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Evaluation of Passive Solar Strategies by finding Solar Zones: For Quality Life in Rural Areas

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Abstract: Today, energy crisis is a challenging problem across the globe. Since solar radiation is being measured accurately at only few sites, thus the solar climate is characterized by a time structure to evaluate solar radiation at any place. The monthly mean of the daily clearness ratio (Kt) is an appropriate variable in that respect, on basis of which India is divided into various zones, by using Wards Method. The objective of the study is to classify India into solar zones and suggest passive design strategy of each zone. Optimum performance of the passive strategy in different zones is analyzed with the help of bioclimatic chart. The preliminary findings indicate that if proper choice of passive solar strategies is done in the respective region, it would reduce the dependency on conventional source of energy, improving the quality life of human beings economically and pollution free as well.

Keywords: Clearness Ratio, Climate, Passive solar strategies, Bioclimatic chart, Solar energy.

1. Introduction

India has a wide variation in climatic condition throughout the country. Solar passive buildings or climate responsive building can prove to be a good measure to fulfill energy needs. Solar radiation plays a vital role in the design and analysis part of such energy efficient building. The annual global solar radiation incident over India ranges from 1200 to 2300 kWh/m^2/year with most of the country having radiation greater than 1900 kWh/m^2/year with about 300 clear sunny days. India's solar radiation is higher than countries like Germany where annual solar radiation ranges from 800 KWh/m^2 to 1200 KWh/m^2 [1].Hence it can be seen that solar energy can meet a significant amount of growing energy demand. For the initial analysis and solar energy system mapping of prevailing solar radiation condition is needed; it will also give an idea about the active and passive solar strategies which will further help in designing of solar efficient buildings in the different regions of the country. Several studies have been done in Africa [2] and China [3] on solar climates and solar maps. In India, however not much work has been done in this field. The basic aim of this study is to define K_t (monthly average daily clearness ratio) as a basic variable to propose a map indicating the prevailing solar climatic conditions in India and hence to identify the different passive designs strategies.

2. Clearness Ratio

The beam of nearly parallel incident sun rays at the top of Earth's atmosphere is referred to as extra-terrestrial radiation (ETR). The integration of the extra-terrestrial spectrum over all wavelengths defines the solar constant ISC. When the solar radiation flux passes through the Earth's atmosphere, its spectral distribution is modified by absorption and scattering processes. Global irradiance (Ihg) is the sum of the direct horizontal and diffuse components of the extra-terrestrial radiation.

Solar radiation is crucial to both passive solar designs and active solar energy conversion systems. In India, solar radiation has not been recorded regularly at many meteorological measuring stations in different regions. As only few measuring sites are available with long-term time-series of accurate measurements. For such a site, the time structure may be derived that characterizes the solar climate. The monthly mean of the daily clearness ratio (Kt) is an appropriate variable in that respect [2].So Kt was used as an indicator of the prevailing solar climatic conditions in the clustering analysis. Kt is defined as follows:

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$$K_t = I_{hg} / I_{he} \tag{1}$$

$$I_{he} = (24/\pi) I_{sc} E_0 [\pi/180(\omega_s(\sin(d).\sin(l)) + (\cos(d).\cos(l).\sin(\omega_s))] \tag{2}$$

$$E_0 = (1 + 0.033 * \cos(d)(360 * n / 365) \tag{3}$$

where n is the date in numeric value, L is Latitude; I_{hg} is measured daily global irradiation on a horizontal surface, MJ/m^2; I_{he} is daily extra-terrestrial radiation on a horizontal surface, MJ/m^2; I_{sc} is the solar constant, MJ/m^2 (used I_{sc}=1365MJ/m^2); E_o is the eccentricity correction factor of the earth's orbit, dimensionless; d is solar declination, degree; and ω_s is the sunset hour angle.

3. Methodology

For Kt, the measured daily global solar irradiation at 33 places were gathered and analysed from NASA Surface meteorology and Solar Energy: RET Screen Database. Ihe i.e. daily extra-terrestrial radiation was calculated with the help of equation (2) in MATLAB. Then clearness ratio Kt is calculated using equation (1) and summarised by averaging the data for each month, resulting in a series of 12 values (one per month) for each site as listed in Table 1.

The parameter Kt is an indicator of the relative clearness of the atmosphere [5]. Low Kt means cloudy sky with low global irradiation. High Kt means high global irradiation, which is dominated by the direct component. A large variation is seen in the measurements of monthly mean global irradiation which is suppressed by the use of clearness ratio Kt.

4. Ward's Method of Hierarchical Clustering

4.1. Procedure

It is found in climatological research, Ward's method is used to provide the most suitable cluster analysis method among the various Hierarchical techniques i.e. single linkage, complete linkage, centroid, Ward's minimum variance and the average distance method.

A hierarchical cluster tree was then formed using Ward's algorithm [6] to determine any possible combination of two data or clusters. This algorithm merged the two sites that were nearest in Euclidean distance (i.e. those having the smallest distance between each other). At each merging step (agglomeration), the two clusters that merged were those that resulted in the smallest increase in the overall sum of the within rescaled distances [7]. A new cluster was formed after merging, and the distance between this clusters and all the other sites were re-calculated. This process was done in an iterative way until there was a unique cluster.

4.2. Number of clusters

To determine the final number of clusters, rescaled distance was calculated from the dendrogram. The rescaled distance was then plotted against the number of cluster (Figure 1). This rescaled distance is a weighted sum of the distances within a cluster. It increases slowly as the merging proceeds, and the number of clusters decreases. There is no universally accepted objective method to decide on the number of clusters to be retained. If a sharp increase at a given number of clusters is observed, it indicates the forming of a heterogeneous cluster from two homogeneous clusters and indicates the end of the process of merging. This critical number is the final number of clusters. Figure 1 shows a sudden change around cluster 5. That means that several classes are very similar and that there is no loss of information by aggregating them. Hence, it seems that a number of 5 clusters are appropriate to describe the time-series of Kt. Another graph was plotted between the coefficients of agglomeration and the number of cluster (Figure 2). It can be seen that there is obvious sharp increase in the curve after 5 clusters. Thus, India should be divided into 5 clusters (5 solar zones).

Table 1: Monthly K_t of each place

CAPITAL	January	Febraury	March	April	May	June	July	August	September	October	November	December
Agartala	0.64	0.63	0.60	0.53	0.46	0.39	0.39	0.42	0.42	0.52	0.60	0.65
Aizawal	0.66	0.64	0.60	0.53	0.45	0.40	0.39	0.42	0.45	0.52	0.60	0.66
Bangalore	0.63	0.66	0.65	0.61	0.57	0.46	0.43	0.43	0.49	0.49	0.52	0.58
Bhopal	0.65	0.65	0.65	0.63	0.59	0.49	0.37	0.35	0.49	0.61	0.65	0.64
Bhubaneswar	0.61	0.62	0.61	0.60	0.57	0.41	0.36	0.36	0.42	0.52	0.58	0.62
Chandigarh	0.62	0.66	0.66	0.67	0.67	0.62	0.53	0.52	0.61	0.71	0.71	0.64
Chennai	0.58	0.64	0.66	0.64	0.58	0.50	0.45	0.46	0.49	0.47	0.47	0.52
Daman	0.69	0.71	0.72	0.69	0.66	0.52	0.45	0.48	0.57	0.66	0.68	0.67
Dehradun	0.64	0.64	0.65	0.66	0.67	0.59	0.48	0.46	0.57	0.72	0.73	0.68
Dispur	0.66	0.65	0.62	0.55	0.48	0.39	0.38	0.41	0.43	0.57	0.67	0.68
Gandhinagar	0.65	0.64	0.64	0.61	0.60	0.53	0.43	0.42	0.53	0.61	0.63	0.63
Gangtok	0.61	0.58	0.55	0.54	0.53	0.50	0.47	0.46	0.49	0.58	0.63	0.64
Hyderabad	0.64	0.66	0.65	0.62	0.58	0.45	0.40	0.40	0.45	0.53	0.60	0.63
Imphal	0.66	0.64	0.58	0.54	0.44	0.40	0.38	0.41	0.43	0.52	0.63	0.67
Itanagar	0.53	0.48	0.42	0.43	0.41	0.39	0.38	0.39	0.40	0.47	0.57	0.58
Jaipur	0.60	0.58	0.59	0.60	0.60	0.57	0.49	0.48	0.53	0.58	0.60	0.58
Kavaratti	0.66	0.68	0.68	0.65	0.57	0.45	0.46	0.50	0.56	0.55	0.59	0.63
Kohima	0.66	0.63	0.57	0.52	0.44	0.40	0.38	0.40	0.43	0.52	0.64	0.67
Kolkata	0.60	0.61	0.60	0.58	0.53	0.41	0.37	0.38	0.40	0.51	0.58	0.62
Lucknow	0.59	0.64	0.67	0.64	0.60	0.52	0.43	0.42	0.48	0.62	0.65	0.62
Mumbai	0.70	0.74	0.73	0.70	0.67	0.52	0.47	0.50	0.57	0.64	0.69	0.70
New Delhi	0.62	0.64	0.65	0.61	0.58	0.53	0.47	0.46	0.54	0.62	0.65	0.61
Panaji	0.70	0.70	0.70	0.68	0.62	0.46	0.43	0.48	0.56	0.60	0.67	0.69
Patna	0.63	0.68	0.68	0.67	0.62	0.51	0.41	0.44	0.46	0.61	0.69	0.65
Pondicherry	0.54	0.60	0.63	0.58	0.56	0.51	0.47	0.49	0.52	0.46	0.45	0.49
Port Blair	0.65	0.69	0.67	0.63	0.48	0.42	0.43	0.43	0.45	0.52	0.55	0.62
Raipur	0.63	0.66	0.65	0.64	0.60	0.44	0.36	0.36	0.45	0.59	0.64	0.65
Ranchi	0.62	0.63	0.60	0.59	0.56	0.43	0.37	0.38	0.42	0.54	0.60	0.62
Shillong	0.65	0.65	0.61	0.55	0.45	0.34	0.32	0.35	0.37	0.53	0.64	0.66
Shimla	0.63	0.61	0.62	0.64	0.65	0.60	0.50	0.49	0.59	0.73	0.74	0.66
Silvassa	0.66	0.67	0.66	0.64	0.61	0.46	0.36	0.35	0.46	0.61	0.65	0.64
Srinagar	0.59	0.61	0.62	0.65	0.66	0.65	0.55	0.55	0.64	0.72	0.70	0.62
Thiruvananthapuram	0.64	0.67	0.66	0.60	0.54	0.48	0.48	0.51	0.56	0.53	0.54	0.60

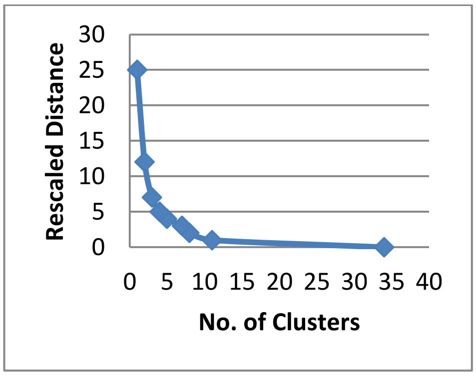

Fig. 1

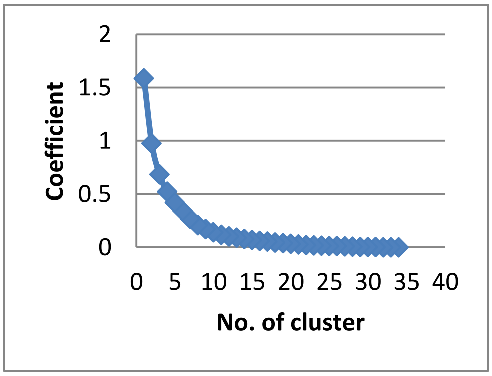

Fig. 2

5. Solar and Climatic Zones

Each of the 33 places was marked on the map of India on the geographical coordinates of the place with the help of Arc GIS and grouped according to the clustering . Arc GIS application natural-neighbour in the spatial interpolation was used to generate an initial map of the solar radiation climate by geographically extending these clusters within the map of India. To see the impact of solar classification on the thermal environment overlapping was done between the solar and climatic zones as shown in Figure 3. It can be seen from Fig. 3, that the cold climates tend to coincide with solar climatic zones with higher Kt (i.e. zones 4 and zone 5). The primary concern (in terms of thermal designs) in cold regions is heat loss and space heating during the long, severe winter months. This suggests that with good access to solar radiation, passive as well as active solar designs could play an important role in the overall energy efficient building design strategy. It can also be seen that the solar climatic zoning depends not only on the latitude (large latitude tends to have higher Kt) but also on the general climates. A brief description of the solar zones with respect to the thermal climates is as follows:

- Zone 1: It is in the north-eastern part of India situated between the Himalayas, China and Assam. This zone has mainly warm and humid climate. Solar radiation is low around 14.2 MJ/m2 with annual average Kt being 0.45, the least clearness ratio in India.
- Zone 2: It has an annual average Kt of 0.53 and an annual mean daily global solar radiation of 17.28 MJ/m2.It is found mainly around the Bay of Bengal. It is similar to zone 1 this zone has prevailing warm and humid climate along with composite climate.
- Zone 3: It is located at the southern and eastern part of India. This zone has mainly hot and warm climate with an annual average of Kt of 0.56. It has an annual mean daily global solar radiation of about 18.9 MJ/m2.
- Zone 4: This zone mainly comprises of the Central India with basin and plains. It has the largest land covering with an annual average Kt of 0.59.This zone has mainly composite climate prevailing throughout the year. It has an annual mean daily global solar radiation of about 19.22 MJ/m2.
- Zone 5: It is located at the northern part of India. This zone covers cold and composite climates. It has the highest clearness ratio in India i.e. the annual average Kt is 0.63. The annual mean daily global solar radiation is 19.34 MJ/m2.

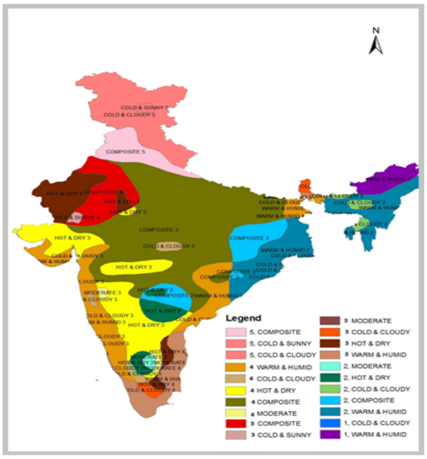

Fig: 3

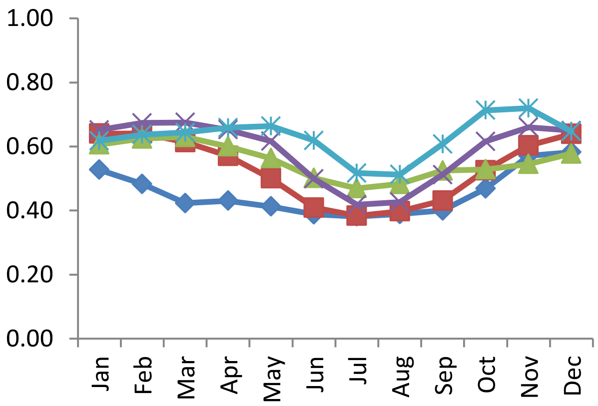

Fig: 4

6. Passive Solar Strategies and Design

The monthly average Kt of each zone was calculated and represented as shown in Fig. 4 to understand the passive design strategy. We see that all the zones follow a similar pattern but with the increasing average Kt of each zone, the Kt value have an increasing value during the traditional winter season (October-March) and decreasing Kt in the traditional summer season (April-September). In Fig. 4, in zone 1 much variation is not seen during the summer season compared to other zones so passive solar heat gain in this region would be of less impact and less considerable for this zone. This zone is in the neighbourhood of china so it resembles the passive strategies of china. Increasing trend denotes higher value of Kt which mean good access to solar radiation in areas where it is cold and hence good potential of saving energy with the use of passive solar designs. This validates with the work done earlier by M.K.Singh [8]. A decreasing trend in the Kt value is seen during the summer season due to tropical climate and pre-monsoons climate characteristic in India due to this passive strategy like internal heat gain, thermal mass with/without night ventilation and evaporative cooling are favourable throughout India. To understand the passive design strategy for each zone, bioclimatic chart were adopted based on the earlier works by Milne and Givoni [9] which evaluated the above optimum strategy.

7. Conclusion

A solar climatic map was proposed with the help of monthly average clearness ratio Kt, as a climate indicator using Wards algorithm for clustering. It is interesting to note that the mean values of all four variables differ from class to class. Therefore, the cluster technique that we used here is quite successful for defining boundaries of the climate regions. Five solar zones were identified. These zones were represented on the map of India with the help of Arc GIS. The solar map along with the climatic map was considered. Higher Kt indicating clear sky was found in cold climates and suggested the use of passive solar designs in those areas. Peak increase during the cooling season suggests that solar heat gain can be effective during the summer months. Further for more precise understanding of passive solar design, each zone can be analysed in bio-climatic chart. It suggested that if proper choice of passive solar strategies is done in the respective region, it would reduce the dependency on conventional source of energy. Although solar mapping does not assist in direct energy calculations, it still gives an idea about distribution of solar radiation availability in India and helps in planning and formulation of strategies to harness passive solar energy effectively for the quality comfort life of human beings during the initial design process.

8. Acknowledgements

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