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Analysis of Flat-Plate Solar Array and Solar Lantern

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Abstract
A very detailed theortical analysis of a solar array has been carried out based on established values of solar radiation data to predict the performance of solar lamp . The analysis is based on established theory about flat-plate collectors. Top heat loss coefficient (U_t), Bottom heat loss coefficient (U_b), Overall heat loss coefficient (U_l), Useful energy (Q_u), efficiency (h_p) of the flat-plate solar array and efficiency (h_l) of the solar lantern has been calculated.

I. Introduction

Energy crisis has lead to develop new energy sources as a way to solve energy problems. Due to increase in prices of fossil and nuclear fuels, a feasibility of solar energy as a new source of energy can be increased when a high energy conversion efficiency and a reduction of cost of equipment is obtained. Due to the above reasons, solar energy is one of the best possible and easily available source of energy. Flat-plate solar array or solar photovoltaic module has potential applications in solar engineering. Flat-plate solar array is most economical and popular in solar lighting and water heating system as it is permanently fixed, having simple construction and requires little maintenance. The design of a solar energy system is generally concerned with obtaining maximum efficiency. The aim of this thesis is to develop a step-wise procedure to predict the performance of a flate-plate array and the efficiency of the solar lamp connected to the flat-plate solar array.

II. Description of the solar lamp

A solar lantern manufactured in India and supplied by Non-Conventional Energy Development Corporation of Andhra Pradesh Limited [NEDCAP] was used. This consists of two components, lantern and solar module.

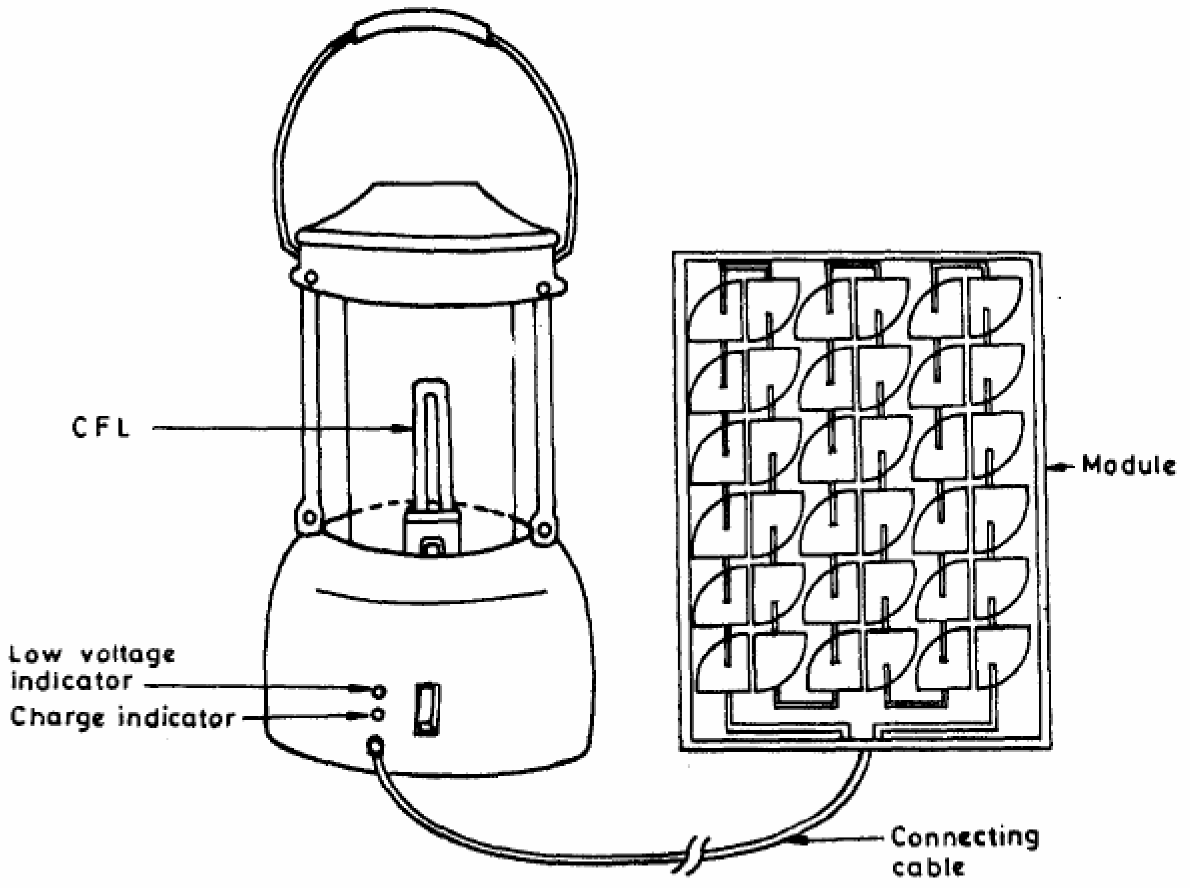

Fig.1: Schematic diagram of PV lantern

Fig 1 shows the schematic diagram of the solar lantern.

III. Technical specifications

PV module: Amorphous silicon type, 10 W_p (W_p-Watt -peak) under standard conditions.
Battery: Sealed lead acid type, 12 V, 7Ah
Charge controller: Built into lantern.
Bulb: CFL bulb
SPV module of dimension 285 mm x 370 mm was used for our analysis

Losses involved in the solar lamp are

1. inverter losses 4 to 15 %
2. dc cable losses 1 to 3%
3. ac cable losses 1 to 3%

However, the overall losses involved in the lantern are taken as 17% of the useful energy.

IV. Methodology

Flat-plate solar array is connected to the battery inside the solar lantern using a d.c.cable.Energy obtained from the solar array is used to charge the battery.Further,the battery is connected the CFL using an inverter present in the setup.Lantern has been charged for 6 hours for 3 hours of work for our analysis.

V. Step-wise procedure for solution

1. The bottom loss co-efficient (U_b) is obtained from the equation (4.1.1)

$$U_b = \frac{K}{L} \qquad (4.1.1)$$

Where ,
K=thermal conductivity (0.045 W/m°c)
L=thickness

2. The top loss co-efficient (U_t) For the collector tilt of 10° is obtained from equations (4.1.2) and (4.1.4). An empirical equation for U_T at 45° was developed by kelvin, fallowing the basic procedure of Hottel and Woertz. This relation fits the graphs for plate temperatures between 40° and 130° to within ±0.2

W/ $m^2 U_T$ = $\left\{ \frac{N}{\frac{344}{T_p}\left[\frac{(T_p - T_a)}{(N+F)}\right]^{0.31}} + \right.$

1hw− 1+σ(Tp+Ta)(Tp2+Ta2)∈p+0.0425N1−∈p −1+(2N+f−1)∈g−N

(4.1.2)

Where,
U_T= top loss co-efficient

N=number of glass cover
f= (1-0.04h_w+5*$10^{-4} * {h_w}^2$) (1+0.058N)
$\in_g$= emittence of glass (0.88)
$\in_p$=emittence of plate
T_a=ambient temperature
T_p=mean plate temperature
h_w=wind heat transfer co-efficient
The parameter h_w can be calculated by wind can be calculated from the formulae:
h_w= 5.7+3.8(wind speed) (4.1.3)
Hence,u_t for collector tilted at 45° is obtained from equation() and (). And, u_t for any collector tilt S°is obtained from the formulae:
$\frac{u_t(s)}{u_t(45)}$= 1-(s-45°) (0.00259-0.00144ϵ_p) (4.1.4)
Where,
S= collector tilt in degrees.
3. Finally, the overall heat loss co-efficient (U_l) is obtained from the equation (4.1.5)
$U_l = U_b + U_t$ (4.1.5)
4. The transmittance—absorbance (τα), product of this cover and absorber plate system is found by multiplying the corresponding values.
5. First calculate $cos\,\theta_T$ and $\cos\theta_z$ as per equations (4.2.6) and (4.2.7), and then calculate factor R from equation (4.2.8). Thus, calculate radiation intensity, I, from equation (4.2.5).
The intensity of solar radiation “I”, is determined by the following relation,
I= HR (4.2.5)
Where,
H= total solar energy incident on the plane of measurement
R= factor
Factor ‘R’, converts the horizontal radiation to radiation on tilted collector for each hour, With the help of Declination angle (δ), Latitude (φ), and collector tilt (s) using the following equations
$cos\,\theta_T$ =Cos (φ-s).cos (δ).cos (ω) +sin (φ-s) sin (δ) (4.2.6)

$\cos\theta_z$ =cos (φ).cos (δ).cos (ω) +sin (φ) sin (δ) (4.2.7)

Where,
ω= sunrise angle
Hanker is calculated from the following formula,
R= $\frac{\cos\theta_T}{\cos\theta_z}$ (4.2.8)
6. Now, substitute the values of I, $(\tau\alpha)$, U_L that are already calculated into the equation (4.2.4) to obtain the useful energy (Q_u).
Basically, it is the product of the rate of transmission of the cover and the absorption rate of the absorber.
Thus,
Q_i=I (τα).A (4.2.2)

As the collector absorbs heat its temperature is getting higher than that of the surrounding and is lost to the atmosphere by convection and radiation. The rate of heat loss (Q_o) depends on the collector overall heat transfer co-efficient (U_l) and the collector temperature (T_c),
Q_o=U_lA ($T_c - T_a$) (4.2.3)

Thus, the rate of useful energy extracted by the collector (Q_u), expressed as a rate of extraction under steady state conditions is proportional to the rate of useful energy absorbed by the collector, less the around lost by the collector to its surroundings.
This is expressed as follows:
$Q_u = Q_i - Q_o = I(\tau\alpha)A - U_l A(T_c - T_a)$ (4.2.4)

Here, Q_u is the total useful energy gain of the collector with this equation. This is a convenient representation.
7. Now, substituting the values of Q_u and I, efficiency of flat plate solar array is calculated by using the equation (4.3.1)
η_p = useful energy obtained/intensity of solar radiation (4.3.1)
8. Now, using the values of q_u and by deducting the losses involved such as transmission losses, inverter losses (mentioned above methology).The overall losses are considered to be 17 % of the input energy. The input energy to the solar lantern is calculated by using the equation (4.3.2)
Input power to the lantern = 0.83*useful energy obtained (4.3.2)
9. Now using the values of input and output energies the efficiency of solar lantern is calculated by using the equation (4.3.3)
η_l = output energy (wattage)/ input power (4.3.3)

VI. Results and Observations

All the results that are obtained are based on numerical calculations, graphs and the values tabulated in the appendix.
1) The overall loss co-efficient (U_l) from Top loss co-efficient (U_t) and Bottom loss co-efficient (U_b) of the flat plate collector with single glass cover has been calculated.
2)It was found that the Bottom loss coefficient (U_b) is almost constant, since it depends only on thickness of collector and thermal conductivity of the collector.
3) Top loss coefficient (U_t) not only depends on geometrical configuration of collector such as thickness, emittance of glass, but also depends on several other parameters like wind speed, ambient temperature, etc.
4) Useful energy from the flat-plate solar array varies between 220 Wh/day to 400 Wh/day depending upon

climatic conditions. High amount of useful energy is available in the months of April, May, June and July
4)Efficiency of the flat-plate solar array varies between 30% to 50 % and decreases to the lowest in April, May, June, July and increases in the following months and the efficiency of the solar lantern varies 40% to 75 % depending upon the climatic conditions prevailing .

VII. Future Scope of Work

1) By using much more efficient materials like mono-crystalline silicon in the construction of flat plate solar array, the efficiency of the collectors can be increased effectively.
2) Radiation losses in the upward direction from the hot absorber plate can be substantially reduced by using glass or plastic covers. Radiation heat loss from the absorber plate can be considerably reduced by using black coatings which have high solar absorptivity.
3) Convection heat loss from the absorber plate to the inner glazing plate can be reduced by evacuating the space (if possible) or optimizing the gap between the plate and the glazing or by use of some transparent, low conductivity structure in between.
4) Side mirrors are used either at north or south edges, or at east or west edges of flat plate collectors in order to increase the efficiency of the collector.

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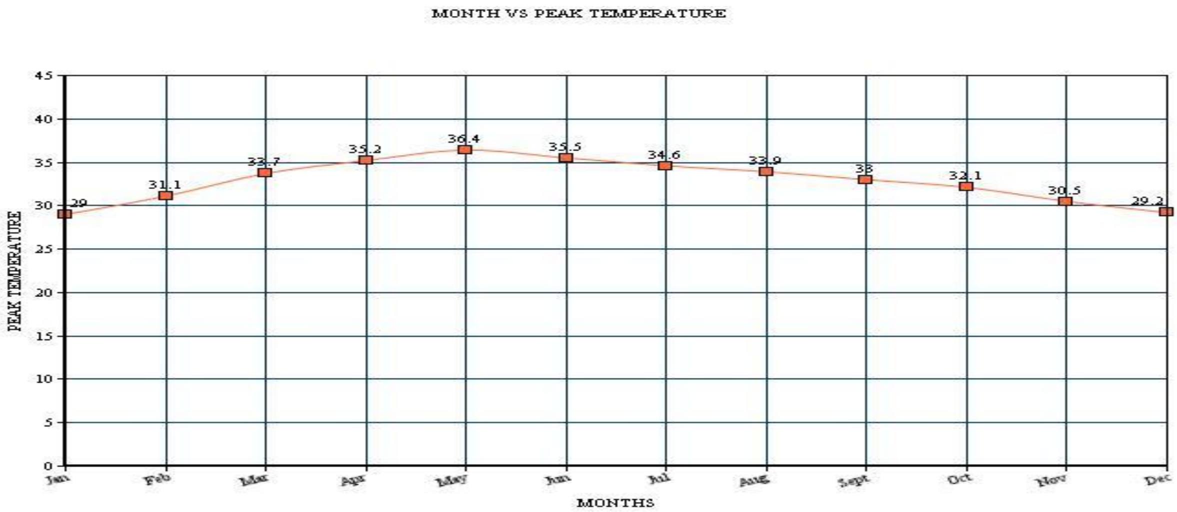
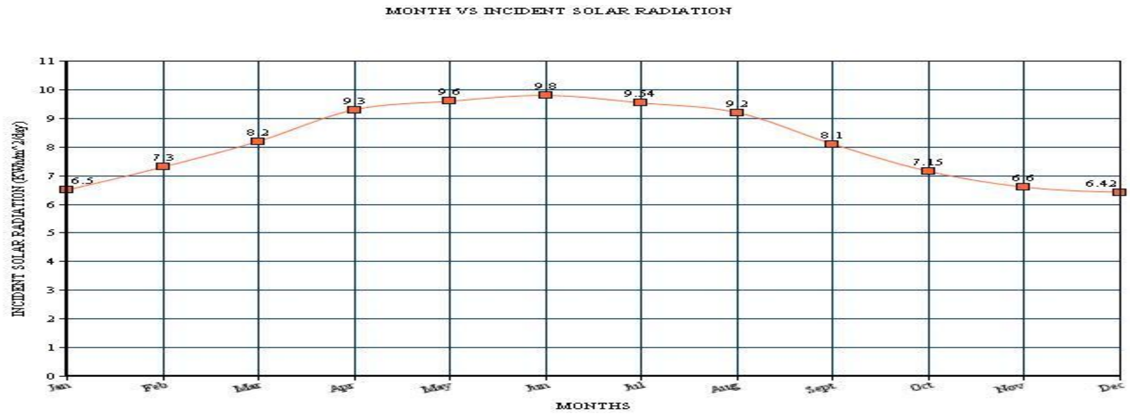
Appendix

1.



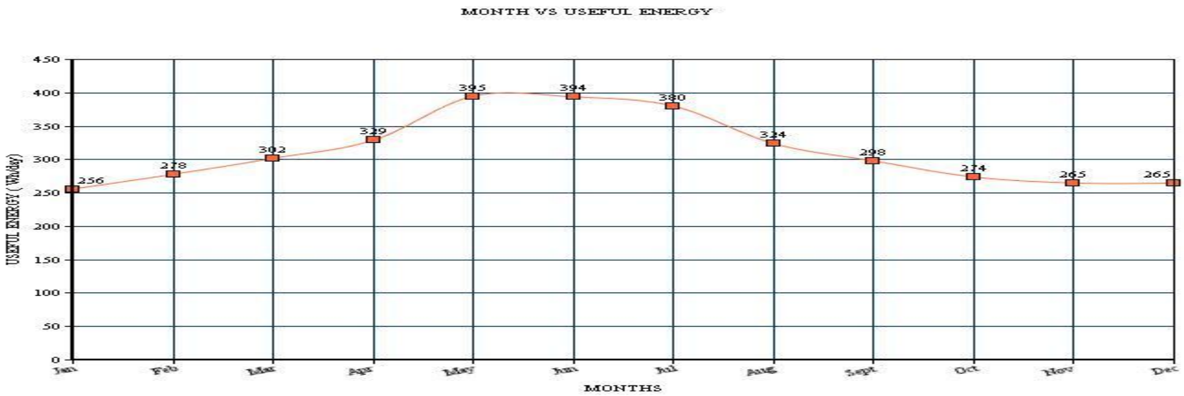
Month vs. Peak Temperature graph shows variation of peak temperature with months. The graph clearly shows that the peak temperatures initially increase gradually, and then falls with time and it becomes maximum in the month of May.

2.



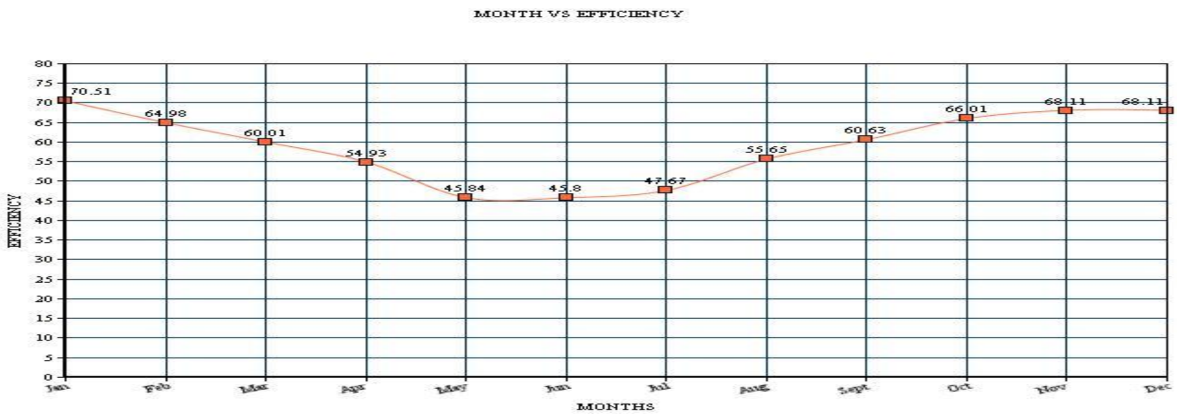
Months vs. Incident solar radiation graph shows variation of incident solar radiation with months**.** The incident solar radiation increases gradually and reaches its maximum and decreases further. Using this we can find the variation of intensity of solar radiation with months.

3.



Month vs. Useful Energy graph shows the variation of useful energy from the plate with months. It is derived from the values of incident solar radiation.

4.



Month vs. Efficiency graph shows the variation of efficiency of solar lantern with months. The efficiency is high in the starting months as the incident energy is less. As we go further the efficiency reduces as the incident radiation increases and the output remains constant. Then it again increases as the incident radiation decreases.

5. TABLE 5.1 Specifications of location

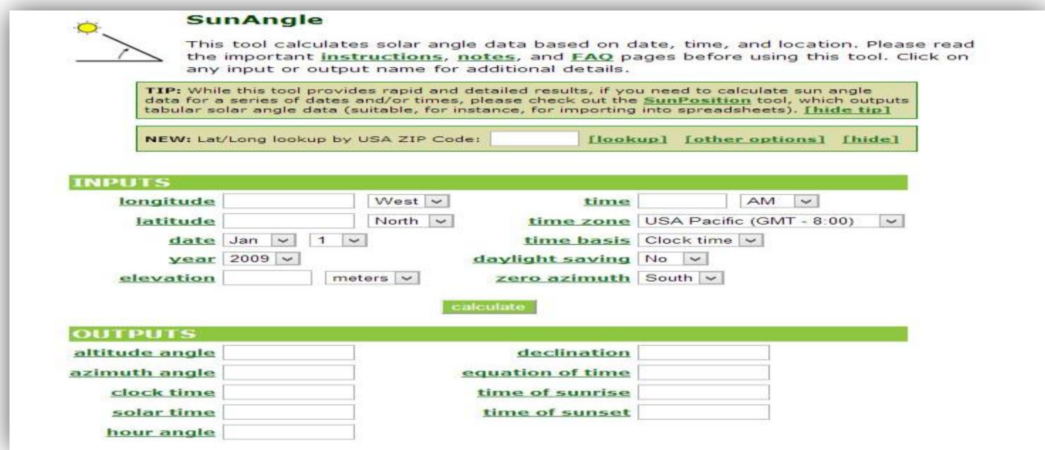
Location	**Visakhapatnam**
Latitude	17°42’ N
Longitude	83°15’ E
Altitude	18 feet above sea level

6. TABLE 5.2 Specifications of flat-plate collector

Number of glass covers	1
Top cover	Glass
Thermal emittance of glass	0.94
Thickness	0.05m
Collector tilt	10°
Cover transmittance	0.87
Mean plate temperature	65°c
Wind speed	5 m/s

7.Tool For Determining Solar Angle (ω)

In order to find out the solar angles (ω) a tool is used from the websitewww.SuSdesign.com/sun angle/.This tool calculates solar angle data based on date like latitude, longitude, time, and location, etc. It looks as below:



8.EXPERIMENTAL RESULTS OF FLAT PLATE SOLAR ARRAY AND SOLAR LANTERN

Months	Incident Solar radiation (kwh/m^2/day)	R Factor	Intensity of Radiation (kwh/m^2/day)	Useful energy from plate (wh/day)	Efficiency of Solar Lantern (%)
January	6.5	1.12	7.280	256	70.51
February	7.3	1.08	7.884	278	64.98
March	8.2	1.04	8.528	302	60.01
April	9.3	1.00	9.300	329	54.93
May	9.6	1.17	11.24	395	45.84
June	9.8	1.13	11.07	394	45.80
July	9.54	1.12	10.68	380	47.67
August	9.2	0.99	9.108	324	55.65
September	8.1	1.03	8.343	298	60.63
October	7.15	1.07	7.650	274	66.00
November	6.6	1.11	7.326	265	68.11
December	6.42	1.13	7.254	265	68.11

TABLE 5.3 DATA FOR THE YEAR 2008 OF VISAKHAPATNAM

MONTHS	**H,($KWH/m^2/day$)**	***T, (°C)***
JANUARY	**6.5**	**29**
FEBRUARY	**7.3**	**31.1**
MARCH	**8.2**	**33.8**
APRIL	**9.3**	**35.2**
MAY	**9.6**	**36.4**
JUNE	**9.8**	**35.4**
JULY	**9.54**	**33.2**
AUGUST	**9.2**	**32.7**
SEPTEMBER	**8.1**	**32.7**
OCTOBER	**7.15**	**32.1**
NOVEMBER	**6.7**	**30.5**
DECEMBER	**6.42**	**29.2**