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Testing and long term performance assessment of solar lighting system and its components

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Abstract: *Along with the ambitious goals of several solar-lighting programs and the viability of Solar Lighting Systems (SLSs) in urban, rural and semi-urban areas, the solar-lighting market is witnessing an ever-increasing gamut of products with various features, quality and specifications. Typical SLSs include solar lanterns, solar home lighting systems, solar task lights, solar torch lights, solar street lights etc. Components of SLSs include a light-source with required optical components, storage device, charging source (Solar module with/without alternate charging options) and electronic circuitry. Aspects such as selection of technology of each component, optimal sizing, design considerations and system-integration based on intended application are critical for the value of chain of such systems. These factors affect the performance a SLS which is defined through typical measureable performance-parameters. This paper brings very useful analysis of test conducted on solar lighting system and its components. Besides the normal applicable tests i.e. run time, charging efficiency etc. the paper is much more focus on long terms performance assessment of SLSs.*

Keywords: Long term performance assessment, Solar home lighting systems, solar lantern

1. INTRODUCTION

It has been prove that solar energy is a viable option particularly for basic lighting applications in rural areas [1-5] and solar lanterns contribute considerably in the major market of solar lighting products that include other products such as solar home systems, solar street lights, solar task lights, solar torches etc. In the recent years, it also has been seen that LED based solar lanterns is fast replacing CFL based lanterns due to characteristics such as longer lifetime, better efficiency, light weight, simpler control circuitry [6].The overall cost of solar portable lights including solar based LED lantern is also slated to fall by approximately 40% by 2015 [7] making it all the more affordable for the rural masses. There are number of major programs and initiatives focus on large-scale field dissemination of solar lanterns in the field [8-13] thus contributing to the ever-expanding solar lantern market. On one hand, although the solar based LED lighting market is fast evolving and is proving to be a promising technology for the future, the market has already witnessed a disparate range of products widely varying in cost and quality. Being a comparatively newer technology, there exists a lack of data for characterizing the quality and performance of the wide variety of solar LED lighting products being launched in the market. There is also an urgent need of long term assessment of the performance of such a variety of solar based LED lighting systems and characterization of their performances.

Country like India where solar lantern is assumed to be very useful for rural areas and there are have been various programs focused on laboratory based testing and performance assessment of solar based LED lighting products and a few suitably equipped laboratories exist for conducting such evaluation [11, 14, 15]. However, in addition to laboratory based technical performance evaluation, efficient dissemination of solar lighting products in the field requires thorough evaluation of the usage patterns and long term assessment to ensure the appropriateness of the products. Therefore, it is very essential to evaluate long term performance assessment of solar lighting system and its components as well.

The Energy and Resources Institute (TERI), India, has Solar Lighting Laboratory which has been extensively engaged in various projects on solar lighting and has been conducting laboratory-based evaluation on solar lanterns and other solar lighting systems.

This paper describes customized test methods for performance assessment of solar lighting systems. This paper presents results and analysis of testing and long-term performance assessment in this evaluation of solar lighting system and its components. This work is a result of a project conducted on different varieties of LED based solar lanterns, their basic lab tests.

2. TEST SETUP AND METHODOLOGY

2.1 Battery capacity measurement at various temperatures

The battery testing facility consists of battery test bed with data acquisition system (DAS) with 2 nos. of environment chambers. The battery test bed consists of hardware and software. The hardware is designed in such a way that charging and discharging rate, nos. of cycle and other parameters can be selectable and controlled through software. Once battery is tested, the data can be plotted between any of two parameters i.e. ampere hour (Ah) pumped into the battery and drawn from the battery. The system has provision for report generation through software. The environment chamber has sufficient space to keep 4 nos. of battery simultaneously and temperature sensors available with battery test bed which is be used to log battery temperature simultaneously. For measuring the battery capacity IEC 61960, IEC 61951-2 and IS 13369: 1992 test standards have been consulted. The list of equipment has been used for battery capacity test are mentioned in Table 1.

Table 1 List of equipment used battery capacity test

1.	Power supply
2.	Batteries
3.	Battery analyzer
4.	Multimeter
5.	Environment chamber

Fig. 1 Battery testing facility at TERI's laboratory

2.2. Long-term illuminance degradation test of solar lanterns

There are two separate wooden box have made to keep solar lanterns and power supply. To avoid any kind of power supply interrupt, UPS of 700VA is connected with power supply. The battery of solar lantern is replaced by a regulated power supply and power supply voltage is adjusted to nominal battery voltage. It has been ensured that voltage of the power supply should not be varied during test. Proper arrangement has made to fix alignment and orientation of the solar lantern while measuring the illuminance. The data has been reported as per 'Stand-Alone LED Lighting Systems Quality Screening', Fraunhofer ISE if the decrease in relative illumiance of the LEDs is less than 10% after 2,000 hours, the light passes the long term test. The list of the equipment has been used in this test are mentioned in Table 2.

Table 2 List of equipment used in long term illuminance test

1.	Two nos. lanterns of different make
2.	Regulated power supply
3.	UPS
4.	Lux meter

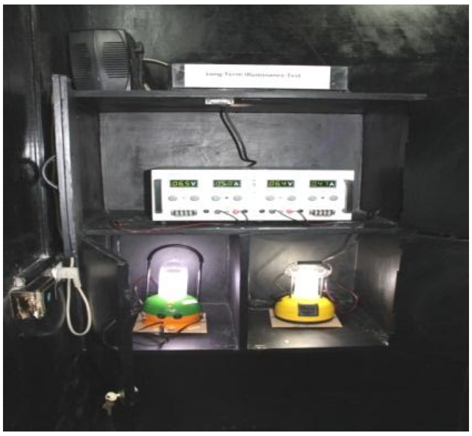

Fig. 2 Photographs of test setup used in long term illuminance test

2.2 Comparative luminous flux measurement between different types of Solar Lantern

There are two types of reference standard defined for measuring total luminous flux.

1. 4 π geometry: It is recommended for all types of solid products including those emitting light in all direction (4π sr) or only in a forward direction (regardless of orientation).According to the guidelines, the total surface area of the SSL product should be less than 2% of the total area of the sphere wall. This corresponds to, for example, a spherical object of less than 30cm diameter in a 2 m integrating sphere. The longest produce should be less than 2/3 of the diameter of the sphere.
2. 2π geometry: It is acceptable for SSL products emitting light only in forward direction (regardless of orientation), and may be used for SSL products having a large housing and fixture that are too large to use the 4 geometry. In this geometry the opening diameter to mount a SSL should be less than 1/3 of the diameter of the sphere. The SSL products shall be mounted within circular opening and in such a way that its front edge is flush with edge of opening (or it can be slightly inside the sphere to ensure that all emitted light is caught in the sphere.LM-79 -IES approved method has been used for measuring lumen.

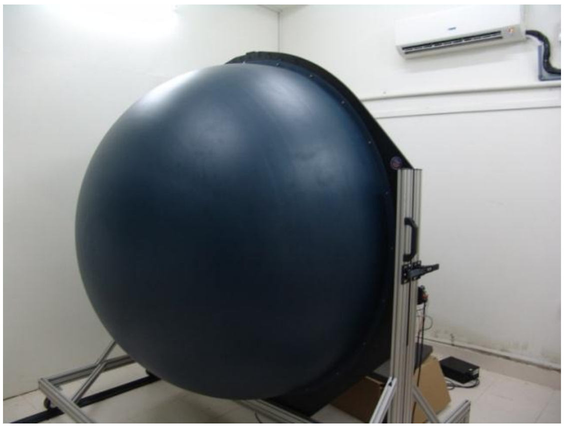

Fig. 3 Integrating sphere

3. RESULTS AND ANALYSIS

3.1. Long-term illuminance degradation test of Solar Lighting Systems

The purpose of this test is to study illuminance degradation in different type of LEDs which are integrated with complete solar lighting system. Here, for the experimental purpose two (2) nos. of LED based solar lanterns, model L1 and model L2 were selected. Model L2 has 3 nos. power LEDs, each LED is of rating 1W and model

L1 has 9 nos. of super flux LEDs, each LED is of rating 0.15W. The technical details of LEDs are mentioned below in the following Table.

Table 3 Technical parameters of selected LED lanterns

Specification	Photo
Model L1	
• Operating Wattage of solar lantern :2.64W • Battery: SMF lead acid battery 6V/4.5Ah • No. of LEDs in the lantern:16 • Combination of LEDs: 4 string of 4 LEDs oriented in circular • Typical operating voltage of LED:3.1V • Typical operating current of LED:20mA • LED type: Super Flux • LED efficacy:129 lumen/W	
Model L2	
• Operating Wattage of solar lantern : 2.43W • Battery: SMF lead acid battery 6V/4.5Ah • No. of LEDs in the lantern:3 • Combination of LEDs: 3 nos. of LEDs mounted at 120O angle • Typical operating voltage of LED:3.45V • Typical operating current of LED:150mA • LED type: Power LED • LED efficacy: 100 lumen/W	

Result and discussion:

The illuminance reading of both LED lanterns are taken for 2000 hours. From the figure 4, we can see that illuminance of the model L1 degrades to 95% for initial 200 hours, but it stabilized after it. There is an approximately 7% degradation over a period of 2000 hours which shows good results in favour of LED. Thus this solar lantern passes the test criteria.

The LED used in lantern model L2 is 1W rated power LED. It can be observed from the below figure that Illumination of model L2 degrades only 3% under 100 hours. After 100 hours, illuminance degrades drastically till 200 hours and it is left 83% of the initial value. Further, illuminance degradation continues and it is left at 76.81% of the initial illuminance. There is approximate 25% degradation in illuminance that has been observed, which significantly affects the LED performance. Therefore, this LED lantern does not pass the acceptance criteria of illuminance test.

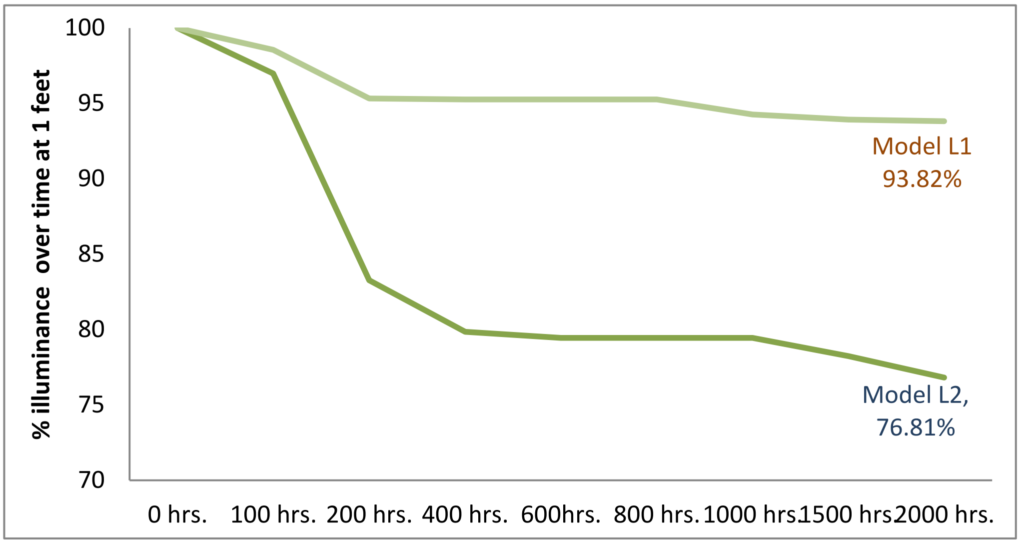

Fig. 4 Percentage illuminance degradation over time of model L1 and L2

3.2 Comparative luminous flux measurement between different types of Solar Lantern

In this experiment, 2 numbers of solar lanterns are tested using the Integrating sphere. One of the solar lantern is LED based and the other CFL based, however the mould of both the solar lantern are kept same, also, the illuminance provided by both the lantern were same as that of the 7W CFL lantern. For this experiment, the model L3 and L4 is used. They are kept in upright position on the test stand of Integrating Sphere. The absorption correction is done for these samples, to remove the error of light radiating from the mould.

Sample ready for testing inside Integrating Sphere	
	
Model L	Model L4

Fig. 5 Photographs of samples under test

Observation table:

Table 4 Reported data on three (3) parameters luminous flux, CCT and averaged CRI using the software tool LightMtrX-SPEC for model L3 and L4

Model No.	Number of LEDs	Operating wattage (W)	Luminous flux (lumen)	Correlated Colour temperature (K)	Colour rendering index (CRI)	Luminous efficacy (lumen/W)
L3	1 CFL	7.00	248.6	5751	68.85	35.50
L4	4 LEDs	4.86	340.6	5570	69.09	69.95

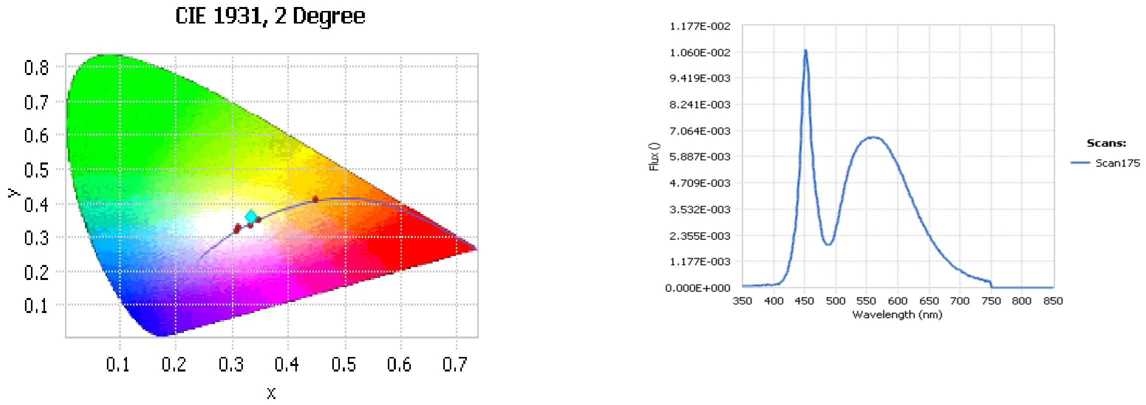

Fig. 6 Spectral flux graph and chromaticity diagram of Solar LED lantern – L

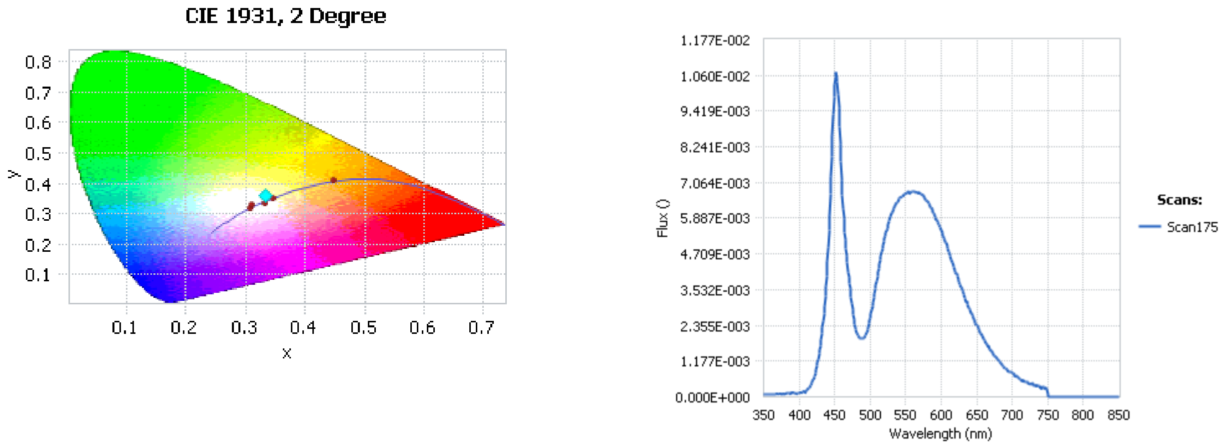

Fig. 7 Spectral flux graph and chromaticity diagram of Solar LED lantern – L43

Result and discussion:

It can be noted here that the LED lantern is producing higher luminous flux and efficacy as compared to CFL lantern. However, the CCT and CRI values are quite close.
It can be concluded that the LED lantern is advantages to use depending on its higher light output, lifetime and performance. Please refer spectral flux graph and chromaticity diagram in Figure 6 and 7.

3.3 Capacity test of Lead-acid and Li-ion battery at various temperatures
The solar lanterns have been used in extreme cold to hot condition which depends on ambient temperature of that place. It is well know that performance of the solar module significantly improved at lower temperature, however the battery capacity decreases in this condition.

The purpose of the experiment is to evaluate capacity of various types of battery at -20OC, 25OCand 45OC temperature and to observe overall effect of temperature on the systems performance. The most common types of battery have been selected for this purpose i.e. 6V/4.5Ah lead battery and 7.2V/2Ah lithium ion battery. Initially 2 nos. of each battery samples were taken in to consideration and battery capacity are measured for 5 times. One of the samples of each type of battery was taken, which had stable battery capacity over 5 cycle test. Details description of the battery is mentioned in the table below.

Table 5 Specification of selected batteries

Lead acid battery	Lithium ion battery
Battery type : Lead acid battery Battery rating : 6V/4.5Ah Manufacturing date: 26/12/12	Battery Type: Li-ion battery Battery Rating: 7.2V/2Ah Manufacturing date: 08/01/2013

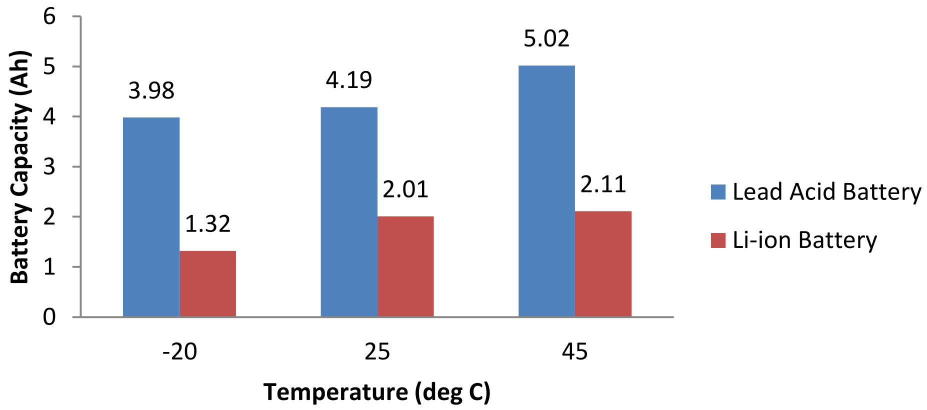

Fig. 8 Observed battery capacity at various temperatures

Result and discussion:

In the below graph, both the lead acid battery (6V/4.5Ah) and Li-ion battery (7.2V/2.2Ah) have undergone charge-discharge cycle at various temperature (i.e. -20 deg. C, 25 deg. C and 45 deg. C). It has observed that, as the temperature increases the battery capacity also increases.

The rate at which the lead acid battery capacity increases is 16 mAh/ deg. C and the rate at which the li-ion battery capacity increases is 11.4 mAh/deg. C. Hence, it may be inferred that the li-ion battery has a lower effect of temperature, compared to lead-acid battery.

4. CONCLUSION

It has been concluded from the above experiments that long term performance assessment for solar lighting systems is very important to ensure the quality of solar lighting products for long run. It also has been observed that LEDs having a life time of 50,000 hours cannot be run for such long time until other associated accessories i.e. electronics, heat sink, mould etc. have not been properly developed.

5. ACKNOWLEDGEMENTS

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