to the configuration logic. In our study, the AEM10941 mini board was configured with an MPPT ratio of 85% and a lithium-ion battery was utilized as the storage element with ratings 3.7 V, 500 mA. This means for this system, once the battery reaches 3.01 V, it is considered depleted and the system shuts down. This also implies that once the battery charges to 4.12 V, the charge is complete and the internal logic maintains battery voltage around V_{ovch} with a hysteresis of a few mV to prevent damage to the storage element and to the internal circuitry. Similarly, a surface mount diode and resistor were already soldered in place for the cold start and primary battery configurations, respectively.

The datasheet provided instructions to leave the LVOUT and PRIM pins floating if they are unused or if no primary battery is incorporated in the system. Thus, for this system, these pins were left unconnected.

Design

The design stage was divided into two sections. The initial section is the circuit design. The circuit design procedure involves the PCB design which was accomplished using Fusion 360 software (Fig. 3). The circuit was designed (Fig. 4a,b) as described by the system architecture above.

The last stage involved designing the PCB. After the schematic was created, the PCB design layout for the system was built. The components arranged such that the traces and routes do not intersect (Fig. 4c,d). Some important considerations taken when the PCB was designed were the clearance and trace widths.

SELMPP[1]–[0]	MPPT ratio (%)	CFG 2–1–0	V_{ovch}	V_{chrdy}	V_{ovdis}	Storage element type
0–0	70	H–H–H	4.12	3.67	3.60	Li-ion battery
0–1	75	H–H–L	4.12	4.04	3.60	Solid state battery
1–0	85	H–L–H	4.12	3.67	3.01	Li-ion/NiMH battery
1–1	90	H–L–L	2.70	2.30	2.20	Single cell supercapacitor
		L–H–H	4.50	3.67	2.80	Dual cell supercapacitor
		L–H–L	4.50	3.92	3.60	Dual cell supercapacitor
		L–L–H	3.63	3.10	2.80	$LiPO_4$
		L–L–L	Custom mode			

Table 1. MPP and system configurations.

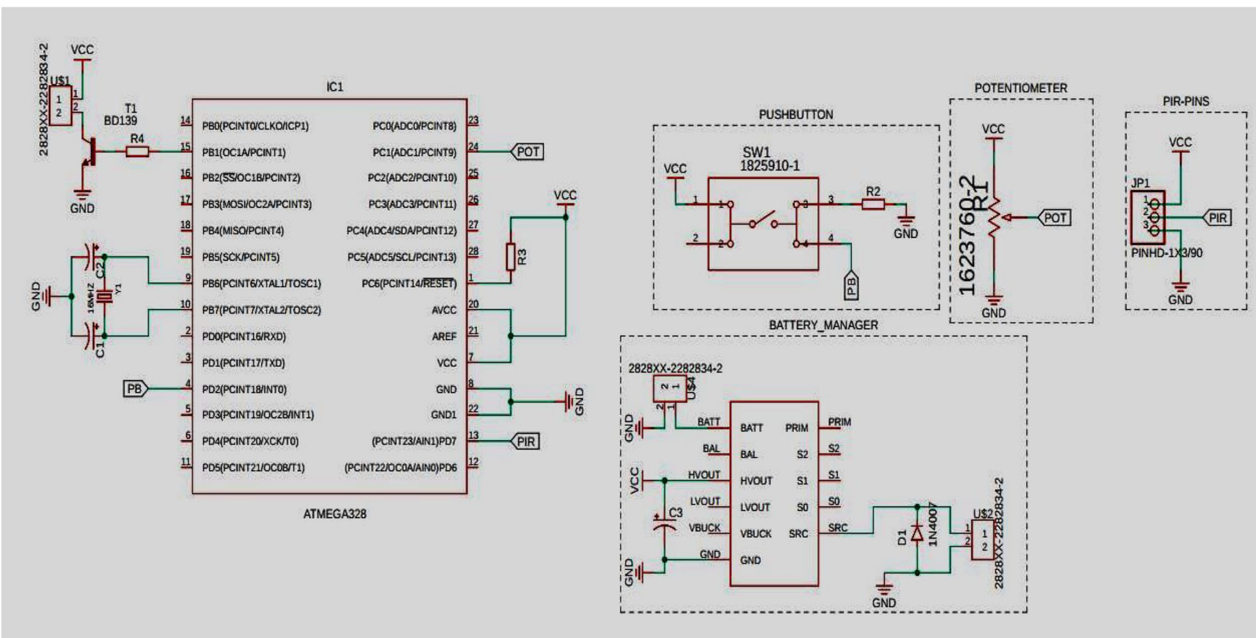

Figure 3. The electrical circuit design using Fusion 360 software.

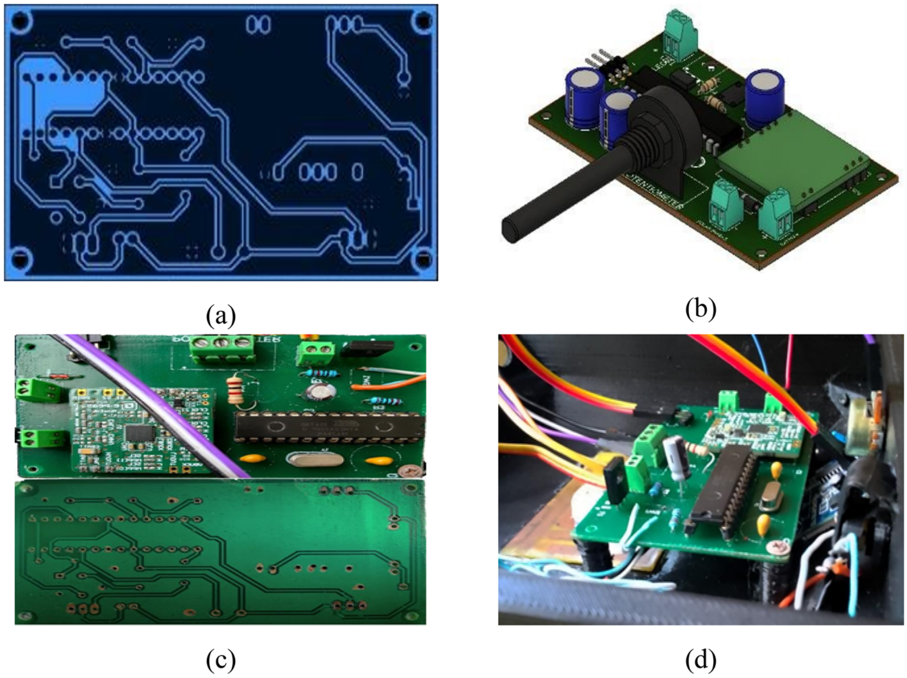

Figure 4. PCB Design Layout (**a**) and 3D view (**b**) of the AEM10941 based solar energy system. (**c**) Prototype with Arduino UNO PCB (top and bottom view); (**d**) PCB in lamp casing.

To counteract the design flaws and ensure that the user needs are met, some considerations are made. First, for solar panel size and placement, the solar cells should be large enough to collect sufficient sunlight, and the placement should be optimized to catch the most sunlight during the day. For this, the top of the lamp was designed such that it will be inclined at a 10° angle. Second, for PIR inclination angle, since the lamp will be used as a security lamp, it is important to choose the right angle of inclination for the PIR sensor's placement. This is done to ensure that it can accurately detect motion especially when placed at any given height. The angle used for this purpose was a 36° decline angle. Third, the lamp should be the right size and lightweight to make it easier to move from one place to another. A minimalistic design that would ensure both functionality and visual appeal. Table 2 outlines the dimensions for several parts of the AEM10941 based solar energy system.

The subsequent stage entails computer-aided design (CAD) modeling and design review. The previously tabulated data and rough sketches served as references for generating a 3D model of the lamp using Autodesk's cloud-based Fusion 360 software.

Performance evaluation

Following the study of[22], performance evaluation of the final manufactured AEM10941 based solar energy system is subjective to at least two dimensions. First, determining what constitutes performance and how that is measured. Second, determining for each measurement of performance what constitutes an acceptable minimum level. References[23–25] in their studies, suggested that the core performance area relevant to all solar portable lights (SPLs) are illumination intensity, illumination quality, runtime, charge time and general maintenance. Other possible performance characteristics, such as multiple lighting modes, mobility, and phone charging, were determined to be desirable functionalities by the authors but beyond the scope of a basic SPL intended to replace candles and kerosene based lighting systems. Due to the lack of some measurement equipment, we limit ourselves to three performance characteristics including illumination intensity, runtime and charging time. Of the above characteristics, illumination intensity was considered by[23–25] as the most important performance criterion to define. It is typically measured in one of two ways, based on the type of light and its application. For task lights,

Nº	Parts	Dimensions (cm)
1	Pillars	25
2	Base support	15 × 15
3	Top housing (base) × (hypotenuse) × (height)	16 × 16.5 × 3
4	Top (angle)	10°
5	Top (PIR housing angle)	36°

Table 2. The AEM10941 based solar energy system dimensions.

such as torches or desk lamps, light is often measured in lux, while for ambient lights, output light is measured in lumens. Given the presumed task of the manufactured AEM10941 based solar energy system, illumination intensity or brightness is measured in lux.

In the laboratory, we conducted a series of measurements to evaluate both the charging and discharging rates and illuminance levels. For the charging evaluation, we carefully removed top portion of the lamp, thereby isolating the solar panel and internal circuitry. This setup allowed the solar panel to be directly exposed to sunlight, supply voltage to the AEM10941 energy harvester. We employed a multimeter connected to the battery to monitor the charging process, with readings recorded at regular intervals using a timer. In contrast, for the discharge assessment, we activated the lamp at maximum brightness within a darkened room to simulate real-world usage conditions. During this phase, we positioned a lux meter beneath the light source to measure illuminance levels emitted by the lamp. Concurrently, a multimeter remained connected to the battery, enabling us to monitor the discharge rate. Similar to the charging evaluations, reading were recorded periodically with the assistance of timer. These measurements provided comprehensive insights into the charging efficiency, discharge behavior and illuminance output of the lamp under varying condition, facilitating a thorough evaluation of its performance and effectiveness.

Results

AEM10941 based solar energy system manufactured

Figure 5 displays the 3D model of the AEM10941 based solar energy system. After the completion of component soldering and testing, the PCB was carefully mounted unto its designated slot on the lamp hardware. The board was secured in place using a combination of screws and superglue. The components that required terminal placement were securely affixed by screwing them into their respective terminals. The final product was then assembled and subjected to a series of rigorous tests to ensure optimal performance. For instance, let recall to readers that the aim of the AEM10941 based solar energy system is to provide sustainable development by bringing illumination at night to remote communities and, in particular the Mbo'o community which lack access to traditional electricity and often rely on expensive and pollution sources of energy such as kerosene lamp. Figure 6 below shows the AEM10941-based solar lamp illuminating a dark room in the Mbo'o community. This image demonstrates the effective lighting provided by the solar lamp in a low-light environment, showcasing its potential to improve visibility and enhance safety in areas with limited access to electricity.

Figure 5. Final product. (1) Solar Panels; (2) "Mode" Push Button switch; (3) Potentiometer; (4) PIR sensor; (5) LED panel Light; (6) Handle.

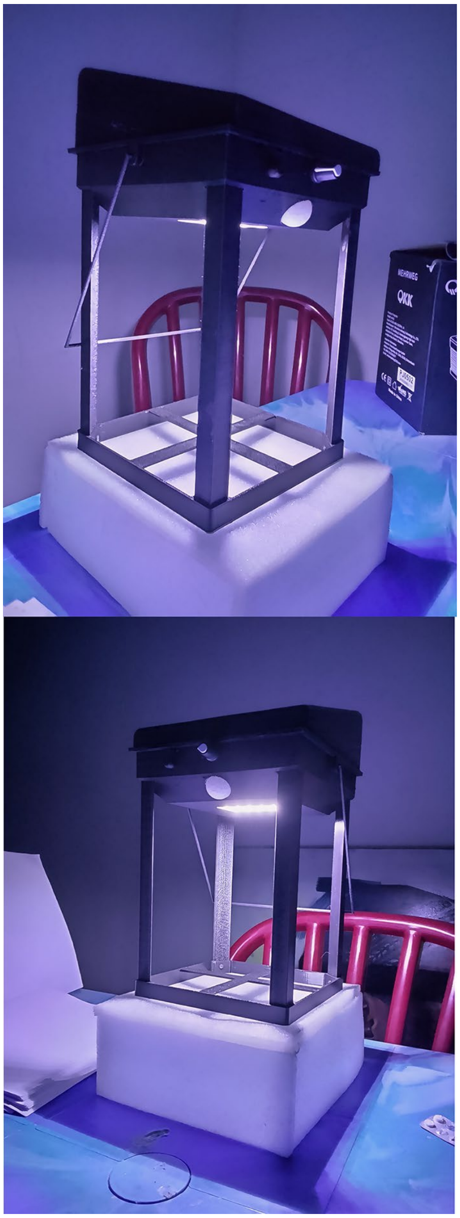

Figure 6. AEM10941-based solar lamp illuminating a dark room.

Electrical and physical characteristics

Both electrical and physical properties of the above final manufactured AEM10941 based solar energy system are indicated in Tables 3 and 4 respectively.

Performance evaluation results

Results of performance characteristics are given in Table 5 for brightness, Table 6 for battery runtime or battery life test and Table 7 for charging test respectively. The graphical representations of the above results of performance evaluation of the AEM10941 based solar energy system are depicted in Fig. 7, which illustrates the empirical findings from the performance evaluation tests of the lamp.

Discussion

The AEM10941 solar energy system underwent a series of performance tests, which revealed that it exhibited a luminous intensity of 50 lx at the lowest brightness setting and 1436 lx at maximum brightness. For[26], acceptable light levels depends on many variables, including the type of task, environmental conditions and eyesight of the user to cite a few. Thus, it has been decided that candles or basic kerosene wick lamp would serve as a baseline indicator of minimally acceptable light output. Laboratory measurements for typical fluorescent lantern gave approximately 340 lumens[27]. Given that 1 lx = 1 lm/m^2, this correspond to about 340 lx. Therefore, the level of

Designation	Characteristics
Solar panel	2Wc, 85% efficiency
Li-ion battery	3.7 V 500mAH
LED power	0.2W/PC × 20PCS
Motion angle	90 ~ 120
Sensitivity distance	4 m/13.1 ft
Delay time	7 s
Switch	Security/indoor mode
Lighting mode	Adjustable brightness

Table 3. Electrical characteristics of the final manufactured AEM10941 based solar energy system.

Height/cm	Length/cm	Width/cm	Weight/g	Incline angle (°)	PIR angle (°)
28	16	16	100	10	15

Table 4. Physical characteristics of the final AEM10941 based solar energy system.

Lamp intensity	Low	Medium	High
Illumination (lux)	50	700	1436
Potentiometer position	1/9KΩ	2/5KΩ	3//0.1KΩ

Table 5. Brightness test results of the AEM10941 based solar energy system.

V (V)	3.7	3.67	3.64	3.61	3.57	3.54	3.50	3.47	3.43	3.39	3.35	3.32	2.98	2.75
Time (h)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Illuminance (lux)	1436	1436	1436	1436	1436	1424	1420	1403	1337	1329	1324	1324	863	0

Table 6. Battery discharge test (case for maximum brightness) results of the AEM10941 based solar energy system.

Battery voltage (V)	2.75	3.39	3.57	3.69
Time (h)	1	2	3	4

Table 7. Charging test results of the AEM10941 based solar energy system. *T/h* Time/hours.

illumination intensity of the final manufactured AEM10941 based solar energy system is in accordance with the standards values.

Another characteristic investigated in the present study is the runtime. From our result, it's clear that the runtime depends on the system's size and level of brightness. For instance, based on user responses about their current kerosene and candle usage patterns in Zambia, 4 h was established as the required nightly runtime for typical fluorescent lantern. Meaning that the typical fluorescent lantern needed the capacity to sufficiently charge the battery in one day to provide 4 h of runtime[22,28]. This standard value of runtime is as smaller as the one obtained through performance evaluation of the manufactured AEM10941 based solar energy system, which is 10 h.

Finally, the last characteristics of our final manufactured system is the charging time. We obtained the value of 3 h as the time needed for the AEM10941 based solar energy system to efficiently charge the battery to full capacity. For our knowledge, there is not a standard value of recharging time. For instance, Reference[22] in his study revealed that almost all research participants were familiar with using batteries in electronic devices, and many inquired about the type of battery that would be used, how long it would last, and whether it could be replaced. The author obtained the value of 5.5 h based on Zambia's latitude and average of 5.5 h peak sun daily.

Advantages of the AEM10941 based solar energy system manufactured

One of the key contributions of this work is its focus on energy efficiency and sustainability. The AEM10941 based solar lamp project offers several advantages over conventional solar lamps. Firstly, the advanced power

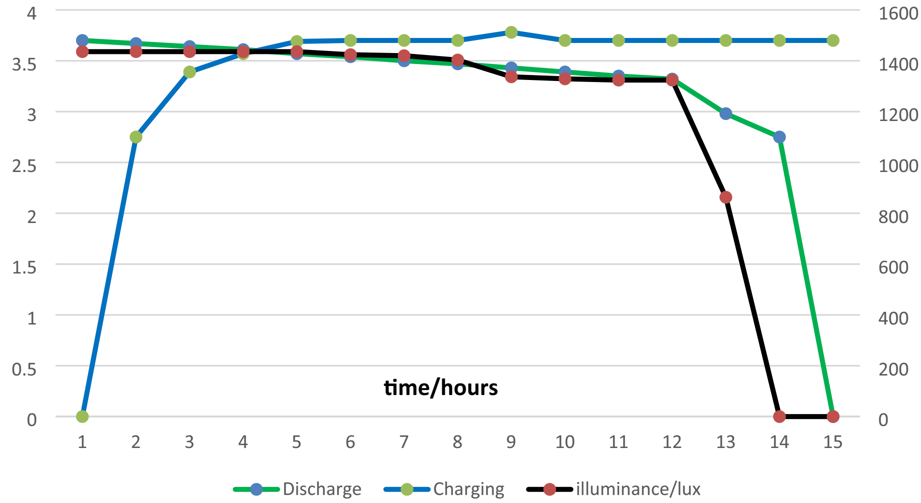

Figure 7. Graphical representations of the above results of performance evaluation of the AEM10941 solar energy system.

management features of the AEM10941 module, such as MPPT and efficient battery charging, ensure optimal energy utilization and longer battery life. This results in extended illumination periods compared to conventional solar lamps. Additionally, the AEM10941 module's intelligent control algorithms enable precise brightness control, allowing users to adjust the lighting levels according to their specific needs. This flexibility enhances user satisfaction and energy efficiency.

In addition, the AEM10941-based solar lamp project uses a clean and renewable source of energy which significantly reduces the harmful environmental impact[29–31]. The average indoor air pollution was up to 20 times less with LED lighting and a smokeless metal stove compared to the use of fuel for lighting and cooking on an open fire place. These improvements over a ten years' time will incur considerable positive health improvements, especially in regard to chronic respiratory chest diseases. It is assumed that this will enable a prolonged life expectancy of about 10 years, from present 54 to 64 years. Thus, the "healthy and long life" HDI factor increases from 0.483 to 0.650. By utilizing solar energy, it eliminates the need for traditional energy sources like fossil fuels and coal. This reduces greenhouse gas emissions, air pollution, and dependence on non-renewable resources[32]. The LED lighting module used in the project is highly energy-efficient, consuming minimal power while providing adequate illumination. This further contributes to a lower carbon footprint and energy conservation.

Also, the AEM10941 based solar lamp also offers a cost-effective solution compared to fueling a mini generator. Solar energy is a free and abundant resource, eliminating the need for ongoing fuel expenses[33–36]. Once the initial investment in the solar lamp system is made, the operational costs are minimal. In contrast, fueling a mini generator involves regular expenses for purchasing and refilling fuel, which can become a financial burden, especially in remote or rural areas where access to fuel may be limited or costly.

Furthermore, the AEM10941 based solar lamp project can have a positive economic impact, particularly in rural areas like the Mbo'o community. In rural areas without reliable access to electricity, the solar lamp system provides a practical lighting solution that enhances productivity and extends working hours during the evening. This can benefit various sectors, including agriculture, education, and small-scale businesses[37]. By eliminating the need for costly and environmentally harmful energy sources, the system reduces the financial burden on rural communities and allows them to allocate resources to other critical needs.

Finally, in comparison to kerosene lamps, the LED lighting module used in the AEM10941 based solar energy system offers superior efficiency and longevity. LEDs are highly efficient and convert a higher percentage of electrical energy into light, resulting in energy savings. The AEM10941 based solar lamp also offers greater flexibility in terms of dimmable and adjustable brightness level. Additionally, LEDs have a much longer lifespan (about 15,000 to 50,000 h of usage) compared to incandescent lamps (about 750 to 2000 h of usage), reducing maintenance and replacement costs. Their energy efficient nature results in minimal heat generation, making them safer to use and lesser risk of fire hazards compared to kerosene lamps. The durability of the AEM10941 based solar lamp and the integration of a switch and LED with the ATmega328PU microcontroller enables the implementation of user-friendly features such as multiple operating modes (indoor and outdoor/security mode). This enhances usability and convenience for users, making the solar lamp system more accessible and adaptable to various lighting needs compared to simpler designs making it a reliable lighting solution for the Mbo'o community.

Conclusion

This paper has demonstrated that the AEM10941 is capable of facilitating the achievement of efficient lighting. The lamp's MPPT ratio was configured to 85%, and a lithium-ion battery was utilized as the energy storage element. To validate its efficiency, the lamp underwent a series of performance tests, which revealed that it exhibited a luminous intensity of 50 lx at the lowest brightness setting, 700 lx at medium brightness, and 1436 lx at maximum brightness. These brightness levels were indicated by numerical values on the lamp, based on the position of the potentiometer. Furthermore, the battery of the lamp was observed to last up to 10 h at full brightness before requiring recharging, indicating that the lamp is dependable due to its prolonged battery life. The AEM10941 component is capable of charging the battery to its full capacity in under four hours. The prototype designed is smart energy saving having a battery management system. Adjustable brightness level, switch-controlled Dual mode; security by PIR motion sensor and indoor mode. The replacement of fuel-based lighting can be done in a sustainable way by using the existing and environmentally friendly renewable energy sources like solar power. Overall, the performance evaluation tests demonstrated that the AEM10941 based solar lamps performance characteristics including illumination intensity, runtime and charging time are in accordance with the standards values and even above. With the AEM10941-based solar lamps, Mbo'o community members can engage in activities that were previously limited by the absence of light. After dark, individuals can study, work on projects, or engage in other productive endeavours, thus expanding opportunities for personal and educational development. Moreover, reliable lighting enhances safety by illuminating pathways and deterring potential threats, contributing to a sense of security within the community. Additionally, by reducing reliance on hazardous kerosene lamps, the solar lamps promote better health outcomes by minimizing exposure to harmful fumes and reducing the risk of accidents. By providing a sustainable and affordable source of power, the AEM10941-based solar lamps empower individuals to pursue economic opportunities and improve their overall livelihoods. Therefore, its comes that the present research work is a significant contribution to engineering, as sustainability is becoming an increasingly important consideration in the design of new technologies.

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All authors contribute in the same way.

Competing interests
The authors declare no competing interests.

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