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SOLAR ENERGY: A VIABLE ALTERNATIVE FOR INDIA

KRISHNAN S.*

The Cathedral and John Connon School, 6,Purshttamdas Thakurdas Marg, Fort, Mumbai- 400 001, MS, India.
*Corresponding Author: Email- shivrk.1996@gmail.com

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Abstract- The objective is to develop a solar energy system for a building (mainly devices requiring low power such as lights, fans and water heaters) in India, which is commercially viable and economically profitable over conventionally available power, sources. A comparative study between LEDs, CFLs and Incandescent light bulbs indicates that LEDs are the preferred option. A formula has been developed for the area of solar panel required for X watts of power.

A desktop model was made to verify the formula. The desktop model consisted of a model building having 12 LED bulbs and a pump. The desktop model was run on a rechargeable battery. This battery was charged using the solar panel. The results showed that the formula was viable. A number of graphs have been drawn for factors that cannot be determined through the formula such as energy generated for angle of inclination of the panel with respect to sun's rays. A methodology for the use of PV modules was then developed. Some disadvantages and disadvantages were also enlisted. This research can be used to develop panel systems for residential complexes, schools, offices, etc.

Keywords- solar energy, LEDs, CFLs, desktop model, India

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Introduction

The research addresses the objective of using solar energy as a renewable source of energy resulting in significant financial savings as well as being viable over a long term.

As a young boy growing in the big modern city of Mumbai, I learned early how important it is to save. Saving energy is something which all of us can do everyday. Solar energy assumes vital importance given:

- India's four major cities Delhi, Mumbai, Kolkata and Chennai have a combined population of over 50 million.
- There is ample sunlight for over nine months in a year.
- Urban India's skyline is dotted with skyscrapers all offering suitable sites for solar panels.
- Pollution levels are ever increasing and traditional energy costs (power from the grid) are rapidly increasing.

India is indeed a solar hotspot with abundant sunlight being available throughout the year. Research done by The Energy Resource Institute (TERI) and by T. V. Ramachandra, Rishabh Jain and Gautham Krishnadas helps confirm this and that the production of solar energy is highly viable since there is high intensity light implying that solar energy can easily be generated from the solar panels.

Further, Hoyt Hottel and Bryan Woertz of MIT have provided a formula for the amount of area required for solar energy collectors such as water heaters. Bloomberg estimates that there is high potential for solar energy.

Various news sources including National Geographic provide empirical data that solar energy will soon be a highly competitive source of energy.

Since daylight hours and time of operation vary between summer and winter we take daylight hours and time of operation during winter.

Objective

To develop a solar energy system for a building (mainly devices requiring low power such as lights, fans and water heaters) in India, which is commercially viable and economically profitable over conventionally available power, sources.

Formula

The formula developed for area of solar panel is as follow

$$\text{Area of Light} \sim \frac{\begin{array}{c}(\text{Power of all DC appliances in the circuit} * \text{time of operation} + \text{power of all AC} \\ \text{appliances in the circuit} * \text{efficiency of Inverter} * \text{time of operation} \\ + (\text{Current in the wire})^2 * \text{Resistance of wire} * \text{time of operation})\end{array}}{(\text{Intensity} * \text{Efficiency of panel} * \text{time of charging})}$$

Literature Review

India is endowed with very good solar energy resource. The average intensity of solar radiation received on India is 200 MW/Km. Even if 10% of the available area can be used, the available solar energy would be 8 million MW, which is equivalent to 5909 mtoe (million tons of oil equivalent) per year [1].

In 1942 'Professor Hoyt Hottel' and his graduate student 'Bryon Woertz' of 'Massachusetts Institute of technology (MIT)' laid the foundation for solar energy analysis with their paper on solar energy collectors. This paper developed the Hottel-Whillier collector model that is a basis for predicting the performance of active solar collectors.

$$Q_u = A_c F_R (I_T(\tau\alpha) - U_L (T_i - T_{amb}))^+$$

where, the useful rate of energy gained by the solar collector, Q_u is calculated using the net useful solar radiation incident upon the solar collector given by $I_T(\tau\alpha)$, corrected for losses given by $U_L (T_i - T_{amb}))^+$.

Solar energy is renewable energy's fastest growing sector with its demand and utilization evidently increasing. Bloomberg estimates the rise in photovoltaic installations to be 140% in 2010

During January (winter), much of the Southern Peninsula receives above 4.5 kWh/m2/day reaching a maximum of 5.5 kWh/m2/day in the Western Coast plains and Ghats regions, a major expanse of the Indian landscape receives above 5 kWh/m2/day while the Western Himalayas (Himachal Pradesh, Uttarakhand, Jammu Kashmir) and Eastern Himalayas (Assam, Arunachal Pradesh, Nagaland) continue receiving insolation in the range of 3-4 kWh/m2/day. During April-May as the summer heat sets in, more than 90% of the country is seen to receive insolation above 5 kWh/m2/day with a maximum-recorded 7.5 kWh/m2/day in the Western dry and Trans-Gangetic plains. With the onset of the summer monsoon throughout the country in June, there is a remarkable lowering of Global insolation towards the Southern (except for Tamil Nadu) and North Eastern ranges. The least recorded value in this period is 3.9 kWh/m2/day. This trend continues till September as the summer monsoon recedes. The Northeastern monsoon originating from Central Asia in October brings the Global insolation below 4 kWh/m2/day in the Lower-Gangetic plains and East Coast plains. The Himalayan foothills, plains, Central Plateau and Western dry zones receive above 4.7 kWh/m2/day as the Himalayas act as a barrier to this winter monsoon and allows only dry winds to the Indian mainland. These observed seasonal variations of Global insolation throughout the country conform to the earlier investigations based on 18 surface solar radiations. [Fig-1a], [Fig-1b], [Fig-1c] and [Fig-1d] showing the intensity of light in India throughout the year [2].

Punjab Energy Development Agency (PEDA) has launched a novel program for lighting education institutions by generating solar power through rooftop Solar Photo Voltaic (SPVs) systems. In the first phase, rooftop SPV systems were installed at Central University, Bathinda, Guru Gobind Singh Educational Trust, Kamalpura Ludhiana, Gian Sagar Medical College Banur, Shivalik Public School SAS Nagar Mohali and Shivalik Public School, Chandigarh with the combined capacity of 230 kilowatt [3].

Banerjee [4] mentioned that Energy Security is a must for India to maintain its growth rate and this requires inter-disciplinary efforts from scientists for better utilization of nuclear and solar energy- the only energy sources to be available in near future, he view that all other energy sources would disappear in next 50 years and it is of great importance that utilization of nuclear energy grows. He stressed that solar energy would be the biggest source of energy in future and that integrated efforts were needed for its best use.

Panicker, et al [5] has developed a desalination system based on solar heat and light. Solar energy-based small and community level Reverse Osmosis (RO) unit for producing safe drinking water. In the RO unit, the feed water is passed through the membrane with the help of a DC (Direct Current) pump connected to the Photovoltaic (PV) panels without any batteries. The unit can be operated for 9 to 10 hours on a sunny day, which can cater to the drinking and cooking requirements of three to four families at an average rate of five liters per person per day. Explaining the system that the RO is a pressure driven process whereby pure water is continuously drawn from salty water through a semi-permeable membrane. The source of solar energy is inexhaustible with no harmful gases like nitrogen oxide, mercury, carbon dioxide or sulphur dioxide being emitted [5].

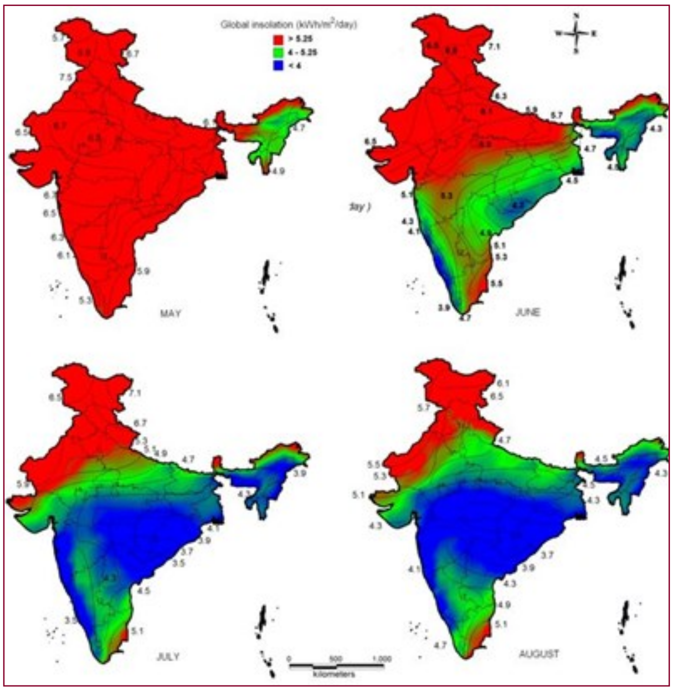

Fig. 1a- Monthly average Global insolation maps of India detailed with isohels (January to April)

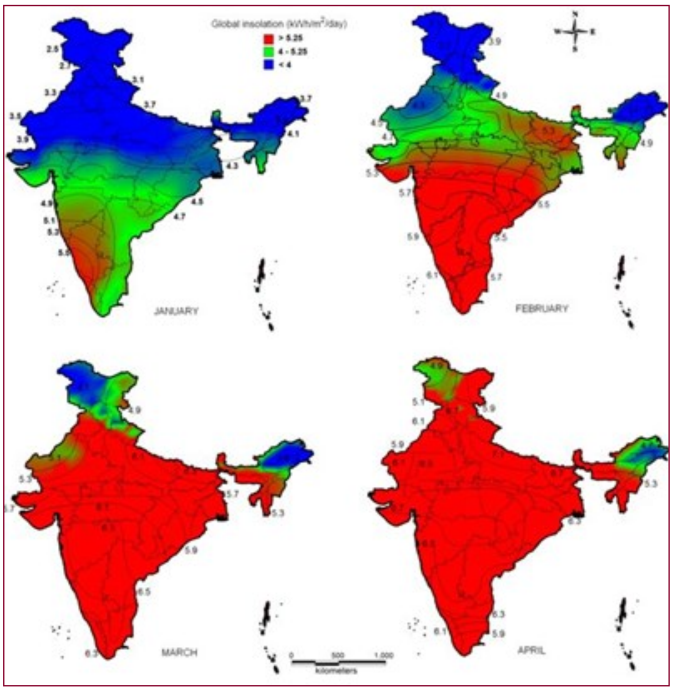

Fig. 1b- Monthly average Global insolation maps of India detailed with isohels (May to August) get average

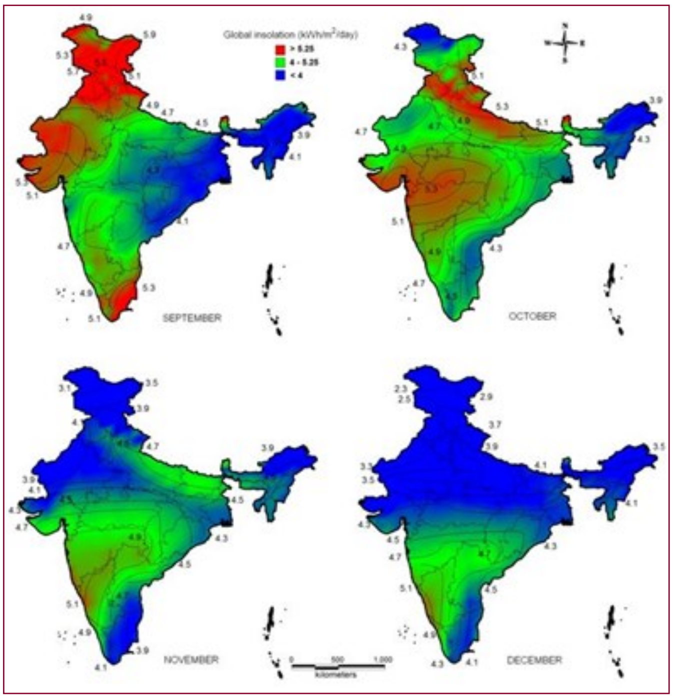

Fig. 1c- Monthly average Global insolation maps of India detailed with isohels (September to December)

As per the National geographic - solar energy use has increased by 20% per annum over the past 15 years, thanks to rapidly falling prices and gains in efficiency. Japan, Germany and United States are major markets for solar cells. With tax incentives, solar electricity can often pay for itself in five to ten years.

One fourth of the academic buildings at the Indian Institute of Technology-Bombay are set to go green by April-end [6]. Around 1 MW power is being generated by solar photovoltaic technology. With 1 MW solar power, 1.5 million units of electricity can be generated. On an average, any urban household consumes 1,000-1,500 units per year. A rough estimate shows solar energy can cost half the current electricity expenditure. A few other IITs will soon follow the suit [6].

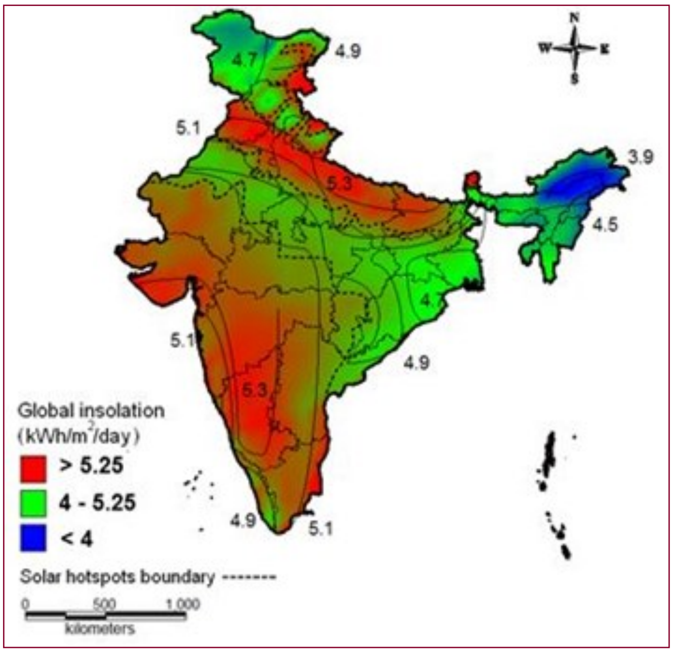

Fig. 1d- Annual average Global insolation map of India showing the isohels and solar hotspots

Design Plan

Science has gone a long way from the days of Tesla, Faraday and Edison Soon there shall be a scarcity of conventional energy sources leading to a need for viable sources of alternate energy.

Table 1- Comparison between LED Lights, Incandescent Light Bulbs and CFLs

	LED	Incandescent Light Bulbs	CFL
Avg. Life Span (average)	47,000 Hrs	1,150 Hrs.	7,000 Hrs.
Initial Cost per watt	$1.54-2.40	$ 0.5-1.2	$0.25-0.5
Watts of electricity used	06-08	60	13-15
Kilo-watts of Electricity used per annum	329 KWh	3285 KWh	767 KWh
Annual Operating Cost	$32.85	$328.59	$76.65
Carbon Dioxide Emissions per annum	451 pounds	4500 pounds	1051 pounds
Sensitive to humidity	No	Some	Yes
Durability can handle jarring and bumping	Very Durable	Not Very Durable - glass or filament can break easily	Not Very Durable - glass can break easily
Failure Modes	Not typical	Some	Yes - may catch on fire, smoke, or omit an odor

The above calculations are based on 30 Incandescent Bulbs per year equivalent [Source: Design Recycle Inc.]

From [Table-1] one can conclude that LED bulbs are the best option. Even though they are more expensive, they are very durable and resistant to changes in atmospheric conditions. Also they consume less power and therefore reduce the amount of area for solar panels thereby reducing the amount of money spent on solar panels. They are also environmentally friendly and hence fulfill one of the main aims of inserting panels, which would to reduce carbon-dioxide emissions.

Analysis

$$\alpha * \mathrm{area}_{\mathrm{light}} * \eta_{\mathrm{solar\,panel}} \sim \mathrm{P}_g^{\;1}$$

Since the current generated by solar panel is in DC, we need to use an inverter to covert the current into AC for all AC appliances, therefore

$$\mathrm{E}_{\mathrm{required}} = \mathrm{P}_{\mathrm{dc}} * \mathrm{t}_{\mathrm{operation}} + \eta_{\mathrm{inverter}} * \mathrm{P}_{\mathrm{ac}} * \mathrm{t}_{\mathrm{operation}} \tag{1}$$

$$\mathrm{E}_{\mathrm{obtained}} = \mathrm{P}_{\mathrm{g}} * \mathrm{t}_{\mathrm{charging}} \tag{2}$$

Applying law of conservation of energy while accounting for loss of energy via joules heating law

$$\mathrm{E}_{\mathrm{required}} = \mathrm{E}_{\mathrm{obtained}} - I^2 R \, \mathrm{t}_{operation} \tag{3}$$

Substituting [Eq-1] and [Eq-2] back in [Eq-3]

$$P_{dc} * t_{operation} + \eta_{inverter} * P_{ac} * t_{operation} = P_g * t_{charging} - I^2 R\, t_{operation}$$

$$P_{dc} * t_{operation} + \eta_{inverter} * P_{ac} * t_{operation} \approx \alpha * area_{light} * \eta_{solar\ panel} * t_{charging} - I^2 R\, t_{operation}$$

$$area_{light} \approx (P_{dc} * t_{operation} + \eta_{inverter} * P_{ac} * t_{operation} + I^2 R t_{operation})/(\alpha * \eta_{solar\ panel} * t_{charging})$$

Therefore

$$\text{Area of Light} \sim \frac{\begin{array}{c}(\text{Power of all DC appliances in the circuit} * \text{time of operation} + \text{power of all AC} \\ \text{appliances in the circuit} * \text{efficiency of Inverter} * \text{time of operation} \\ + (\text{Current in the wire})^2 * \text{Resistance of wire} * \text{time of operation})\end{array}}{(\text{Intensity} * \text{Efficiency of panel} * \text{time of charging})}$$

The ~ sign has been put due to factors such angle of inclination of the plane with respect to ground and ambient temperature and weather conditions. Maximum efficiency is for 90° inclination with respect to the sun's ray.

Comparative Efficiency of Panel Vs. Angle of Inclination

A solar panel generates most electricity when it is angled at 90° to the sun. [Fig-2] shows approximate efficiency at other angles.

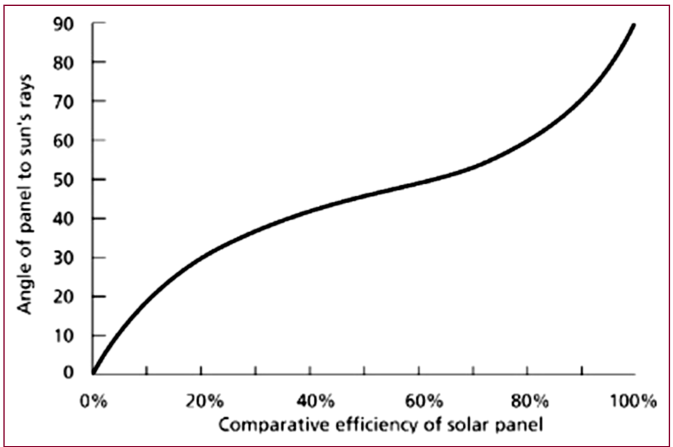

Fig. 2- Comparative Efficiency of Panel Vs. Angle of Inclination

Dependence of efficiency of panel on its temperature and the comparison between Evacuated tube solar panel & flat plate solar panel are shown in [Fig-3] and [Fig-4] respectively.

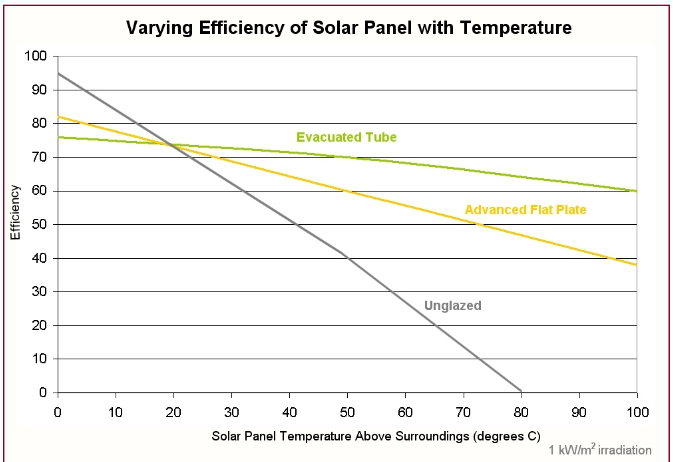

Fig. 3- Dependence of efficiency of panel on its temperature [*Source: Viridhan solar*]

Methodology for Use of Solar Voltaic Energy in Buildings

Panels can be put on roofs of buildings. For tall buildings this will be optimal. A solar thermal collector will also be attached to the roof near the tank for water heating, which can be then provided to all the occupants for bathing and washing.

- Panels can also be attached to individual lights if there is area shortage though this may reduce the amount of energy available from the panels.
- A device will be used for switching off the lights once the sun comes up. Manipulating the resistance of the transistor so as to switch the light off at the correct time shall do this. This will prevent energy wastage as the lights will be switched on and off at the required times.
- Energy for lifts, pumps and other heavy equipment has not been given as it requires heavy power and hence increases costs exponentially.

NB: This is a broad estimate based on the growing Indian middle class who tend to live in high rise apartments in cities – a typical building houses between 30 to 50 families. This middle class comprises over 250 million i.e. 20% of India's population of 1.25 billion

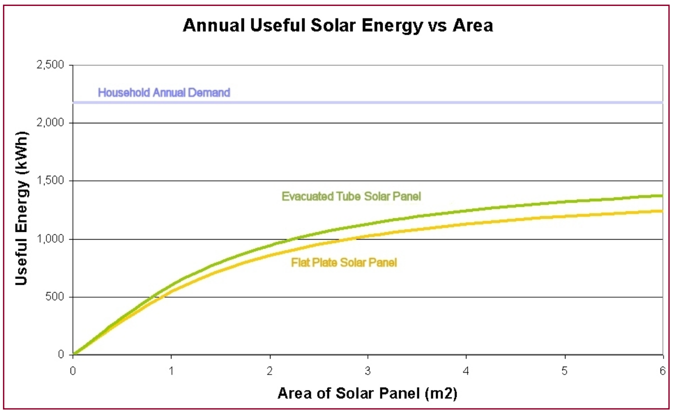

Fig. 4- Evacuated tube solar panel Vs. flat plate solar panel [*Source: Viridhan solar*]

A problem with solar panels is the fact that the initial investment is very large and this makes the use of panels difficult in most developing countries. This can be attributed to high manufacturing costs and restrictive trade laws. With sufficient subsidizations of panels and friendly trade laws these problem can be solved.

The biggest disadvantage for this kind of electricity is that it cannot be converted efficiently. The only possible way of converting it is storing the current in a battery (until we get adequate amount of current) and then converting the D.C. current to A.C. via an inverter. A big disadvantage of the batteries is that they are quite expensive and are difficult to dispose.

Another big disadvantage is need for large area.

But even though there are such disadvantages the uses of solar panels will be of essential importance due to the scarcity of energy sources and the eco-friendliness of solar power. In 2011, over 1.4 billion people did not have electricity in the world out of which 300 million were from India. This shows the scarcity of electricity throughout the world thereby showing the need for non-conventional sources of energy.

Some possible applications of solar panels without the use of batteries include flashing lights and Solar powered pumps

Use of solar and wind energy hybrids also seem to be a viable energy alternative. There used to be government subsidization for these hybrid systems (for farmers in India) but it has been cancelled.'

Electricity charges in India are quite high [Table-2].

Table 2- Average residential electricity charges in India for the year 2012

No of kWh	Charge per unit
0-100	₹ 1.05
101-300	₹ 2.50
301-500	₹ 4.40
Above 500	₹ 5.30

These costs versus a GDP per capita of US$ 1,508.54 (2011) seem unaffordable. With inflation rates quite high (around 4.7%), the costs are going to increase a lot more. This shows that investment in panels is necessary and justified.

Desktop Model

A desktop model has been prepared to illustrate how solar energy works [Fig-5].

Fig. 5- Desktop model.

Key Parts of the Model

- Model 5 story office building.
- LED lights (0.051 watt light) and water pump (2 watts) fully wired up with connectors.
- Plastic container for water tank.
- On/off switches.

1st generation solar panel with max power of 9 W; optimum voltage 17.5 V.

Observations

- Once the solar panel has been charged under sunlight, the LED lights fully light up the model building as illustrated.
- There is sufficient power to pump water to the tank on top of the building- about 8 inches high. For the water pump, the battery requires to be fully charged and then used.

Conclusion

From the above the above paper we can make the following conclusions

- India receives great amount of sunlight and hence is good for the production of solar energy.
- Area of solar panel can be calculated using the above suggested formula.
- LED lights are the most environment friendly and most cost effective option for use of solar panels.
- It is important for the scientific community to create low cost and high quality solar panels.

Future Perspectives

Today in India mainly first generation solar panels are available (bulky and low powered chunky heavy metal). The next generation of solar panels is like small bricks. What we need is really small inexpensive solar panels similar to for example components in the mobile telephone universe.

Abbreviations & Symbols

- A_c : Collector area (m^2).
- $area_{light}$: required area (m^2).
- $E_{obtained}$: energy obtained (kWh).
- $E_{required}$: energy required (kWh).
- F_R : Collector heat removal factor (collector effectiveness).
- I_T : Solar radiation incident on the tilted collector (Wm-1s).
- I : current in the wire (A).
- $\eta_{inverter}$: efficiency of inverter.
- $\eta_{solar\ panel}$: efficiency of solar panel.
- P_g : power generated (kW).
- P_{dc} :total power for all DC appliances (kW).
- P_{ac} :total power for all AC appliances (kW).
- Q_u : U rate of energy gain of collector (J).
- R : resistance of wire (Ω).
- T_{amb} : ambient temperature (K).
- T_i : Inlet fluid temperature (K).
- $t_{operation}$: time of operation (hrs.).
- $t_{charging}$: time during which we get sunlight (hrs.).
- U_L : Collector loss coefficient.
- ∝ : Intensity of sunrays (kWh1m-2s-1).
- τα : Effective transmittance-absorbance product.
- ~ : tends to.
- + : a controller is present to prohibit negative values of Q_u.

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