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Estimation of Incoming Solar Energy Budget at the Horizontal Surface of the Earth in the Foothills of the Northern Indian Himalaya

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Abstract

The accurate information of solar energy budget distribution at a particular geographical location is essential in prediction of climate studies, and design and development of solar energy devices. This paper presents the status of incoming solar energy budget at the horizontal surface of the Earth in the foothills of the northern Indian Himalaya during October 2012. The distribution of incoming solar energy budget estimated using well known empirical models. The empirical models run taking into account sunshine hours, solar declination angle, geographic latitude of the observation site, the eccentricity correction factor and the sunset hour angle as main parameters of the study. The monthly average value of the total solar energy budget incident at top of the atmosphere and the Earth's surface estimated 326 $Wm^{-2}d^{-1}$ and 165 $Wm^{-2}d^{-1}$, respectively. The study confirms that the upper part of the Kullu valley in the northern Indian Himalaya is an ideal site for harvesting solar energy. The economic feasibility analysis in term of harness solar energy suggests that by popularizing the use of solar energy devices through awareness campaigns, we can solve a part of energy demand and thereby can reduce the dependency on non-renewable sources of energy.

Keywords: Solar radiation, direct solar radiation, diffuse solar radiation, sunshine hours, empirical models, solar declination angle.

Introduction

The energy radiated by the Sun in all the directions called solar radiation[1]. This energy is the main driving force of the Earth and its atmosphere[2]. The energy comes from the sun cover a wide spectrum of ultra-violet (200 to 400 nm, about 10% of the energy), visible (400 to 700 nm, about 40% of the energy), and infra-red (700 to 4000 nm about 50% of the energy) radiation[3]. Solar energy received at the Earth's surface mainly in two basic components i.e., direct and diffuse. Direct solar energy is the energy arriving at the Earth's surface with the Sun's beam. Diffuse solar energy is the total amount of solar energy falling on surface from all parts of the sky apart from the direct Sun. The sum of the direct and diffuse components reaching a horizontal surface is global radiation[4,5]. The regional distribution of global radiation is important as it provides useful information about the total available solar potential at a particular geographical location. The Earth's global energy budget of incoming solar radiation indicates that 78 Wm^{-2} day^{-1} of the total solar radiation incident at the top of the atmosphere i.e., 341Wm^{-2} day^{-1} is absorbed by the Earth's atmosphere and 161 Wm^{-2} day^{-1} absorbed by its surface. The remaining 102 Wm^{-2} day^{-1} of incoming solar radiation lost into space due to surface reflection, cloud reflection, and back scattering[6].

Nowadays solar energy is being used for various purposes such as electricity production, water heating, crop drying, house heating, etc. With the increasing demand for energy, the continuous depletion of conventional sources of energy and the growing concern regarding environment pollution[7], have pushed mankind to explore and harness solar energy for future need[8]. In the ancient past, a few countries make an attempt to play a leading role to explore solar energy more efficiently, but most of that research work remained mainly academic. In 1970s with hike in oil prices, several countries started measurement of solar radiation to generate solar energy database. But still, there are few database stations those are measuring global solar radiation especially in the Indian Himalaya. To generate a long-term solar energy database from such stations where no measure data are available many researchers have made an attempt to estimate global solar radiation from other measured meteorological parameters like as sunshine hours, relative humidity, and temperature e.g.,[7, 9-16]. The magnitude of the incoming solar energy budget is also useful to regulate the hydrological cycle[17]. Therefore, the knowledge of global solar energy budget distribution at a particular geographical location is essential in the prediction regional climatic implication studies and design of the renewable energy systems particularly in the development of photovoltaic power and solar heating systems[11,13].

In view of the importance of the incoming solar energy budget, the present study carried out under three major objectives: i. to estimate sunshine hours, ii. to estimate solar energy budget at the top of the atmosphere (TOA) and Earth's surface, iii. awareness, utilization and implementation of solar energy devices. To meet out these objectives the present study is organized broadly into three parts. The first pars deals with the problem faced by the society in utilization of solar energy budget and solution to the problem, the second part deals with the estimation of the Earth's solar energy budget, and last part concern with the utilization and economic feasibility of energy budget. However, the reported results are on the short-term observation, but the long-term study of this work would describe a prospect on solar energy distribution and its available solar energy potential. This study has a unique importance of the regions, where the *in-situ* observations are so far. Therefore, by way of estimating the current status of total incoming solar energy budget, there would be possibilities in the future to suggest a model to harness solar energy. This study also highlights that by popularizing the use of solar energy we can solve a part of energy demand and can reduce the dependency on non-renewable sources.

Material and Methods

The present study carried out during October 2012 in the upper part of the Kullu valley, in the foothills of the northern Indian Himalaya at different locations namely: Haripur, Jagtsukh, Bran and Goshal. All these experimental sites are within the radius of 10 km. This part of Kullu valley is one of the famous tourist places in the world and is well below the snow line. To know about the status of Earth solar energy budget, its applicability in the area and the problem faced by the society in utilization of solar energy budget this study completed in five steps:

Step I: conduct pre-survey through a well structure questionnaire among the villagers to find the local problem and issues faced by the people in utilization of solar energy budget. Thereafter, to find the solution to the problem.

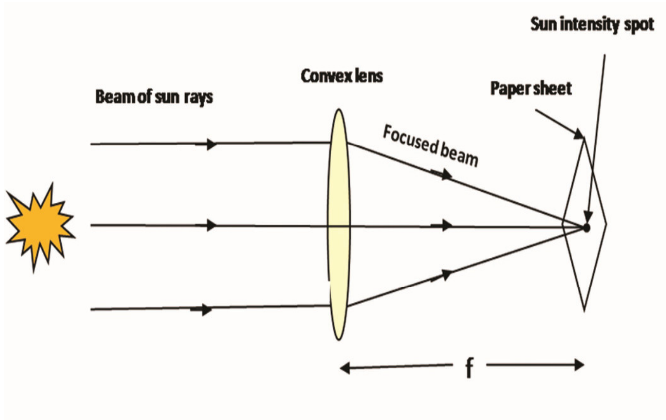

Figure-1
Schematic representations of measuring solar intensity spot

Step II: concerned with the estimation of sunshine hours. Generally Pyranometer is used to measure the sunshine hours, which record the sunshine duration when solar flux equals or exceeds 120 Wm^{-2}. But due to lack of instrument we adopted a basic method to measure daily sunshine hours (n) by estimating the intensity of the sun. The schematic representations of measuring solar intensity spot to measure daily sunshine hours is shown in figure-1. The solar radiations made to pass through the convex lens. After passing they focused at the focal point, where sheet of white paper placed to measure rate of sun intensity spot. On clear day the measurement made in a time period of 30 minute interval, while on partly cloudy day it made frequently in a time period of 10 minute. When the Sun was under thick cloud, time period not counted for sunshine hours. Each day after sunset the time period integrated to obtain total sunshine hours.

Step III: We run empirical models to estimate solar energy at TOA and at the Earth's surface. The basic input parameter to run these models are: sunshine hours (n), solar declination angle (δ), geographic latitude of the observation site (φ), the eccentricity correction factor $(r_o/r)^2$ and the sunset hour angle (ω). The detail description of the model used to estimate solar radiation incident at the TOA (H_o) is provided in Iqbal[18] and only brief outlines are presented here,

$$H_o = I_{sc}\left(\frac{r_o}{r}\right)^2\left[\frac{\cos\varphi\cos\delta\sin\omega + \omega\sin\varphi\sin\delta}{\pi}\right] \text{Wm}^{-2}\text{d}^{-1} \qquad (1)$$

where I_{sc} is the solar constant and the generally accepted value is 1367 $Wm^{-2}d^{-1}$. The solar declination angle computed as[19],

$$\delta = [0.006918 - 0.399912 \cos\theta + 0.070257 \sin\theta - 0.006758 \cos 2\theta + 0.00907 \sin 2\theta - 0.002697 \cos 3\theta + 0.00148 \sin 3\theta] \text{ rad} \qquad (2)$$

The day angle computed as[18],

$$\theta = 2\pi\left[\frac{d-1}{365}\right] \text{ rad} \qquad (3)$$

Where, d is the day of the year. The eccentricity correction factor calculated by the expression[19],

$$\left(\frac{r_o}{r}\right)^2 = \left[\begin{array}{l}1.00011 + 0.034221\cos\theta + 0.00128\sin\theta + \\ 0.000719\cos 2\theta + 0.000077\sin 2\theta\end{array}\right] \qquad (4)$$

Sunset hour angle derived from equation[18],

$$\omega = \cos^{-1}(-\tan\varphi\tan\delta) \text{ rad} \qquad (5)$$

A well known empirical model which is applicable anywhere in the world deployed to estimate global (H)[20] and diffuse (H_d)[21] solar radiation reaching at the Earth's surface,

$$H = \left[0.18 + 0.62\left(\frac{n}{N}\right)\right]H_o \text{ Wm}^{-2}\text{d}^{-1} \qquad (6)$$

$$H_d = \left[1.391 - 3.560\left(\frac{H}{H_o}\right) + 4.189\left(\frac{H}{H_o}\right)^2 - 2.137\left(\frac{H}{H_o}\right)^3\right]H \text{ Wm}^{-2}\text{d}^{-1} \qquad (7)$$

where N is maximum possible hours of sunshine and calculated using formula[22],

$$N = \left[\left(\frac{2}{15}\right)\left(\frac{180}{3.142}\right)\right]\omega \tag{8}$$

Step IV: concerned with the utilization of solar energy budget and analysis of economic feasibility.

Step V: conduct awareness campaign followed by post-survey to know the level of villagers in conserve and harness of solar energy budget.

Results and Discussion

To find the problem faced by the society in the utilization of solar energy budget was one of the typical tasks. For this, conduct pre-survey through well structure questionnaires among the villagers of the study area. After analyzing the questionnaires it reveals that the major problem faced by the people in the harness of the incoming solar energy budget and its utilization through solar device are lack of awareness, lack of available sunshine hours, insufficient amount of solar potential, higher installation cost of solar devices being used to harness solar energy, and lower efficiency. Perhaps the awareness campaign may be one of the solutions to maximize the use of solar energy. But, to spread awareness among the villagers would be effective only in the case if our geographical location has a sufficient amount of solar potential. If there is no any estimation about available solar potential then to conduct awareness campaign would be meaningless. To estimate incoming solar energy budget and analysis of economic feasibility while utilization of solar energy may be the best approach.

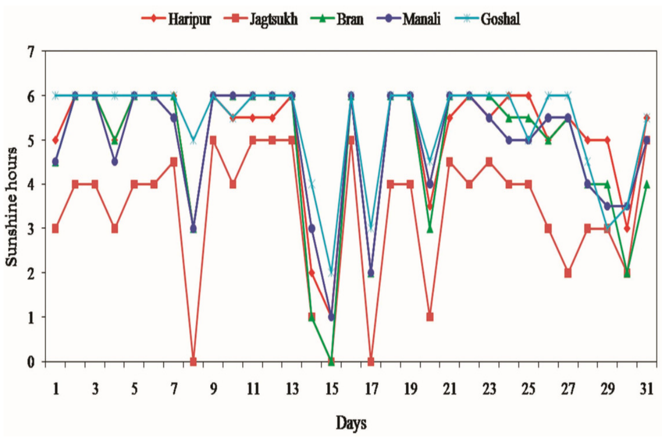

Figure-2
Variation in daily pattern of sunshine hours during October 2012

In this study, the incoming solar energy budget estimated by applying empirical models. The most important input parameter to run these models is sunshine hours. The estimation of sunshine hours remains the most important part of our study. figure 2 shows the variation in the daily pattern of sunshine hours. At each site, the variation in sunshine hours almost found in similar pattern. During the observation period the sunshine remained throughout the period in average 5 hours per day.

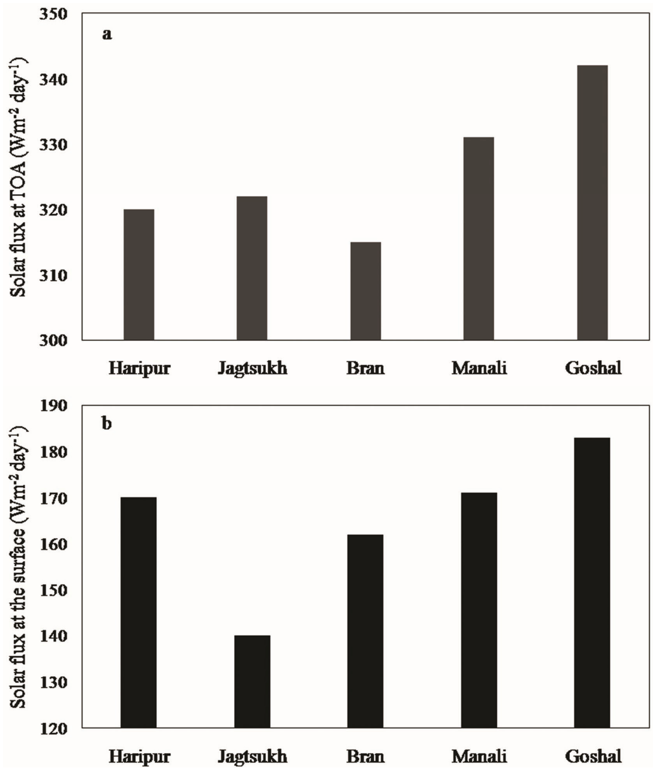

Figure-3
Distribution of solar energy budget during October 2012 (a) at TOA and (b) Earth's surface

Figure 3a is shows the status of the TOA solar energy budget. The highest TOA solar energy budget is obtained for Goshal location i.e., 342 $Wm^{-2}d^{-1}$ while minimum for Bran i.e., 315 $Wm^{-2}d^{-1}$. The composite daily average value of the TOA solar energy budget in the upper Kullu valley found 326 $Wm^{-2}d^{-1}$. Figure 3b is shows the status of total surface solar energy budget. The highest surface energy budget is found for location Goshal having value 183 $Wm^{-2}d^{-1}$ with a large fraction of direct beam i.e., 78% followed by the Manali having value 171 $Wm^{-2}d^{-1}$ with a large fraction of direct beam i.e., 75%. The minimum energy budget estimated for location Jagtsukh i.e., 140 $Wm^{-2}d^{-1}$ where the fraction of direct solar beam component was 56%. The Goshal is a higher attitude station under study, whereas Bran is situated at a lower altitude. This is the fact that the higher the altitude the greater the solar radiation under cloud-free conditions. However, the little higher value obtained for the Jagtsukh location as compared to Bran. This is due to less sunshine hours, as Jagtsukh is situated on the slope of the hill and sun shadow is the possible cause of lower value. On average, the composite daily average value of the total solar energy budget in the upper Kullu valley obtained 165 $Wm^{-2}d^{-1}$. Figure 4 is shows the variation in the daily distribution of direct and diffuse solar energy budget estimated for upper Kullu valley during October 2012. The composite daily average value of the direct and diffuse solar energy budget in the upper Kullu valley estimated 116 $Wm^{-2}d^{-1}$ and 49 $Wm^{-2}d^{-1}$, respectively. The value of direct solar beam was highest on 9 October followed by 12 October. The lowest value noted on 15 October.

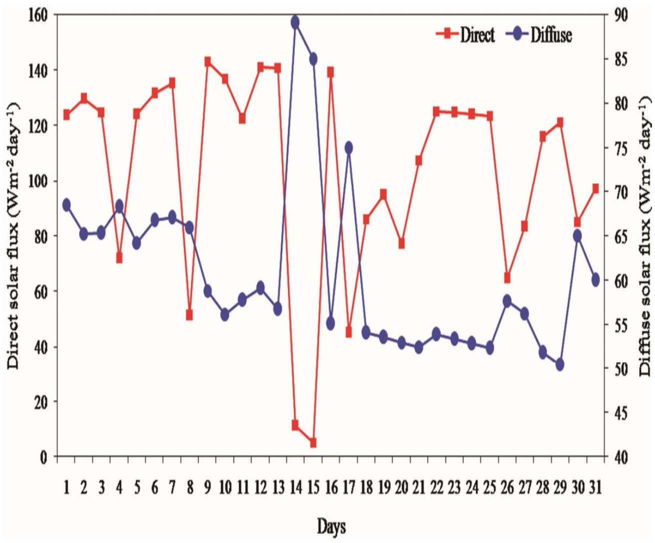

Figure-4
Pattern of daily distribution of direct and diffuse solar energy budget during October 2012

Figure 5 representing the status of the incoming solar energy budget of the upper Kullu valley. This energy budget indicates that 161 $Wm^{-2}d^{-1}$ amount of incoming solar radiation observed by the Earth's atmosphere plus lost into space. This value is found lower than the Earth's global average value (i.e., 180 $Wm^{-2}d^{-1}$)[6]. On the other hand, the surface reaching solar energy at our location was estimated 51% of the solar radiation incident at TOA, whereas at a global level this amount was 47%[6]. This study also confirms that the magnitude of direct radiation reaching at the surface of the upper Kullu valley was higher than that of the Earth's global energy budget while of diffuse solar radiation well below the Earth's global averaged energy budget.

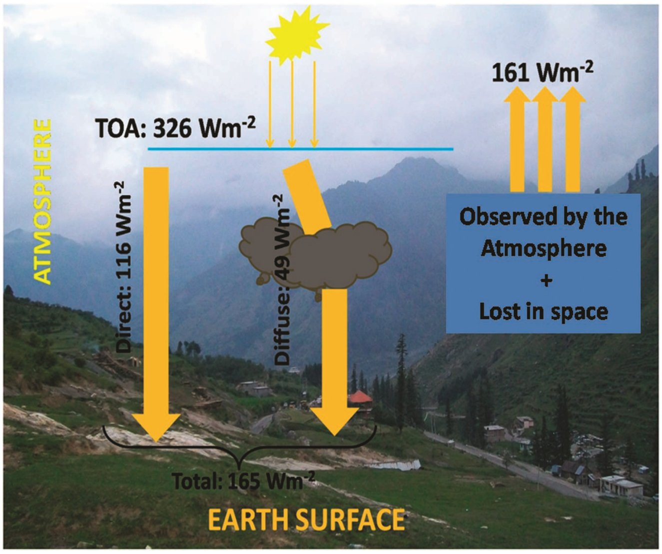

Figure-5
Solar energy budget of incoming solar radiation of upper Kullu valley during October 2012

To know the level of knowledge about the utilization and implementation of solar energy devices, pre-survey and post-survey was conducted through well structured questionnaire. Before awareness campaign, we performed the analysis about the utilization of the solar energy devices and their economic feasibility. From the pre-survey report it comes to know that the people of the upper Kullu valley mainly depend to meet out their energy demands on fuel wood, kerosene oil and electricity. About 60% of the total energy utilized to heat the water for various purposes. From the experimental database it reveals that the upper Kullu valley receives a sufficient amount of solar energy (i.e., 165 $Wm^{-2}d^{-1}$), what is expected to run solar energy devices. So, these tabulated solar devices (table 1) can play a vital role in the life of villagers. A solar water heater of 100 liter capacity can save 3128 kg fuel wood, 374 liter kerosene oil and 2230 unit of electricity, having approximately cost 21875 per year. A domestic type solar cooker can save 4 Liquefied Petroleum Gas (LPG) cylinder of having approximately cost 1700 per year. A commonly used solar panel, around 3000 unit of electricity having amount about 6000 per year.

Table-1
Statistical analysis of solar devices

Solar devices	Saving/Year	Amount (Rs)	Consumer cost (Rs)
Solar water heater (100 liter)	Fuel wood: 3128 kg Kerosene/oil: 374 liter Electricity: 2230 unit	21875	17472
Solar cooker domestic	LPG cylinder: 4	1700	1390
Solar cooker dish type	Fuel wood: 7956 kg	38780	2925
Solar panel of area 0.367 m^{-2}	Electricity: 3000 unit	6000	---------

Source: Himurga Himachal Pradesh (http://himurja.nic.in/)

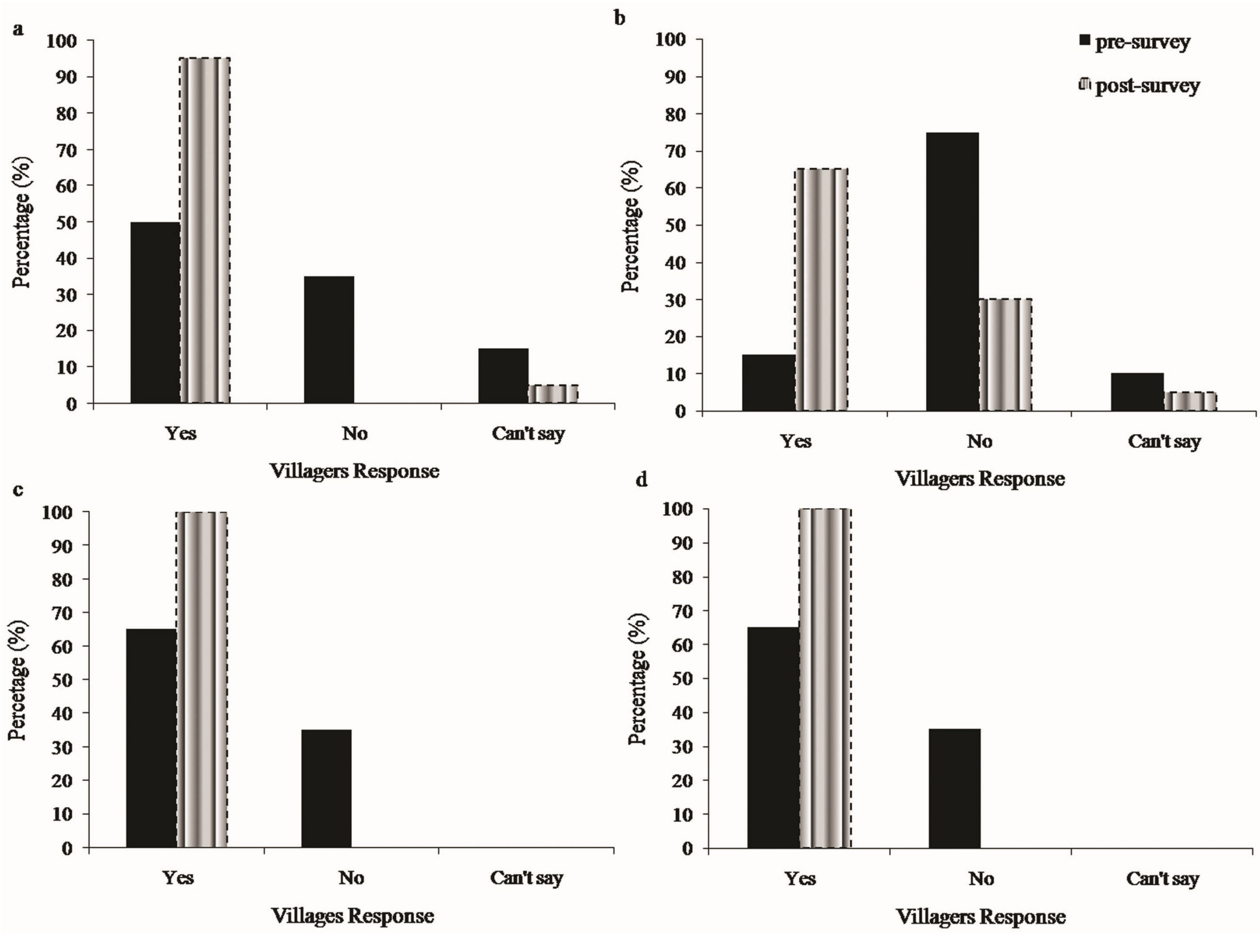

Figure-6
Difference in frequencies of correct responses of villagers during pre-survey and post- survey

After conducting experiments and analyzing economic feasibility. Local communities were aware about the available solar potential and its utilization techniques. So, they can maximize the use of solar energy to fulfill their routine energy demands. In the last, we conduct a post-survey. In response to the queries made about the knowledge of solar energy and its related devices, the following perceptions were received from the people of the upper Kullu valley, which are presented in figure 6(a-d). The first quarry made on "solar energy would be the main source of energy in near future". In response to this (figure 6a) 50% said yes, followed by 35% no and 15% can't say. After creating awareness the response was very much positive and 95% people were very well known. The second quarry was on the "current status of global solar radiation reaching at the surface of upper Kullu valley". During the pre-survey the response from responded was 12%, while after awareness campaign it goes to 65% (figure 6b). The third quarry was "about the potential of solar energy". In response to this (figure 6c) 65% said yes, followed by 35% no. After creating awareness the response was 100% people were very well known about the potential of solar energy. The last quarry conducted on the "implementation of solar energy devices". During pre-survey (figure 6d) only 65% villagers said they would like implementation solar devices. After creating awareness the response reached 98%.

Conclusion

The estimation of the local Earth energy budget is essential for climate studies, which have been become most burning issue in the world today. Solar radiation data received at the site is essential for energy planners, engineers and agriculture scientists. It provides useful information for energy policy makers if they intend to compare and use the incoming solar radiant energy in the Himalayan region with different climate conditions. In comparing the incoming solar energy budget with Earth's global average energy budget, found that direct and total radiation reaching at the Earth's surface under study, remained above the Earth's global energy budget. The diffuse radiation was found below the Earth's global average energy budget. This indicates that Kullu valley has a sufficient amount of energy to run solar devices efficiently. So, the upper Kullu valley has great potential to harness this energy. By conducting awareness campaigns, it's come to know that by popularizing the use of solar energy devices we can solve a part of energy demand and can reduce the dependency on non-renewable sources of energy.

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