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Analyzing various approaches for Measurement of Solar PV Potential through Urban Built Form Geometry modifications

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Abstract— In India fossil fuel are depleting fast due to ever rising population, over-exploitation, besides increasing the environmental cost. Conventional thermal power has some demerits due to the depletion of recourses, pollution, etc. Society is shifting from agricultural to Industrial / Commercial based , with modern lifestyle which leads to urbanization .Since land area is fixed multistoried buildings are growing fast. The demand for electrical energy is also increasing rapidly. This calls for other form of energy generation, especially through renewable resources. India is privileged with its geographical position closed to equator and has almost 300 days with 10hours solar irradiance with average value of 1335W/$m^{2.}$ So the urban planning with utilization of solar panels need to be incorporated together to reduce energy consumption and save fuel for the future generations. This huge amount of solar resource potential gets wasted which can be utilized by urban built form geometry modifications taking the building shape and density aspects and implementing solar panels on the roof of the buildings also. The design need to be done in a way so that maximum solar potential can be utilized and shadows due to other buildings are avoided. The main aim of this research work is to analyze various methods for calculating the solar PV potential and measure the potential of solar photovoltaic capacity..

Keywords—: Irradiance , Energy output, Solar PV Potential , Solar Radiation, and Urban Built Form Geometry

I. INTRODUCTION

Day by day fossil fuel is decreasing in India and thus it has become urgent to search alternative energy sources to meet up the present day demand. Due to rapid urbanization, all the service sectors, IT sector, shopping malls, banks offices are consuming a huge amount of electrical energy and people are shifting from agricultural based to Industrial / Commercial based society with modern lifestyle. Day by day as land is getting reduced and buildings are coming up with multiple stories, utilization of solar energy is playing a crucial role. Solar energy is clean , inexhaustible, environment friendly and a potential resource among the various renewable energy options. Sunlight is a free source of light energy which lasts for about half a day. So it has become highly important to properly utilization of this abundant source of energy by installing solar panels on the top of the buildings. These solar panels can provide the essential amount of energy required in those buildings. For installing these solar panels in the roofs, the design of the buildings in that area should be done with proper architecture because if clusters of buildings come up without inter building gap then the lower stories do not get daylight. So they need to stay in artificial lighting. Thus from energy point of view clusters of design and utilization is not a good proposition.

Urban planning with utilization of solar panels is thus needed to be incorporated together to reduce energy consumption and save fuel for the future generations. Our main aim of this research work is to estimate various methods of calculating the solar PV potential and to compare and study between different methodologies to utilize maximum Photo Voltaic potential.

II.SOLAR RADIATION DATA FOR INDIA

India lies within the latitudes of 7 degree north and 37 degree North with annual intensity of Solar Radiation between 400 and 700 cal/cm^2/day. Most part of India receive 4-7 kWh/m^2/day of solar radiation with 250 – 300 sunny days in a year. The direct normal Solar Radiation can be shown in figure 1. [Therefore solar radiation is a

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key factor determining electricity produced by the photo voltaic (PV) systems which is usually obtained using Geographical Information System(GIS)].[1]

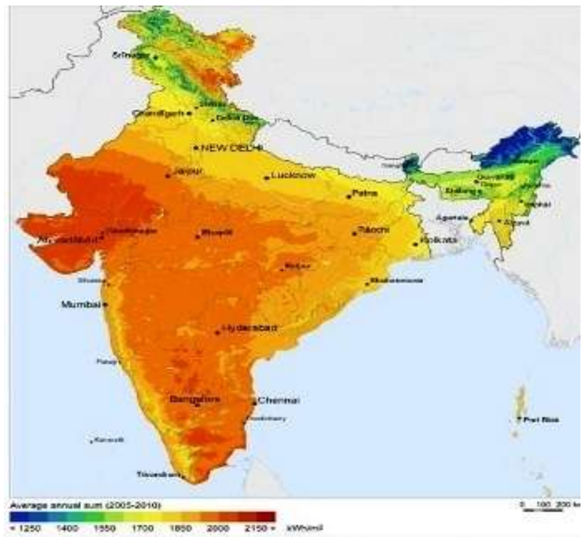

Fig 1: Solar Radiation Map in India

III. SOLAR ENERGY

[The average solar radiation towards the earth on average is 1367 W/m^2 but due to absorption or scattering of molecules in the atmosphere, the maximum level that reaches the earth is 1000 W/m^2][2]. The solar radiation towards a horizontal plane is typically divided into direct, diffuse and ground reflected radiation, where direct radiation is the radiation that is not intercepted by any obstructions or clouds and diffuse radiation is blocked by clouds and objects and then reflected .

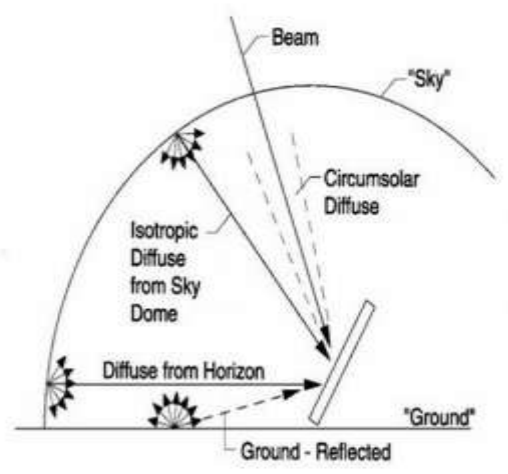

Fig-2:Solar radiation types towards a tilted surface

The solar irradiation towards a horizontal or inclined surface differs depending on the latitude of the place .For understanding the amount of solar irradiance in India, the geographical position of our country is needed to be considered. There is a huge resource of solar energy that can be obtained from India due to its geographical location from 8 degree North to 36 degree North latitude. The sunlight duration in Kolkata, India is quite high with average sunrise time 5:12a.m. in the morning and sunset time 5:59p.m. in the evening.

The longest day is on 22nd June with sunrise time at 4:53a.m and sunset time at 6:25p.m.The shortest day is on 22nd of December with sunrise time at 6:12a.m. and sunset time of 16:57p.m. This huge amount of solar resource potential gets wasted which can be utilized by taking the building shape and density and implementing solar panels on the roof of the buildings.

IV. SOLAR RADIATION MEASUREMENTS

The solar radiation data bank can be obtained by the use of the following instruments:

a)Pyranometer: The pyranometer measures global or diffuse radiation on a horizontal surface. It covers total hemispherical solar radiation with a view angle of 2π steridians.

The pyranometer designed by the Eppley laboratories, USA, operates on the principle of thermopile. It consists of a black surface which heats up when exposed to solar radiation. Its temperature rises until the rate of heat gain from solar radiation equals the heat loss by conduction, convection and radiation. On the black surface the hot junctions of a thermopile are attached, while the cold junctions are placed in a position such that they do not receive the radiation. An electrical output voltage (0 to 10mV range) generated by the temperature difference between the black and white surfaces indicates the intensity of solar radiation. The output can be obtained on a strip chart or on a digital printout over a period of time. This is a measure of global radiation.

The parameter can also measure diffuse sky radiation by providing a shading ring on disc to shade the direct sun rays. The shading ring is provided with an arrangement such that its plane is parallel to the plane of the sun's path across the sky. A continuous record can be obtained either on an electronic chart or on an integrated digital printout system. As the shading ring blocks a certain amount of diffuse sky radiation besides direct radiation, a correction factor is applied to the measured value.

b) Data acquisition system for measurement of solar radiation: This system does not require an instrument

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operator to measure the radiation data. With a personal computer(PC), the system uses an analog to digital conversion(ADC) card, which serves as a vital interface between the sensor and the PC to obtain analog data from the sensor. The data so received is processed in the PC with appropriate software.

The radiation falling on the pyranometer generates thermo- electric emf which is fed into one of the channels of the ADC card provided with the PC. The numerical value of the instantaneous voltage in the digital form is stored in the Programmable Peripheral Interface(PPI). A printout of a solarflux can be obtainrd by processing the data. The block diagram of such a radiation measuring system is as follows:

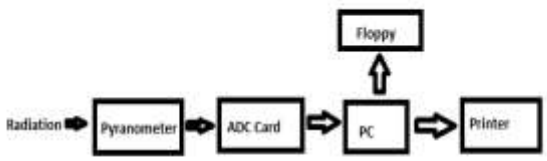

Fig-3: Block Diagram of a radiation measuring system

c)Pyrheliometer: A pyrheliometer is an instrument which measures beam radiation on a surface normal to the sun's rays. The sensor is a thermopile and its disc is located at the base of a tube whose axis is aligned in the direction of the sun's rays. Thus, diffuse radiations are blocked from the sensor surface. The pyrheliometer designed by Eppley Laboratories, USA, consists of bismuth silver thermopile with 15 temperature – compensated junctions connected in series. It is mounted at the end of a cylindrical tube, with a series diaphragms(the aperture is limited to an angle of 5.42 degree). The instrument is mounted on a motor - driven heliostat which is adjusted every week to cover changes in the sun's declination. The output of the pyreheliometer can either be recorded on a strip chart recorder or integrated over a suitable time period. The pyrheliometer readings give data for atmospheric turbidity and provide a clearness index.

d)Sunshine recorder: The duration in hours of bright sunshine in a day is measured by a sunshine recorder. It consists of a glass sphere installed in a section of spherical metal bowl, having groones for holding a recorder card strip. The glass sphere is adjusted to focus sun's rays to a point on the card strip. The glass sphere is adjusted to focus sun rays to a point on the card strip. On a bright sunshine day, the focus image burns a trace on the card. Through the day the sun moves across the sky. The images move along the strip. The length of the image is a direct measure of the duration of bright sunshine.

IV. THE PHOTOVOLTAICTECHNOLOGY

The photovoltaic effect is a direct conversion of light into direct current electricity using a PV panel. [The PV system consists of one or more PV modules connected either directly to the electricity load (off-grid), either to the electricity network (grid-connected)][3].Apart from the PV modules, in most cases the system consists of an inverter to convert the power from a direct current (DC) to an alternating current (AC) in order to be able to utilize the generated electricity. If the system is off-grid, then a storage battery is required in order to provide electricity during periods with low or no solar radiation. If the system is grid-connected, then a storage battery is not required, as long as the unused electricity can be fed-in to the grid.

In an urban environment, PV systems are normally connected to the electricity grid. Their application or integration in buildings is steadily growing, especially for building integrated PV systems (BIPV), placed on the facades, opaque or semi-transparent glass-glass, shading device integration, different types of roofs, PV roof tiles (IEA-PVPS, 2014). However, according to IEA-SHC Task 41 (2013), [one of the main barriers for implementing PVs in buildings is the lack of architecturally attractive products, which implies for further developments to improve the flexibility in size, colour, and surface texture which would increase the attractiveness of the PV products][4].

There are several types of PV panels, with varying efficiency and cost, however the most commonly used, representing the largest fraction of the PV cells market are the crystalline silicon cells with efficiency between 15-20%. [In an urban context the panels can be shaded by surrounding buildings, vegetation or other objects, which could lead to significant loss in efficiency, which consequently would decrease the output. This is due to the fact that the cells inside the module are connected in series, which means that if a cell is shaded this will lead to current failure in the whole string. In order to reduce the effect of shading, bypass diodes can be used to redirect the current to flow in another path and thus allow for the other cells to operate][5] .

[Another cause of shading that needs to be considered is the mutual shading of the panels when placed on a flat roof. Kanters&Davidsson (2014) performed a study on the total solar potential and economic consequences of mutual shading of PV systems, where they examined different tilts and row spaces of the panels in Lund, Sweden. The research revealed that the effect of mutual shading significantly reduces the output of a model when the row distance is smaller than 1m (Kanters&Davidsson, 2014). It

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was also concluded that the maximum annual energy output of a flat roof is reached when the system had an inclination of 0° and row distance of 0 m, due to the fact that there is no overshadowing, as well as due to lack of distance between the panels lead to a greater system size. However, such inclination is not practically possible because it introduces problems of snow and rain runoff (Kanters&Davidsson, 2014). Additionally, inspection and maintenance is not possible, due to the lack of row spacing. Based on current electricity prices, the shortest payback time of a system was registered to be at an inclination of 30° for Lund, which resulted in a smaller system size and subsequently smaller electricity output (Kanters&Davidsson, 2014).][6]

A high ambient temperature and solar radiation heating up the PV panel have a negative effects on its efficiency and its production (Gomes et al., 2013). With an increased panel temperature the band gap becomes smaller and the extraction of voltage is reduced, leading to a decrease in the cellefficiency.[The whole system is also subjected to other losses such as inverter losses, DC and AC cable losses, soiling and others (NREL, 2015).][7]Different approaches to utilize the photovoltaic energy arediscussed herein after .

V.EXISTING METHODS OF SOLAR PV & BUILT FORM ANALYSIS

1.[Thestudy on Solar and Daylight Availability in the Urban Fabric,by R Compagnon, University of Applied Science of Western Switzerland presented the method to quantify the potential of facade and roof in urban areas by obtaining the irradiation and illuminance values. They have used the sky model and used the radiance lighting simulation software and 3D building models to compute the solar potential.][8].

2. [Another essential work was the new integrated Urban Modeling Environment (UMI- an Urban simulation Environment for Building energy use, Daylighting and Walkability byChristoph, et al. MIT,Department of Architecture, USA) . The basic approach of UMI is similar to suntool and it mainly aims the Young City Projects. It has used the WINDOWS based NURBS modeler Rhinoceros as its CAD modeling platform, EnergyPlus for thermal building-by building simulations, Daysim for daylight simulations and custom Python scripts for workability evaluations.][9]

3. [In another approach the tool is a plug-in for the Rhinoceros3D CAD modeler and follows a two-step workflow. During the initial step, hourly solar radiation levels on all facades within an urban scene are simulated based on Radiance/Daysim. During the second step, exterior radiation levels are converted into hourly interior illuminance distributions using a generalized impulse response. Climate based daylighting metrics, such as daylight autonomy, are also computed.The results yielded by the new method are carefully compared to regular and substantially more time-consuming Daysim simulations][10].

4. [There is another methodology which comprises solar simulation of eighteen generic models; each represents a particular combination of built form and density. This paper examines the relationships between built forms, density and solar potential, with reference to three design criteria i.e. openness at ground level, daylight factor on building façade and PV potential on building envelope. The result shows the different effects of horizontal and vertical randomness on urban solar potential and it also reveals the interrelation between randomness, plot ratio and site coverage, which can provide helpful insights for planning solar cities][11].

5. [The methodology that we shall be using for our study is SAFAR (Suitable Area to Floor Area Ratio).The aim of this study is to bring further knowledge to the solar potential metric SAFAR, which was introduced by Kanters& Wall (2014). In their study, Kanters& Wall (2014) partly looked into the effect of early urban planning design decisions, where form density, orientation and roof type were examined.][12]

VI. COMPARATIVE STUDY

The best method among these methodologies which has been inculcated in this paper is the Suitable Area to Floor Area Ratio. In this method the urban planning is done taking care of the floor Space Index, urban Density and Compactness Ratio of the Action Areas for the Urban Planning. Then the irradiance is obtained based on the sky model. The parameters are then put in the RADIANCE Software by which the photovoltaic potential of the area under the solar panel is calculated through simulation.

The drawback of the first technique is that it only takes care of the illumination considering the roofs as well as facades. In SAFAR the photo voltaic potential is being calculated taking care of the FSI Solar Planning. Thus the facade areas can be utilized for plantation or other essential purposes.

In the second method Rhinoceros as its CAD modeling platform, ENERGYPLUS for thermal building-by building simulations, DAYSIM for daylight simulations and custom Python scripts for workability evaluations. Four different tools were required to obtain the PV potential and that too

was obtained in form of DayLight and Thermal Energy. In SAFAR the PV Potential was obtained directly from the RADIANCE Software.
Other parameters like the Space Index, Urban Density, Compactness Ratio are considered while doing the architectural planning of the city.

Name of Methodology	Software Used	Approach
Study on Solar and Day Light Availability in Urban Fabric	RADIANCE - Lighting simulation software	Obtaining irradiance and illuminance values
UMI-an Urban Simulation Environment for Building Energy Use	CAD modeling platform Energy plus Daysim	Daylight and Heat Calculations
Urban DayLight Simulation Calculating the daylight of Urban Designs	3D CAD Modeller DAYSIM	Hourly solar radiation by DAYSIM Software. Climate based daylighting Metric.
Urban Form Density and Solar Potential	Eighteen Generic Models	Examines relationship between built form and density.
SAFAR	RADIANCE Software	Suitable Area to Floor Area Ratio is considered

The third method is a lengthy method on which hourly solar radiation levels on all facades within an urban scene are simulated. The observations may get hindered due to climate changing phenomenon like rain or storm. SAFAR Methodology is free from such obstructions.

The fourth method comprised of eighteen generic models comprising a built form and density. The daylight factor and PV potential was then studied and compared between the different built form models. In SAFAR methodology the urban planning is made according to the urban density and Compactness ratio of the city to be planned utilizing the maximum amount of Photo Voltaic Potential. This Urban density is essential parameter for urban planners regarding sustainability in cities. [Increasing the density in cities reduces the energy for transportation, as well as optimizes the land use, however, building density also directly affects the solar access and daylight, what consequently leads to an increase in the heating demand and use of artificial lighting (O'Brien et. al, 2010)][13] . Therefore, considering building density at the early design phase is important for creating a balance between solar access, daylight and energy use.

VII. CONCLUSIONS

In this paper a comparative study has been done among the different approaches to understand the potential of solar PV potential in urban planning. The best method among these which was suggested to be used for further work is the Suitable Area to Floor Area Ratio. Comparative studyshowing the pros and cons of all the given methodologies has been made in this paper. The future work aims in obtaining the irradiance in the action area based on the SAFAR model.The floor Space Index, urban Density and Compactness Ratio of the Action Areas will be calculated and analyzed with Radiance software for understanding the dependence of Solar PV potential on urban built form geometry modifications. The parameters can be used in the Radiance Software to calculate the photovoltaic potential of the area under the solar panel by simulation. Thus an energy efficient urban planning approach can be made by utilizing the non-conventional photovoltaic energy.

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DESIGNS 1 Harvard Graduate School of Design, Cambridge, MA 2 Massachusetts Institute of Technology, Cambridge, MA www.urbandaylight.de

[11]Vicky Cheng1 , Koen Steemers1 , Marylene Montavon2 and Raphaël Compagnon3 Urban Form, Density and Solar Potential, 1 Department of Architecture, The Martin Centre, University of Cambridge, UK 2 Solar Energy and Building Physics Laboratory (LESO-PB), EcolePolytechniqueFédérale de Lausanne, Switzerland 3 University of Applied Sciences of Western Switzerland, Ecoled'Ingénieurs et d'Architectes de Fribourg, Switzerland.

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