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Experimental Evaluation of a Reflective Solar Light Tube with Photovoltaic-Supported Nighttime Illumination: Daytime Illuminance, Spatial Uniformity, Electrical Output, and Weather-Dependent Performance in a School Library in Floridablanca, Pampanga, Philippines

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ABSTRACT

This study experimentally evaluated a solar light tube (SLT) system installed in a library room at Floridablanca National Agricultural School, Pampanga, Philippines. Four SLT units were assessed using daytime illuminance measurements, nighttime illuminance readings, separate nighttime operating-duration trials, and electrical measurements under the sunny, cloudy, and rainy categories represented in the dataset. Daytime illuminance ranged from 157.3 to 5,080.0 lux. Nighttime illuminance measured from 6:00 p.m. to 8:00 p.m. ranged from 462.0 to 478.3 lux; separate operating-duration trials reported 15–16 hours. Across seven electrical trials, output voltage ranged from 12.00 to 12.17 V, output current from 3.00 to 3.13 A, and the calculated output-to-input power ratio from 60.97% to 63.85%. Mean illuminance was 1,310.06 lux under sunny conditions, 466.55 lux under cloudy conditions, and 225.44 lux under rainy conditions. A one-way analysis of variance was reported as $F = 3.43$, $p = 0.047$. This finding is exploratory because the hourly observations may not be independent and the analysis assumptions were not documented. The results characterize the tested prototype; long-term performance, glare, visual comfort, seasonal variation, and weatherproofing were not established.

Keywords: Solar Light Tube; Tubular Daylighting Device; Daylighting Performance; Indoor Illuminance; Illuminance Measurement; Spatial Uniformity; Photovoltaic System; Battery-Supported Lighting; Output-to-Input Power Ratio; School Library; Sustainable Lighting; Weather-Dependent Performance.

1.0. Introduction

Solar energy has been regarded as one of the most available clean energy sources for years, which can provide clean, trustworthy, and sustainable light sources for home and institutional applications. The rising demand for mitigating environmental impact and decreasing the dependency on fossil fuel-based energy grids is fueling the global adoption of cleaner and greener technologies in which solar is positioned as a key enabler in futuristic sustainable development plans [1]. One of the first developments in this field is the recycled bottle lamp, a basic daylighting system that employs plastic bottles filled with water and bleach to bend sunlight into interior areas. With its low-cost and easy availability, this technology served as a basis to show how recycled materials could be used to provide daylight indoors. The selected library room at Floridablanca National Agricultural School requires suitable lighting for reading and other learning activities. The manuscript reports baseline illuminance of approximately 150–200 lux and uses 300–500 lux as a working reference range for educational tasks [2, 3, 4]. This range should not be presented as a verified requirement for this specific library until the applicable lighting standard and task plane are confirmed. The prototype was evaluated to document indoor daylight delivery and the separate performance of its battery-supported lighting after dark.

1.1. Study Objectives

1) Design and construct a solar light tube using a reflective tube, acrylic components, and a diffuser for installation in the selected library room.

2) Measure indoor illuminance at the specified room locations during daytime and nighttime testing.

3) Calculate the minimum-to-average illuminance uniformity ratio from the reported measurement points.

4) Measure photovoltaic-system input and output voltage and current, calculate power, and report the output-to-input power ratio.

5) Record nighttime operating duration and report nighttime illuminance only for the hours in which lux readings were actually collected.

6) Compare measured indoor illuminance among the sunny, cloudy, and rainy weather categories represented in the dataset, while acknowledging limitations in the statistical design.

2.0. Literature Review

Early daylighting research examined water-filled bottle lamps as a means of redirecting sunlight into interior spaces. Laboratory photometric work has shown that the luminous performance of these devices depends on the incident sky conditions, solar angle, and installation geometry [5, 6, 7, 8, 9]. Community deployments and practical descriptions of bottle-based lighting also illustrate the use of simple materials to provide daylight in settings with limited access to electricity [10, 11]. These devices should not be treated as equivalent to reflective solar light tubes, because their optical paths and construction differ. The present study therefore focuses on a reflective tube with a separate photovoltaic-supported nighttime lighting function.

Hybrid daylighting systems that combine daylight collection with photovoltaic charging and stored-energy lighting require separate assessment of optical performance and electrical performance. Daylight illuminance, nighttime illuminance, operating duration, and electrical power are different outcomes and should not be conflated.

In particular, a high lux reading at one point or time does not by itself demonstrate visual comfort, low glare, or uniform illumination across an entire room. Spectral characteristics of white LEDs can also be relevant to classroom lighting quality, but spectral output was not measured in this study [12]. Lighting design objectives and evaluations of school lighting also provide context for interpreting indoor lighting performance [13, 2].

Prior bottle-based and small solar lighting systems can be affected by optical losses, material aging, dust, water ingress, battery degradation, and changes in available solar radiation. These factors can affect long-term output and reliability; they should be tested rather than assumed to be resolved by a reflective tube design. Previous solar-lighting work has also identified practical design and reliability considerations [9].

For the present study, the solar light tube (SLT) uses a reflective duct to transport daylight through a roof opening into an enclosed room. A reflective inner lining is intended to reduce losses during transmission. The system also includes photovoltaic components and a battery-supported LED load for use after dark. These design features provide the basis for evaluating daytime illuminance, spatial uniformity, electrical measurements, and nighttime operating duration; the study does not establish annual energy savings or visual-comfort performance. Reviews of light-pipe models and earlier solar-light-pipe performance studies provide broader technical context for this design [14, 15, 16].

Recent research evaluates tubular daylighting devices using daylight availability, illuminance distribution, and visual-comfort measures rather than peak illuminance alone. Ferahta and Dahmani (2025) compared tubular daylighting configurations for classrooms using a multi-criteria approach [17]. Noor and Joarder (2026) examined a horizontal light-pipe system for a library reading area in a tropical climate [18]. Mesloub et al. (2026) evaluated a hybrid arrangement of tubular daylighting devices and light shelves for deep classrooms [19]. These studies support the need to examine distribution and visual comfort in addition to illuminance. The present study contributes field measurements from a school-library setting, while glare assessment and annual daylight metrics remain outside its scope.

3.0. Methodology

3.1. Conceptual Framework

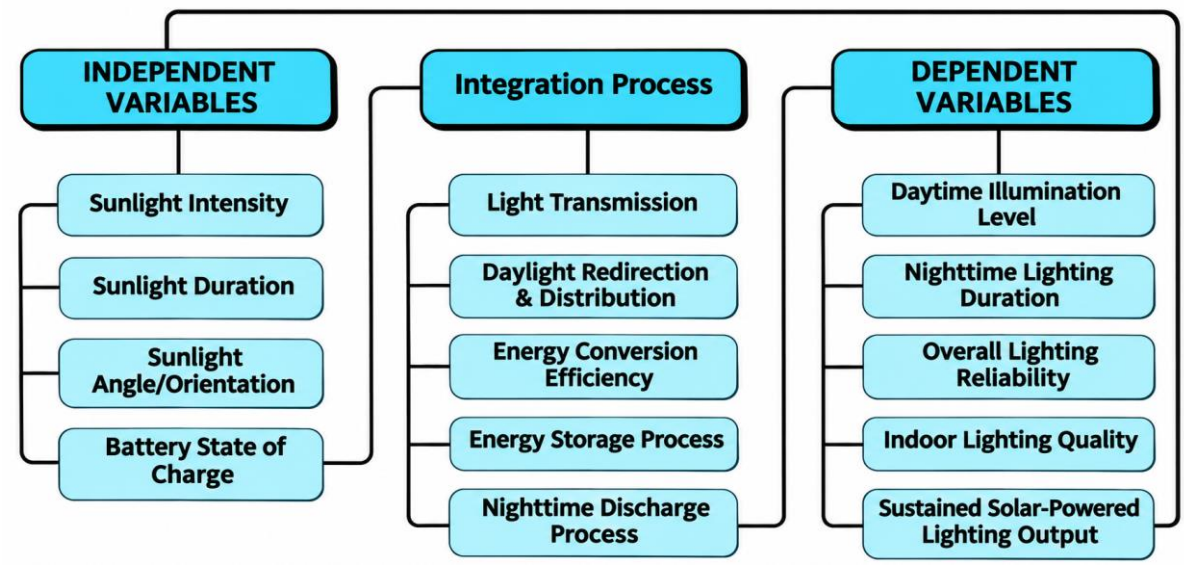


Figure 1. Conceptual Framework Showing the Solar Light Tube's Daylight-Transmission Pathway, Photovoltaic Energy Collection, Battery Storage, And Supplemental Nighttime Led Operation.

As shown in Figure 1, the solar light tube (SLT) is intended to transmit daylight into the room and provide supplemental light-emitting diode (LED) illumination at night. The factors considered include available sunlight, time of day, solar orientation, and battery state of charge. These factors can influence daylight collection, electrical-energy storage, and nighttime operation.

The SLT integrates optical transmission with a photovoltaic-supported lighting system. Daylight travels through the hollow reflective tube and exits through the diffuser into the room. The reflective lining is intended to reduce optical losses, while the diffuser helps distribute the transmitted light. The photovoltaic panels convert solar energy into electrical energy, which is stored in a lithium-ion battery for later use. At night, the stored energy powers the LED lights. Figure 1 summarizes the intended flow of energy from collection and conversion to storage and nighttime use.

The dependent variables were daytime illuminance, nighttime operating duration, measured electrical output, and illuminance uniformity at the selected measurement points. Daytime illuminance describes the daylight delivered

indoors; nighttime operating duration describes how long the LED load operated on stored energy; electrical measurements describe voltage, current, and calculated power at the specified measurement points; and uniformity describes the distribution of illuminance among the sampled locations. These outcomes were influenced by sunlight availability, time of day, system configuration, and battery state of charge. Long-term reliability and continuous renewable-lighting performance were not established by the short-term tests.

3.2. Design Considerations of the Solar Light Tube

The SLT design uses an 8 × 8 in. acrylic top cover with a thickness of 5 mm to protect the upper tube opening while allowing daylight to enter. A circular acrylic plate, 6.25 in. in diameter and 3 mm thick, is fitted at the lower end. The lower plate and its holder are intended to diffuse transmitted light and support the assembly; their actual effect on glare and spatial distribution was not measured separately.

The main light-guiding housing is a 6-in.-diameter PVC tube with a reported length of 4.5 ft. Its inner surface is lined with reflective chrome-effect vinyl to direct daylight toward the lower diffuser. A 3D-printed holder supports and aligns the circular acrylic plate. The reflective lining is intended to reduce optical losses, but its reflectance and the tube's transmission efficiency were not independently measured.

A galvanized frame with reported outer dimensions of 12 × 12 in., inner dimensions of 8 × 8 in., and a 1-in. profile supports the upper assembly. Metal flat-bar brackets and roof fasteners secure the assembly. Long-term resistance to rain, ultraviolet exposure, wind loads, and water ingress was not proven by the reported short-term lighting tests.

The combined acrylic components, PVC tube, reflective lining, printed holder, galvanized frame, and brackets form the prototype assembly. Installation durability and roof-seal performance require separate inspection and long-term testing.

3.3. Electrical Design

3.3.1. Electrical Load

The reported lighting load consists of two mini-LED spotlight bulbs rated at 10 W each, for a nominal combined load of 20 W. Daily energy demand should be calculated from the measured or rated load power and the actual operating duration, rather than inferred from illuminance readings alone [20].

3.3.2. Solar Panel Sizing

The photovoltaic energy requirement was estimated from the daily load demand and an assumed overall system efficiency to account for wiring, controller, and other system losses [21]. The assumed efficiency factor is a design input, not a measured efficiency of the assembled prototype.

The minimum nominal PV array rating is estimated from the daily energy requirement and the assumed daily peak-sun-hours value. The selected peak-sun-hours assumption and the resulting panel-sizing calculation should be reported explicitly so that the sizing estimate can be reproduced [22, 23, 24].

In Equation (1), E_{PV} is the required photovoltaic energy per day (Wh/day), E_{load} is the daily load energy demand (Wh/day), and η_{sys} is the assumed overall system efficiency (dimensionless). The manuscript uses $\eta_{sys} = 0.8$ as a planning assumption; it should not be described as a measured prototype efficiency.

$$E_{PV} = E_{load} / \eta_{sys} \quad (1)$$

Where E_{PV} is the required photovoltaic energy (Wh/day), E_{load} is the daily load energy demand (Wh/day), and η_{sys} is the assumed overall system efficiency (dimensionless).

3.3.3. Battery Capacity (Lithium-Ion Type)

The energy-storage component must supply the lighting load during the reported nighttime operating period. Battery sizing depends on load energy, nominal battery voltage, usable depth of discharge, conversion losses, and battery condition. The battery capacity and usable energy reported here describe the stated design; independent capacity testing was not reported. General off-grid storage literature provides background for the energy-storage discussion [25].

Battery capacity can be estimated from the daily energy demand divided by the product of system voltage and the permitted depth of discharge, with any relevant conversion losses included. In this calculation, depth of discharge (DoD) is the fraction of nominal battery capacity intended to be used. The estimate is a sizing calculation and should be distinguished from the observed nighttime operating duration [26, 27].

3.3.4. Wire Sizing

Weather-resistant conductors are needed to limit voltage drop and prevent overheating. Conductor selection depends on current, conductor material, insulation rating, cable length, installation method, ambient temperature, overcurrent protection, and applicable electrical codes. The reported design specifies a 2-mm-diameter conductor for a nominal 5-A load. Conductor ampacity and installation compliance were not independently assessed in this study [28, 29].

The conductor dimension is reported as a design detail. Because conductor type, cross-sectional area, protective-device rating, and installation method were not fully documented in the test dataset, code compliance cannot be concluded from the reported diameter alone.

3.3.5. Electronic Components

The charge-controller current rating is commonly estimated from PV array current or power, system voltage, and a suitable design margin. The 1.25 factor used in this manuscript is a sizing assumption; the applicable controller input/output side and module specifications determine its use [30, 31]. The controller's actual rating, battery-chemistry setting, protection functions, and wiring configuration were not independently verified in the reported tests. The lighting load operates on low-voltage direct current (DC).

A remote-control receiver module is described as part of the LED circuit. The receiver is intended to accept wireless commands and control the LED circuit, but its switching function was not evaluated as a separate outcome in the reported illuminance and electrical measurements. The product description cited for the controller may not establish the exact behavior of the installed module [32].

The receiver is intended to accept wireless commands from the transmitter and control the LED circuit. Its operation was not evaluated as a separate outcome in the reported illuminance and electrical measurements.

3.4. Testing Phase

3.4.1. Daytime and Nighttime Illuminance

Daytime illuminance was measured hourly from 8:00 a.m. to 5:00 p.m. Nighttime illuminance readings were reported for 6:00 p.m., 7:00 p.m., and 8:00 p.m. Separate nighttime operating-duration trials reportedly continued until the battery-powered lighting stopped, after approximately 15–16 hours. These are distinct procedures: the three-hour lux dataset does not show that illuminance remained at the measured level throughout the full runtime.

A lux meter was used to record indoor illuminance. The manuscript uses 300–500 lux as a working reference range for educational tasks; the applicable standard, task surface, and measurement plane were not independently established for this specific library [33, 4]. Nighttime operating duration was recorded separately from the hourly illuminance readings.

Illuminance readings were taken at the front, middle, and back points along the reported light-distribution line. The points were reported as 3 ft apart, and the lux meter was positioned 0.8 m above the floor. A detailed room plan and diffuser-to-point distances were not included in the supplied manuscript, limiting independent reproduction of the measurement layout.

$$E_{avg,SLT} = (E_{front} + E_{middle} + E_{back}) / 3 \quad (2)$$

Where $E_{avg,SLT}$ is the mean illuminance for one solar light tube (lux), and E_{front}, E_{middle}, and E_{back} are the illuminance readings at the front, middle, and back measurement points (lux), respectively.

3.4.2. Uniformity Testing

Uniformity testing was used to describe how evenly illuminance was distributed across the selected indoor measurement points under the recorded weather conditions. Uniformity is a separate metric from mean illuminance and does not, by itself, establish visual comfort or the absence of glare.

In lighting design, uniformity is one factor used to evaluate the distribution of light and the potential for strong contrasts and shadows in occupied spaces [3].

The room was assessed using four measurement zones, with one SLT unit located near the center of each reported quadrant. Based on the room dimensions used for this manuscript (8.53 m long and 6.19 m wide), the calculated floor area is approximately 52.80 m² (8.53 m × 6.19 m = 52.8007 m², rounded to 52.80 m²). This calculated area replaces the inconsistent 48 m² figure. The four-zone layout is described as used in the study; the precise placement of each measurement point should be checked against the original site layout before publication.

$$E_{AVG} = (E_{avg1} + E_{avg2} + E_{avg3} + E_{avg4}) / 4 \quad (3)$$

Where E_{AVG} is the mean illuminance across the four measurement zones (lux), and E_{avg1} through E_{avg4} are the average illuminance values for zones 1–4 (lux).

Equation (3) calculates the arithmetic mean of the four zonal illuminance values included in the dataset.

The mean provides a summary of the measured illuminance at the selected points; it should not be interpreted as a full-room spatial average unless the measurement grid is sufficiently representative of the room [34].

$$U0 = Eminimum / EAVG \quad (4)$$

Where U_0 is the minimum-to-average illuminance uniformity ratio (dimensionless), E_minimum is the lowest zonal average illuminance (lux), and E_AVG is the average illuminance across all four zones (lux).

The minimum-to-average uniformity ratio was calculated by dividing the lowest zonal average illuminance by the average of the four zonal readings. Values closer to 1 indicate a more even distribution among the sampled points. Any threshold used to judge compliance must be tied to the applicable lighting standard, task, and measurement plane; a uniformity ratio alone does not establish adequate lighting [35, 36].

3.5. Solar-Powered Output and Electrical Performance Analysis

During photovoltaic operation, input voltage (V in) and input current (I in) were measured to estimate input power (P_in). The manuscript reports the measurement points but does not fully document whether all voltage and current readings were synchronized or averaged [37].

Input voltage (V_in) was measured across the PV-panel output terminals using a digital multimeter connected in parallel. Input current (I_in) was measured in series between the PV panel and the charge-controller input. Measurements were taken at the reported daytime intervals. Input power was calculated as follows:

$$Pin = Vin \times Iin \quad (5)$$

Where P_in is input electrical power (W), V_in is input voltage (V), and I_in is input current (A).

The input/output power ratio was calculated from the measured electrical quantities. Because measurements were taken at the PV input and the controller-to-battery output, the reported ratio describes those measurement points under the test conditions; it is not a full-system efficiency measurement unless all relevant losses and measurement conditions are accounted for.

3.5.1. Power Efficiency Analysis

Power ratio was calculated by dividing the measured output power (P_out) by the measured input power (P_in) and multiplying by 100. Here, P_in refers to the PV-side voltage-current product and P_out refers to the reported controller-to-battery voltage-current product. The resulting percentage should be described as the measured output-to-input power ratio at those measurement points, rather than as an independently verified efficiency of the complete lighting system.

$$\eta = (Pout / Pin) \times 100\% \quad (6)$$

Where η is output-to-input power ratio (%), P_out is measured output power (W), and P_in is measured input power (W).

3.6. SLT Illumination Under Varying Conditions

Indoor illuminance was compared across the three weather categories recorded in the dataset: sunny, cloudy, and rainy. Hourly values were tabulated from 8:00 a.m. to 5:00 p.m. for each category. Weather labels, sky conditions, and irradiance were not independently quantified in the reported dataset, so the categories should be treated as recorded classifications rather than calibrated meteorological conditions.

The investigation evaluated baseline system performance, its ability to collect diffuse ambient daylight under lower-irradiance conditions, and its performance in providing indoor illumination to the library across the recorded weather conditions.

Descriptive statistics and a one-way analysis of variance (ANOVA) were used to compare the recorded weather-group values. An exploratory significance level of $\alpha = 0.10$ was selected for this preliminary prototype evaluation. The reported p-value is below this threshold; however, the same hours were measured across weather categories and may not constitute independent observations. Because the design and ANOVA assumptions were not documented, the result should be treated as exploratory and confirmed using a suitable repeated-measures or otherwise justified analysis with additional data.

4.0. Results and Discussion

4.1. Solar Light Tube Design

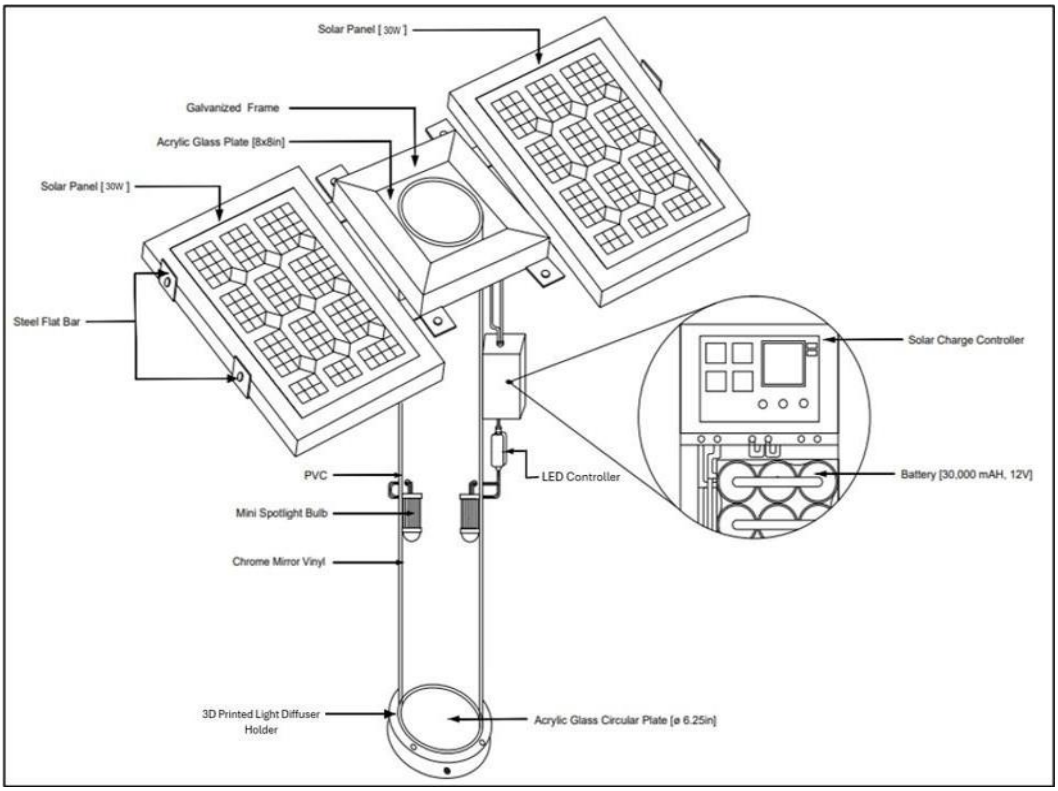


Figure 2. Design illustration of the solar light tube assembly, showing the photovoltaic panels, upper acrylic cover, reflective PVC tube, LED load, battery, controller, and lower diffuser.

Figure 2 presents the design drawing of the prototype. The upper assembly uses a galvanized frame and an 8 × 8 in. acrylic top cover. The drawing shows two nominal 30-W photovoltaic panels mounted on a steel flat-bar arm, giving a nominal combined panel rating of 60 W. This nominal rating is close to the approximately 59-W PV input power reported in the electrical table; the panel ratings and wiring configuration are based on the design information available for this manuscript.

The upper assembly connects to a 4.5-ft PVC tube lined internally with reflective chrome-effect vinyl. The lighting assembly contains two 10-W mini-LED spotlight bulbs, giving a nominal load of 20 W, and a reported 12-V, 30-Ah

(30,000-mAh) lithium battery. The battery chemistry and nameplate capacity were not independently verified in the reported measurements. The LED load and its operating duration are evaluated separately from the daylight-only illuminance measurements.

At the lower end of the tube, a 3D-printed holder secures a 6.25-in.-diameter, 3-mm-thick circular acrylic diffuser plate. The holder and plate are intended to distribute the transmitted daylight and LED light; separate measurements would be needed to quantify their effect on distribution or glare.

The electrical assembly includes a solar charge controller and an LED control module. Component model numbers, detailed protection ratings, and the module's switching behavior were not evaluated as separate experimental outcomes.

4.2. Daytime Illumination

Table 1. Hourly Illuminance Readings (Lux) For Each of the Four Solar Light Tube Units from 8:00 A.M. To 5:00 P.M.

Time	SLT 1	SLT 2	SLT 3	SLT 4
8:00 a.m.	162.7	158.7	160.3	157.3
9:00 a.m.	334.7	231.3	346.0	262.3
10:00 a.m.	386.0	466.0	452.7	457.7
11:00 a.m.	608.3	597.3	600.7	613.3
12:00 p.m.	908.3	892.3	877.3	899.0
1:00 p.m.	5057.3	5056.3	5080.0	5008.0
2:00 p.m.	3708.0	4186.3	3676.0	4184.3
3:00 p.m.	949.3	936.0	899.0	937.7
4:00 p.m.	556.7	599.7	545.3	604.7
5:00 p.m.	429.3	514.3	438.7	527.3

Table 1 lists the daytime illuminance readings for the four SLT units. The maximum recorded value was 5,080.0 lux at 1:00 p.m.; the minimum was 157.3 lux at 8:00 a.m. The readings varied substantially by time of day, with the largest values recorded around midday.

The recorded illuminance generally increased toward midday and decreased later in the afternoon.

The maximum illuminance of 5,080.0 lux was recorded at 1:00 p.m. by SLT 3. The values show that the prototype transmitted substantial daylight under the recorded conditions. The peak is an illuminance reading at the measurement location, not a measure of total luminous output or proof of comfortable lighting throughout the room.

Several midday readings exceeded the 300–500 lux working reference range used in this manuscript. Values above that range do not by themselves demonstrate better visual comfort; glare, luminance contrast, and the applicable task-plane requirement were not measured and should be assessed separately. General visual-comfort guidance emphasizes that illuminance alone is insufficient to describe the quality of the lit environment [38].

4.3. Daytime Uniformity

Table 2. Daytime Minimum-To-Average Illuminance Uniformity Ratio Calculated from the Four SLT Readings at Each Measurement Time.

Time	Average lux	Minimum lux	Uniformity Testing
8:00 a.m.	159.75	157.3	0.985
9:00 a.m.	293.58	231.3	0.788
10:00 a.m.	440.58	386.0	0.876
11:00 a.m.	604.92	597.3	0.987
12:00 p.m.	894.25	877.3	0.981
1:00 p.m.	5050.42	5008.0	0.992
2:00 p.m.	3938.67	3676.0	0.933
3:00 p.m.	930.50	899.0	0.966
4:00 p.m.	576.58	545.3	0.946
5:00 p.m.	477.42	429.3	0.899

The reported daytime minimum-to-average uniformity ratio ranged from approximately 0.79 to 0.99 in Table 2. This indicates a relatively even distribution among the four sampled points at the listed times. Uniformity alone does not establish that the illuminance was adequate or that glare was absent.

At 8:00 a.m., the average illuminance was approximately 160 lux, with a reported uniformity ratio of 0.985. At 1:00 p.m., the average was approximately 5,050 lux, with a ratio of 0.992. The large change in illuminance across the day indicates strong time-of-day dependence. Because glare and luminance contrast were not assessed, the high midday readings should not be described as proof of safe or comfortable lighting.

4.4. Nighttime Illumination

Table 3. Nighttime illuminance readings (lux) for each of the four solar light tube units at 6:00 p.m., 7:00 p.m., and 8:00 p.m.

Time	SLT 1	SLT 2	SLT 3	SLT 4
6:00 p.m.	471.0	468.3	471.0	473.3
7:00 p.m.	477.0	466.0	462.0	478.3
8:00 p.m.	462.0	464.3	471.0	464.7

The recorded nighttime readings from 6:00 p.m. to 8:00 p.m. ranged from 462.0 to 478.3 lux across the four SLT units. These readings describe only the three reported measurement times. The manuscript separately reports 15–16 hours of battery-supported operation; the available lux readings do not establish that the same illuminance was maintained throughout the entire operating period.

The measured nighttime values fell within the 300–500 lux working reference range used in this manuscript during the hours sampled. This does not establish compliance with a formal lighting standard, nor does it establish performance at unmeasured times during the reported 15–16-hour runtime.

4.5. Nighttime Uniformity

Table 4. Nighttime minimum-to-average illuminance uniformity ratio calculated from the four SLT readings at each measurement time.

Time	Average lux	Minimum lux	Uniformity Testing
6:00 p.m.	470.90	468.3	0.994
7:00 p.m.	470.83	462.0	0.981
8:00 p.m.	465.50	462.0	0.992

The reported nighttime uniformity ratios ranged from 0.981 to 0.994 for the sampled hours. These ratios indicate similar illuminance values at the four sampled points during those measurements. The result should be interpreted within the limited measurement period and should not be taken as proof that glare was absent or that all areas of the room met a lighting standard.

4.6. Comparison with Conventional Lighting

The manuscript reports a contextual conventional-lighting baseline of approximately 150–200 lux for an 18-W bulb. The method does not describe a controlled side-by-side test of the conventional bulb and SLT under identical conditions, so this comparison should be treated as contextual rather than as a direct performance test. The daytime SLT readings reached more than 5,000 lux at the sampled point during the recorded sunny period, but that peak alone does not establish better overall lighting quality.

The prototype also included photovoltaic charging and a battery-supported LED load. The reported nighttime illuminance of 462.0–478.3 lux was measured only at 6:00 p.m., 7:00 p.m., and 8:00 p.m.; separate trials reported 15–16 hours of operating duration. These two results should remain distinct. A controlled comparison with conventional lighting, including equal work-plane measurements and energy-use measurements, is needed before making a stronger comparative claim.

4.7. Solar Energy Harvesting Output and Power Efficiency

Table 5. PV-Side Input and Controller-To-Battery Output Electrical Measurements and Calculated Output-To-Input Power Ratio Across Seven Trials.

Date	Voltage avg. (Vout)	Current avg. (Iout)	Pout	Voltage avg. (Vin)	Current avg. (Iin)	Pin	Output/Input Ratio (%)
Trial 1	12.04	3.08	37.1 W	17.8	3.3	59.3W	62.56 %
Trial 2	12.0	3.02	36.4 W	17.9	3.3	59.2W	61.48 %
Trial 3	12.03	3.00	36.1 W	17.9	3.3	59.2W	60.97 %
Trial 4	12.16	3.13	37.7 W	17.7	3.4	59.5W	63.36 %
Trial 5	12.01	3.04	36.5 W	17.7	3.4	59.4W	61.47 %
Trial 6	12.17	3.1	37.8 W	17.8	3.3	59.2W	63.85 %
Trial 7	12.02	3.04	36.6 W	18.0	3.3	59.4W	61.61 %

Across seven reported electrical trials, output voltage ranged from 12.00 to 12.17 V and output current from 3.00 to 3.13 A. The corresponding reported output power ranged from 36.1 to 37.8 W. These values refer to the stated

controller-to-battery measurement point; the circuit diagram and exact meter placement were not fully documented in the supplied manuscript.

The reported PV-side voltage ranged from 17.7 to 18.0 V, while the PV-side current ranged from 3.3 to 3.4 A.

The resulting reported input power was approximately 59.2–59.5 W across the seven trials. These measurements are broadly consistent with a nominal 60-W array, if the reported two 30-W panels were the components installed and measured under the same test conditions.

The reported output-to-input power ratio ranged from 60.97% in Trial 3 to 63.85% in Trial 6. This ratio is calculated from the listed input and output values. It should not be presented as the efficiency of the entire solar lighting system without a defined system boundary, synchronized measurements, and accounting for battery-storage and other losses.

4.8. Nighttime Operating Duration

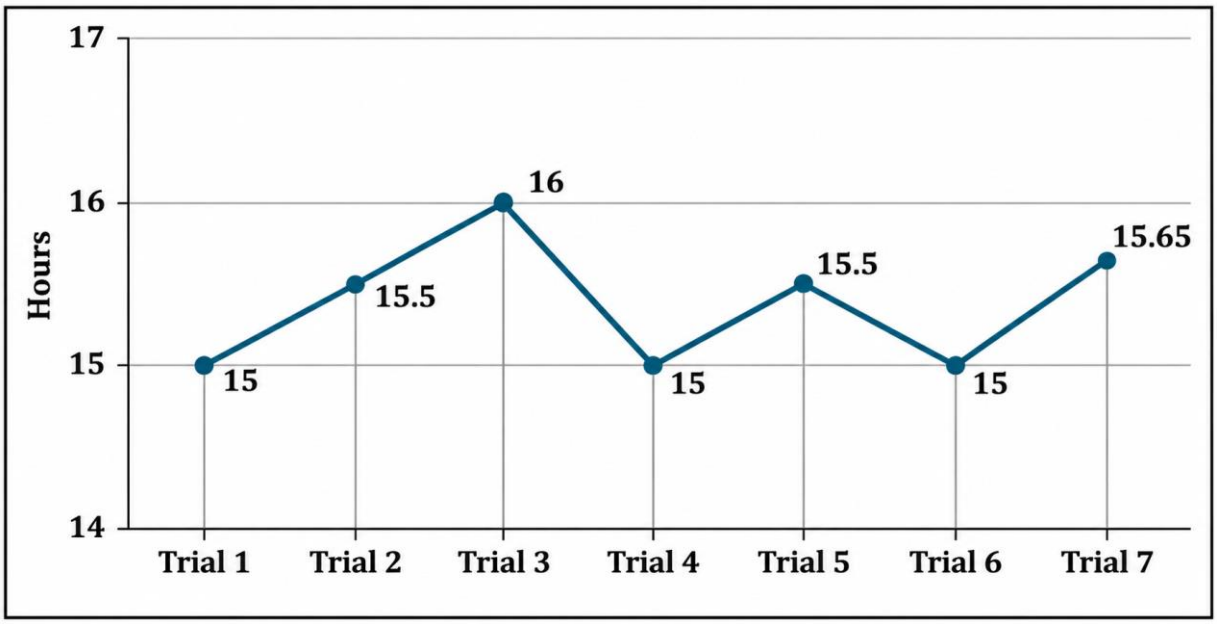


Figure 3. Reported Nighttime Operating Duration of the Solar Light Tube System Across the Test Trials.

Figure 3 summarizes the reported nighttime operating-duration trials. The system reportedly operated for approximately 15–16 hours before the battery-powered lighting stopped. This is the observed duration under the reported test conditions and is not a guarantee of runtime with different loads, battery conditions, or weather.

The reported runtime was highest in Trial 3 (16.0 hours) and lowest in Trials 1, 4, and 6 (15.0 hours). These values are presented as recorded in the manuscript; the original trial log was not available for independent verification.

The operating duration depends on the battery state of charge, load, conversion losses, and battery condition. The reported trials indicate that the prototype remained operational for the stated period under the tested conditions, but do not establish long-term battery performance or uninterrupted operation under all conditions.

4.9. Illuminance Under Varying Weather Conditions

Table 6. Hourly Mean Indoor Illuminance (Lux) Recorded Under the Sunny, Cloudy, and Rainy Categories in the Dataset.

Time	Sunny (avg. lux)	Cloudy (avg. lux)	Rainy (avg. lux)
8:00 a.m.	162.7	158.0	175.7
9:00 a.m.	334.7	338.7	206.7
10:00 a.m.	386.0	402.7	114.7
11:00 a.m.	608.3	611.3	387.3
12:00 p.m.	908.3	924.0	409.7
1:00 p.m.	5057.3	380.0	212.3
2:00 p.m.	3708.0	554.7	194.3
3:00 p.m.	949.3	280.0	188.0
4:00 p.m.	556.7	552.7	186.0
5:00 p.m.	429.3	461.7	179.7

Table 6 shows that the recorded illuminance differed across the sunny, cloudy, and rainy categories. The highest listed sunny value was 5,057.3 lux at 1:00 p.m.; the highest cloudy value was 924.0 lux at noon; and the highest rainy value was 409.7 lux at noon. The values suggest weather-associated variation in the dataset, although weather conditions were not independently quantified using irradiance or meteorological measurements.

Table 7. Descriptive Statistics for Illuminance Values Grouped by the Recorded Weather Category (N = 10 Values Per Group).

Groups	Count	Sum	Average	Variance
Sunny	10	13100.60	1310.06	2782320.92
Cloudy	10	4665.53	466.55	44846.29
Rainy	10	2254.4	225.44	9047.86

Table 8. One-Way ANOVA Summary Comparing the Listed Illuminance Values Among the Three Weather Categories (Exploratory A = 0.10).

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Group	6486800.27	2	3243400.13	3.43	0.047	2.51
Within Group	25525935.76	27	945405.02			
TOTAL:	32012736.03	29				

Table 7 reports mean illuminance values of 1,310.06 lux for sunny conditions, 466.55 lux for cloudy conditions, and 225.44 lux for rainy conditions, based on ten listed values per category.

The sunny category had the highest reported mean, followed by the cloudy category and then the rainy category. These are descriptive comparisons of the listed values, not evidence that weather alone caused the differences.

The reported one-way ANOVA gives $F = 3.43$ and $p = 0.047$. At the exploratory significance level $\alpha = 0.10$, this p-value is below the threshold. However, the hourly observations may be temporally related, and the manuscript does not document tests of independence, normality, or variance homogeneity. The result should therefore be treated as preliminary, not as conclusive evidence of a general weather effect.

5.0. Conclusion and Future Recommendations

5.1. Conclusion

The prototype was designed to transmit daylight through a reflective solar light tube and provide supplemental LED illumination from stored solar energy. Daytime illuminance ranged from 157.3 to 5,080.0 lux in the reported measurements. Nighttime illuminance ranged from 462.0 to 478.3 lux at the three sampled times between 6:00 p.m. and 8:00 p.m.; the reported nighttime uniformity ratios ranged from 0.981 to 0.994. Daytime uniformity was generally high in the listed values. The measured results apply to the sampled points and times only.

Across seven electrical trials, reported output power ranged from 36.1 to 37.8 W, and the calculated output-to-input power ratio ranged from 60.97% to 63.85%. Separate operating-duration trials reported 15–16 hours. Because nighttime illuminance was sampled only through 8:00 p.m., the data do not establish that the measured lux level persisted for the entire runtime. The results describe the tested prototype and should not be generalized to other seasons or installations.

The weather-category means were 1,310.06 lux (sunny), 466.55 lux (cloudy), and 225.44 lux (rainy). The reported ANOVA result was $F = 3.43$, $p = 0.047$, which is below the exploratory $\alpha = 0.10$ threshold. This statistical result remains preliminary because the hourly observations may not be independent and the ANOVA assumptions were not documented.

5.2. Future Recommendations

The following future work is recommended based on the prototype and the limits of the reported measurements:

1. Repeat illuminance measurements across more days and seasons, with weather conditions documented consistently to assess seasonal variation and repeatability.

2. Increase the number of measurement locations and report the measurement-grid layout, work-plane height, and distance from each SLT diffuser.

3. Evaluate glare, luminance contrast, and visual comfort in addition to illuminance and uniformity.

4. Conduct long-term testing of the acrylic covers, reflective lining, roof seals, brackets, and other components under rain, heat, dust, and ultraviolet exposure.

5. Verify photovoltaic panel ratings, charge-controller specifications, battery capacity, wiring protection, and measured energy balance using calibrated instruments.

6. Test the system in additional indoor settings, including classrooms, public restrooms, warehouses, and public markets, and compare performance with applicable lighting requirements.

7. Investigate hybrid approaches where classical image processing is combined with lightweight machine learning models while preserving transparency and scientific interpretability.

Declarations

Source of Funding

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Competing Interests Statement

The authors declare that they have no competing interests that could have influenced the conduct of this research or the presentation of its findings.

Consent for Publication

The authors declare that they approved this study for publication.

Authors' Contributions

The authors contributed to developing and evaluating the solar light tube, collecting and analyzing experimental data, and preparing or reviewing the manuscript. All listed authors are responsible for confirming that this summary accurately reflects their individual contributions and that they approve the final submitted version.

Informed Consent

The study involved the experimental evaluation of a solar light tube system and the measurement of illuminance and electrical parameters, without human participants.

Availability of Data and Material

The data and materials supporting the findings are available from the corresponding author upon reasonable request. The underlying measurement logs, calculations, and figure source files should be retained by the authors to support verification of the reported results.

Institutional Review Board Statement

The study involved engineering experiments and measurements and did not involve human participants or animals.

Ethical Approval

The research involved the experimental testing and evaluation of a solar light tube system and did not involve human or animal subjects.

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Declaration of Artificial Intelligence

ChatGPT, an artificial intelligence tool developed by OpenAI, was used to assist with language editing and manuscript organization. The authors are responsible for verifying all technical details, data, citations, and references and for approving the final version submitted for publication.

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