Journal of Energy & Environment 4 (2005) 75 – 82

Evaluation of a Solar Photovoltaic Lantern in Bangladesh Perspectives

M. M. H. Bhuiyan*, M. Hussain and M. Ali Asgar*****

**Institute of Nuclear Science & Technology, Atomic Energy Research Establishment*
Bangladesh Atomic Energy Commission, Savar, G.P.O. Box. No. 3787, Bangladesh.
***Dept. of Physics and Renewable Energy Research Centre, Dhaka University, Bangladesh.*
****Dept. of Physics, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*
Email: mosharraf22003@yahoo.com
(Received on 15 Jan 2005, revised on 19 Apr 2005)

Abstract

The performance of a lantern having a 7.5 watt-peak module has been evaluated using solar radiation data of different places of Bangladesh. It is found that the lantern is capable of supplying light for a period of maximum 3 hours every day all over Bangladesh. Computations show that if the module size is increased to 10 watt peak, the lantern will be capable of supplying adequate light for 4 hours. The operation of the lantern is monitored at Dhaka and the performance of the lantern is found to be in accordance with the theoretical prediction.

Introduction

Lighting is one of the basic requirements of modern living. The best way of obtaining light at night is through electricity from the grid. But the bulk of the rural homes in Bangladesh depend on kerosene lamps to meet their lighting requirement, as commercial electricity is hardly available to them. There are mainly two types of kerosene lamps, the simple wick type (kupi) lamp and the hurricane lantern. These lamps provide insufficient and poor quality of light, consume imported fossil fuel and pollute the environment. Recently, compact high efficient fluorescent lamps have been developed which give light equal to or greater than that of 40 watt 220volt ordinary incandescent electric bulbs. These lamps consume 7 watt of electric power only. The low consumption along with long life of the lamps, improvements in low maintenance rechargeable batteries and developments of sophisticated electronic control, allow highly efficient portable lamps to be designed and built. These may be charged during the day time by solar cell modules to provide light during night in towns as well as remotest villages [1-5]. The advantages of these lanterns are that they can be used in thatched cottages or moved anywhere by shopkeepers, hawkers and guards. Fire hazards and hazards from electrical short circuits of all types may be avoided. If one portable electric lantern is made available for every house, without electricity, overall situation in Bangladesh will improve. In fact, this may bring a major change in the lifestyle of the common people of rural and remote areas.

The amount of energy obtained from the sun is different for different places. The suitability of a commercially available lantern system for Dhaka and a number of other places over Bangladesh is investigated in this paper.

Description of the Lantern

A commercially available solar lantern manufactured abroad was used. This consists of two components, the lantern and the solar module. The schematic diagram of the system is shown in Fig. 1.

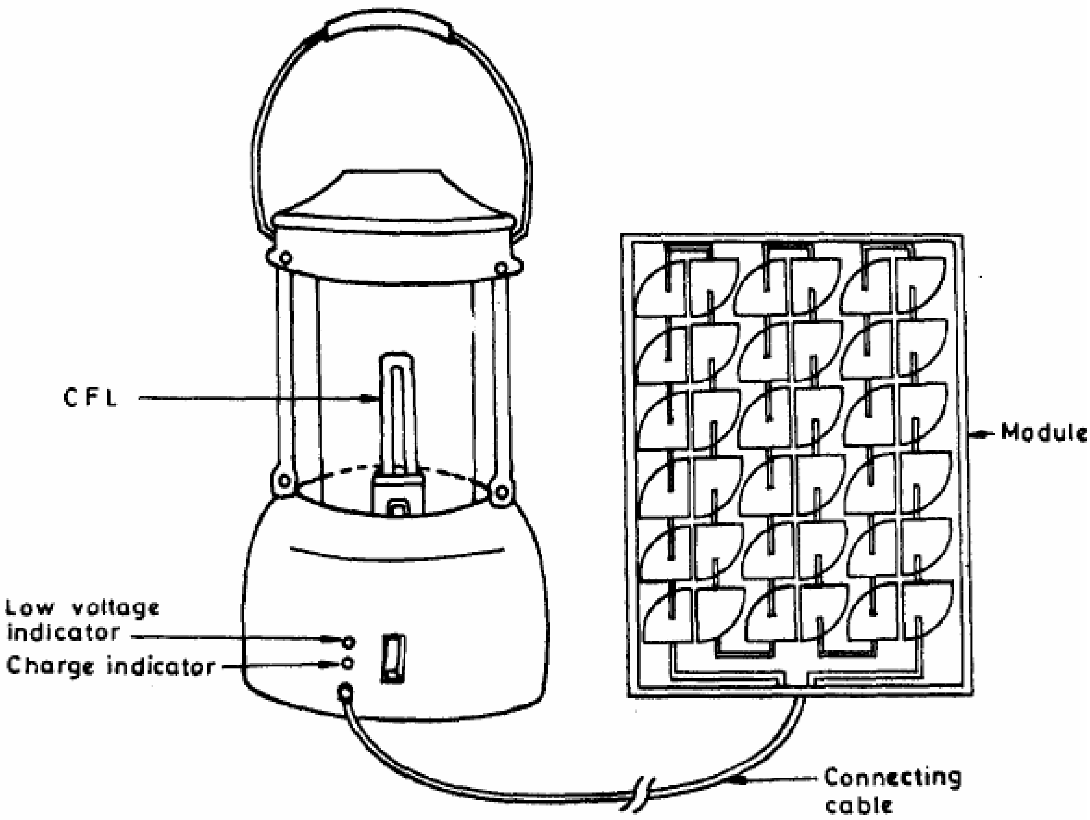

Fig. 1 Schematic diagram of a PV lantern

Technical data are:

Lamp: 7.5 watt nominal PL tube
Battery: Sealed lead acid type, 12 V, 7Ah, 84 watt
PV module: Amorphous silicon type, 7.5 W_p (W_p- watt, peak) under standard conditions
Charge controller: Built into lantern, over voltage protection operates at around 14.1 V (20^{o}c), low voltage protection operates at around 11.4 V

Methodology

The output produced by a solar panel depends on insolation falling on solar cells. The temperature has a non-negligible effect on the solar cell characteristics. The output produced by the module is 7.5 W_p at standard conditions i. e 1000 W/m^2 at 25 ^{o}c temperature as per manufacturer's specifications. The output at other condition can be written [6] as follows.

$$\text{Module output over a day on a horizontal module} = G \times 7.5\,[1 - 0.0041(T_c - T_r)]\ \text{Wh} \quad (1)$$

where, G = daily global radiation on horizontal surface (in Bangladesh), KWh/m^2

T_c = cell temperature

T_r = reference temperature, ^{0}c

The cell temperature can be expressed as

$$T_c = T_{amb} + KP_{in} \quad (2)$$

where, T_{amb} = ambient temperature, ^{0}c
K = 0.02 to 0.03 (^{0}c. m^2/Wh)
P_{in} = the incident solar radiation on the tilted solar module, Wh/m^2

P_{in} may be written in terms of G and tilt factor as

$$P_{in} = G \times \text{tilt factor} \quad (3)$$

The cell temperature of the module was computed from equation (2), using hourly average ambient temperature and the hourly measured average global radiation data [7] for Dhaka. The global radiation data [8-9] for different stations in Bangladesh has been presented in the Appendix. The module output on the tilted surface is different from that on horizontal surface. For the months of May, June, July and August for tilt angle $\beta=10^0$, in the Appendix shows that the product of tilt factor and global radiation G is more than that for tilt angles 20^0or 30^0 [10]. So, in order to get high module output through out the year the selected tilt angle is 10^0. This small angle will also allow automatic draining of rainwater. There is a non-negligible effect on the module output due to the dust on the solar cells. Therefore, a 10% degradation of the module output due to dust accumulation [11] has been considered. The expected module output for Dhaka in different months of the year is shown in Table 1. All charges supplied to the battery cannot be extracted from it but only an estimated 95% of charge [11] may be extracted. In the lantern, there is some circuitry loss and assuming 10% loss, the average efficiency of the lamp may be in the region of 85% [11]. If the difference between the energy available from the module and energy required for lighting is positive, the battery will remain charged and if this difference is negative then battery charge will decrease.

For experimental study the lantern was kept in a room of one stored Energy Park Building of Dhaka University and PV module was placed outside the building in the open space on a frame of iron angle. The module was kept tilted at 10^0 towards the sun facing south. The potential of the battery kept inside the lantern was measured by using a digital voltmeter. For the experiment, the lantern was in charging mode using the module from 7.00 am in the morning to 5 pm in the afternoon. At 5.00 pm, the lamp of the lantern was switched on and the battery started discharging.

Results and Observations

Calculations have been done for monthly load and battery state for different hours of lighting with the 7.5 W_p panel and 7.5 watt lamp following [11]. Table 1 shows the estimated output of this module at Dhaka. The results obtained is that the lamp should work satisfactorily up to 3 hours of full lighting every night at Dhaka as the battery remains fully charged over every months of the year shown in Table 2.

Table 1 Estimated output of a 7.5W module at Dhaka

Month	Average cell temperature in ^{0}c	Daily insolation for Dhaka kWh/m^2	Daily output for the horizontal module (at $\beta=0^0$) Wh	Tilt Factor (at $\beta=10^0$)	Daily output for the horizontal module (at $\beta=10^0$)	Daily module output with 10% degradation Wh
Jan	23.5	4.03	30.40	1.13	34.30	30.87
Feb	26.5	4.78	35.60	1.09	38.80	34.92
Mar	33.6	5.33	38.56	1.04	40.10	36.09
Apr	39.0	5.71	40.36	1.00	40.36	36.32
May	38.1	5.71	40.52	0.98	39.70	35.73
Jun	38.7	4.80	33.97	0.97	32.95	29.65
Jul	36.3	4.41	31.54	0.98	30.90	27.81
Aug	37.5	4.82	32.29	0.99	31.96	28.76
Sep	39.6	4.41	31.09	1.02	31.71	28.53
Oct	38.3	4.61	32.68	1.06	34.64	31.17
Nov	31.4	4.27	31.18	1.03	32.11	28.89
Dec	23.6	3.92	29.56	1.15	33.99	30.59

Table 2 Estimated monthly energy availability and battery state of charge for 3 hours of full lighting of a 7.5 watt lamp every night with 7.5 watt-peak module at Dhaka

Month	Monthly energy to load from module (A)Wh	Monthly load for 3 hours full lighting (B) Wh	Monthly difference (A-B)Wh	Battery state of charge		
				Start Wh	Finish Wh	% of full charge
Jan	813	697	116	84	84	100
Feb	831	630	201	84	84	100
Mar	950	697	253	84	84	100
Apr	926	675	251	84	84	100
May	941	697	244	84	84	100
Jun	756	675	81	84	84	100
Jul	732	697	35	84	84	100
Aug	757	697	60	84	84	100
Sep	727	675	52	84	84	100
Oct	821	697	124	84	84	100
Nov	736	675	61	84	84	100
Dec	813	697	116	84	84	100

For 3.5 hours of full lighting, Table 3 shows energy available and battery state of charge. It is observed that the lamp can provide 3.5 hours of lighting for the months of January to June. In the month of July the battery is completely discharged and the battery life may be damaged if it is discharged for more than 3.5 hours of lighting. So, 7.5 watt-peak module is unable to provide 3.5 hours of full lighting over the whole year.

Table 3 Estimated monthly energy availability and battery state of charge for 3.5 hours of full lighting of a 7.5 watt lamp every night with 7.5 watt-peak module at Dhaka

Month	Monthly energy to load from module (A)Wh	Monthly load for 3.5 hours full lighting (B) Wh	Monthly difference (A-B) Wh	Battery state of charge		
				Start Wh	Finish Wh	% of full charge
Jan	813	813	0	84	84	100
Feb	831	735	96	84	84	100
Mar	950	813	137	84	84	100
Apr	926	787	129	84	84	100
May	941	813	128	84	84	100
Jun	756	787	-31	84	84	100
Jul	732	813	-81	84	53	
Aug	757	813	-56	53	(-28)	
Sep	727	787	-60		battery	
Oct	821	813	8		discharged	
Nov	736	787	-51			
Dec	813	813	0			

Table 4 Estimated monthly energy availability and battery state of charge for 3.5 hours of full lighting of a 7.5 watt lamp every night with a 10 watt-peak module at Dhaka

Month	Monthly energy to load from module (A)Wh	Monthly load for 3.5 hours full lighting (B) Wh	Monthly difference (A-B) Wh	Battery state of charge		
				Start Wh	Finish Wh	% of full charge
Jan	1013	813	270	84	84	100
Feb	1107	735	372	84	84	100
Mar	1266	813	453	84	84	100
Apr	1234	787	447	84	84	100
May	1254	813	441	84	84	100
Jun	1007	787	220	84	84	100
Jul	975	813	162	84	84	100
Aug	1009	813	196	84	84	100
Sep	969	787	182	84	84	100
Oct	1094	813	281	84	84	100
Nov	981	787	194	84	84	100
Dec	1083	813	270	84	84	100

Further, by increasing the module size to 10 W_p, 3.5 or 4.0 hours of full lighting can be obtained with the same lamp at Dhaka. Tables 4 and 5 show that the battery remains fully charged for 3.5 and 4 hours of full lighting respectively over every months of the year with 10 watt module. For 4.5 hours of full lighting in the month of August, the battery is fully discharged. Hence the system is not suitable for 4.5 hours of full lighting at Dhaka with 10 watt module.

Table 5 Estimated monthly energy availability and battery state of charge for 4 hours of full lighting of a 7.5 watt lamp every night with a 10 watt-peak module at Dhaka

Month	Monthly energy to load from module (A)Wh	Monthly load for 4 hours full lighting (B) Wh	Monthly difference (A-B) Wh	Battery state of charge		
				Start Wh	Finish Wh	% of full charge
Jan	1013	930	153	84	84	100
Feb	1107	840	267	84	84	100
Mar	1266	930	336	84	84	100
Apr	1234	900	334	84	84	100
May	1254	930	324	84	84	100
Jun	1007	900	107	84	84	100
Jul	975	930	45	84	84	100
Aug	1009	930	79	84	84	100
Sep	969	900	69	84	84	100
Oct	1094	930	164	84	84	100
Nov	981	900	81	84	84	100
Dec	1083	930	153	84	84	100

Experimental results of Table 6 shows the practical performance of the lantern with 7.5 watt peak module for the month of August 2000 as a sample. The tilt angle of the module was 10^0. This Table shows that on 01/08/2000, the battery of the lantern started charging in the morning at 7.00 am with a potential of 11.85V and became 13.4V at 5.00 pm and then the lamp was switched on and it started discharging. The lantern became off at 8.10 pm after 3 hours and 10 minutes of lighting with battery discharged to 11.91V or so. After the cut off, the battery voltage increases slightly when there is no load. This cut off is required for protection of the battery from over discharge a long life of the battery. In the next day on 02/08/2000, the battery voltage was 11.93V at 7.05 am. After charging till 5.00 pm, the lamp produced light for 2 hours and 55 minutes.

This Table further shows that on average the lantern gives about 3 hours of light daily for the month of August. This Table also shows that the total period of lighting is not same for different days of this month. This is due to the fact that solar radiation varies from day to day. Thus the experimental performance of the lantern is found to be in agreement with the theoretical prediction. For the months when insolation is higher, the lighting time will be more than 3 hours.

In the Appendix it was found that the lowest radiation availability is at Sylhet and highest at Rajshahi. So, calculations have been done for the suitability of the 7.5 W_p lamp with 7.5 W_p and 10 W_p modules for the stations Sylhet and Rajshahi following the same procedure as before. It was found that 7.5 W lamp with 7.5 W_p modulel and 84 Wh battery performs satisfactorily for 3 hours of full lighting at sylhet and for 3.5 hours at Rajshahi.

As the solar radiation at Sylhet is the lowest in Bangladesh, it can be predicted that the lantern will perform satisfactorily for a minimum of 3 hours of full lighting over the whole Bangladesh. It is also found that if 4 hours of lighting is required the module size should be increased to 10 W_p for Sylhet

Table 6 Operational data of the lantern with 7.5 watt peak module for the month of August 2000 at Dhaka

Date	Charging				Discharging				
	Start		Finish		Start		Finish		Total Time (T_4-T_3) hr. min
	Time T_1 (am)	Potential in volt	Time T_2 (pm)	Potential in volt	Time T_3 (am)	Potential in volt	Time T_4 (am)	Potential in volt	
01	7.05	11.85	5.00	13.40	5.00	13.40	8.10	11.91	3.10
02	7.00	11.93	5.00	13.00	5.00	13.00	7.55	11.90	2.55
03	7.00	11.92	4.55	13.50	4.55	13.50	8.07	11.91	3.12
05	7.03	11.90	4.50	13.30	4.50	13.30	7.55	11.93	3.05
06	7.05	11.95	5.00	12.80	5.00	12.80	7.35	11.92	2.35
07	7.00	11.94	5.00	12.95	5.00	12.95	7.40	11.91	2.40
09	7.03	11.92	5.00	13.00	5.00	13.00	7.45	11.95	2.45
12	7.05	11.96	5.00	13.09	5.00	13.06	8.00	11.94	3.00
16	7.00	11.95	5.00	13.60	5.00	13.60	8.20	11.95	3.20
17	7.05	11.97	5.00	13.20	5.00	13.20	8.05	11.94	3.05
20	7.04	11.96	4.55	13.50	4.55	13.50	8.10	11.92	3.15
21	7.05	11.93	4.50	13.00	4.50	13.00	7.40	11.93	2.50
22	7.00	11.95	5.00	13.40	5.00	13.40	8.10	11.93	3.10
23	7.05	11.94	5.00	13.00	5.00	13.00	7.50	11.96	2.50
24	7.00	11.97	5.00	13.70	5.00	13.70	8.20	11.95	3.20
26	7.00	11.96	5.00	13.50	5.00	13.50	8.10	11.93	3.10
27	7.00	11.95	5.00	13.20	5.00	13.20	7.50	11.96	2.50
28	7.05	11.96	5.00	13.80	5.00	13.80	8.25	11.94	3.25
29	7.04	11.95	5.00	13.20	5.00	13.20	7.55	11.95	2.55
30	7.02	11.96	5.00	13.00	5.00	13.00	7.50	11.90	2.50
31	7.00	11.92	4.30	13.70	4.30	13.07	7.32	11.95	3.02

Conclusion

From the present study, the performance of a commercial lantern is found to be satisfactory for 3 hours of full lighting over whole Bangladesh. For a longer period of lighting, the module size may be increased from 7.5 W_p to 10 W_p. The price of the lantern is rather high, about 6,500 Taka (1 Taka = US$0.0167). If similar lanterns are manufactured in Bangladesh, the cost will reduce and a good section of the house owners would be able to purchase those to have a better quality of life.

References

[1] S. Rubab and T.C. Kandpal, "Energy Sources," Taylor and Francis, Vol. 19, 1997, pp 813-820.

[2] K. Mukhopadhayaya and B. Sensharma and H. Saha, "Solar PV lanterns with centralized charging system- a new concept for rural lighting in the developing nations," Solar energy materials and solar cells, Elsevier Science, Vol. 31, 1993, pp 437-445.

[3] S. Rubab and T. C. Kandpal, "Financial estimation of SPV lanterns for rural lighting in India," Solar energy materials and solar cells, Elsevier Science, 1996, pp 261-270.

[4] B. Bhargava, "Solar lantern programme in India," Urja Bharati, Vol. 5, No. 1, 1994, pp 17-20.

[5] K. Mukhopadhyaya and G. Bhattacharya, "Solar photovoltaic lantern for rural usage," in Proc., 6th Photovoltaic science and engineering, New Delhi, 1992, pp 911-915.

[6] G. C. Jain, "Development and manufacture of photovoltaic system in developing countries," National physics laboratory, New Delhi, 1981.
[7] L. Rahman, "The measurement and study of global solar radiation at Dhaka," M. Sc. thesis, Physics Department, Dhaka University, 1992.
[8] M. Hussian, S. K. Aditya, "A study of global radiation in Dhaka, Bangladesh," in Proc., Integrated Renewable Energy for Rural Development Solar energy society of India, Tata McGraw-Hill, New Delhi, 1990, pp 39-46.
[9] S. K. Adittya, "Estimation of solar radiation at different stations in Bangladesh," Department of Applied Physics and Electronics, Dhaka University, Private communication, 1997.
[10] A. Huda, "Studies on global radiation tilt factor at Dhaka", M. Sc thesis, Physics Department, Dhaka University, 1994.
[11] M. A. Green, "Solar cells-Operating principles, technology and system applications," Prentice-Hall, Inc., Englewood Cliffs.

Appendix

Monthly average daily global radiation (G) for some stations in Bangladesh

Month	Dhaka kWh/m^2	Rajshahi kWh/m^2	Sylhet kWh/m^2	Bogra kWh/m^2	Barisal kWh/m^2	Jessor kWh/m^2
Jan	4.03	3.96	4.00	4.01	4.17	4.25
Feb	4.78	4.74	4.63	4.69	4.81	4.85
Mar	5.33	5.88	5.20	5.68	5.30	5.80
Apr	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
Jun	4.80	5.25	4.53	5.26	4.39	5.12
Jul	4.41	4.79	4.14	4.34	4.20	4.81
Aug	4.82	5.16	5.56	4.84	4.43	4.93
Sep	4.41	4.96	4.07	4.67	4.48	4.57
Oct	4.61	4.88	4.61	4.65	4.71	4.68
Nov	4.27	4.42	4.32	4.35	4.35	4.24
Dec	3.92	3.82	3.85	3.87	3.95	3.97

Tilt factor for Dhaka

Month	Tilt Factor for tilt angle $\beta=10^0$	Tilt Factor for tilt angle $\beta=20^0$	Tilt Factor for tilt angle $\beta=30^0$
Jan	1.13	1.14	1.31
Feb	1.09	1.16	1.20
Mar	1.04	1.06	1.05
Apr	1.00	0.98	1.95
May	0.98	0.94	0.89
Jun	0.97	0.93	0.88
Jul	0.98	0.94	0.89
Aug	0.99	0.97	0.93
Sep	1.02	1.01	0.99
Oct	1.06	1.11	1.13
Nov	1.03	1.22	1.29
Dec	1.15	1.27	1.37