ESTIMATING THE ROOF TOP SOLAR POTENTIAL OF DTU CAMPUS

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CANDIDATE'S DECLARATION

I, Ashutosh Kumar, Roll No. 2K17/ENE/04 student of M. Tech (Environmental Engineering), hereby declare that the project Dissertation titled "ESTIMATING THE ROOFTOP SOLAR POTENTIAL OF DTU CAMPUS." which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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I hereby certify that the Project Dissertation titled "ESTIMATING THE ROOFTOP SOLAR POTENTIAL OF DTU CAMPUS." which is submitted by ASHUTOSH KUMAR, 2K17/ENE/04, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Abstract

Renewable energy is being seen as a transformative solution to meet energy as well as climate challenges, both globally and nationally. Solar photovoltaics (PV) technology is emerging as an extremely attractive option, particularly with abundantly available solar resource, modular technology and zero fuel costs for alternative source of energy. The accessibility of shadow-free rooftop region is one of the greatest difficulties in deployment of rooftop solar PV system.

In this study three step methodology is adopted to find the total roof top solar PV potential and total solar insolation of DTU campus.

In the first step, the calculation of the potential rooftop area available on DTU Campus was done by relying exclusively on freely available satellite imagery (Google Maps, Google Earth, and Wikimapia). The open source instruments are sufficient to estimate the rooftop potential of locations without the need for costly satellite imagery or time-consuming and complex image processing algorithms. In the second step the 3D model of the building is created and the shape and size of shadow area is found at different time to calculate total shade free region. The shadow is mainly due adjacent buildings or due to objects on roof. In the third step, we further revised the estimate using 3D simulation and shading analysis of building clusters to identify discounting factors that account for inter-building shading. The total solar insolation for the topography of the DTU campus is also determined in Arc Map.

The total shade free region from 2D mapping is 38099.3 square meter and from 3D simulation is 37112.8 square meter the maximum and minimum deviation in shade free region from both methods are 12.3% and -13.60% respectively. The total solar radiation on the rooftop is found to be 10201.33 MWh/year while the Photovoltaic potential is 3711.28kWp. The total solar radiation for the topography of DTU campus is found to be 58.5 GWh.

Keywords: Renewable Energy, Solar Radiation, Solar PV potential, GIS, SAR,

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Chapter 1

Introduction

1.1 General

Energy is an important input for economic development and for the improvement of quality of life. Earth is estimated to be blessed with huge energy, categorized as conventional and non-conventional sources, for the generation and use of electricity. Conventional energy sources are rapidly depleting and its scarcity is at top priority throughout the worldwide, where harnessing renewable energy appears to be one of the sustainable ways to satisfy the growing worldwide requirements for electricity.

One way to achieve viable development is to produce electricity through cleaner and more promising solar energy. Among other renewable energy sources, Solar has the biggest energy potential.

India is one of the leading nations with excellent Direct Normal Irradiance (DNI), which depends on geographic place, earth-sun motion, Earth rotational axis tilt and atmospheric attenuation owing to suspended particles. India is projected to have an enormous solar energy capacity of around 5000 trillion kWh per year. The incident of solar radiation over India is equal to 4–7 kWh per square meter per day with annual radiation varying from 1200–2300 kWh per square meter. It has an average of 250–300 clear sunny days and 2300–3200 sunshine hours per year.

In India, the solar energy sector has seen exponential growth over the past five years and we expect it to grow in the same way over the next decade or so with various national and regional pro-solar policies in place. In particular, a large number of initiatives under JNNSM's umbrella are boosting the solar PV sector. The Government of India has announced a revised target of 100 GW of solar PV by 2022, out of which 40 GW must be achieved through decentralized grid-connected rooftop systems. A significant quantity of these rooftop structures are anticipated to occur in the country's multiple urban and semi-urban centres to achieve the targets prescribed by the Ministry of New and Renewable Energy (MNRE). More importantly, it becomes essential to create a conventional methodology for estimating solar installation potential on the rooftop. This' resource assessment' is the primary step in city-level planning of distributed solar power plants on the rooftop. A quick and reliable assessment of available rooftop areas, classified according to the existing category of power consumers-residential, commercial and industrial users-can assist planning authorities in drafting effective regional rooftop solar policies and in designing implementation processes.

1.2 Solar resource availability for Delhi.

Solar irradiation is the amount of radiant solar energy available per unit area and is usually expressed as kilowatt-hours per square meter per day (kWh / m2/day). As sunlight flows through the atmosphere, only some of it hits the ground, with the remainder being reflected, absorbed and dispersed. The quantity actually reaching the surface relies on a number of variables such as latitude, season, time of day, air quality and other environmental conditions (e.g. clouds, aerosol particles, etc.). These radiations can be used to produce energy through techniques such as solar PV systems. According to the RET Screen database, Delhi's average solar irradiation is about 5 kWh / m2/day34. Such a level of solar irradiation is good, but not as high as it is to be expected due to the high levels of dust in the city. The world's largest irradiation is 7-8 kWh / m2/day in, for instance, North Africa. Delhi's solar irradiation is smaller than that of India's western and southern states, such as Rajasthan, Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, and Karnataka, which have an average 6-7 kWh / m2/day irradiation and are regarded to be the country's most appropriate solar areas. But the town of Delhi gets greater irradiation compared to many other world cities.

Delhi borders Haryana on the north, west and south, and Uttar Pradesh on the east. The National Capital Territory's complete land area is around 1,484 km^2 with about 700 km^2 of constructed area. Delhi's constructed area / raw rooftop room that is possibly accessible for solar power generation is around 119 km^2. Raw rooftop space includes only built structures that can accommodate the size and weight of solar installations. From this, the estimated, genuinely accessible solar-suitable rooftop space is about 31 km^2, which could fit 2,557 MW of solar power41. The solar-suitable rooftop space is the unblocked and shadow-free rooftop region that gets optimal sunlight for this purpose.

The residential buildings of Delhi constitute 49 percent of the solar potential and Industrial buildings have 15 percent of the total potential. Government buildings, commercial buildings, and government and semi-public equipment have 13 percent, 10 percent, and 13 percent, respectively, of complete capacity. Transport facilities such as airports and railway stations have only 0.1 percent of the potential-but they can do excellent pilot projects.

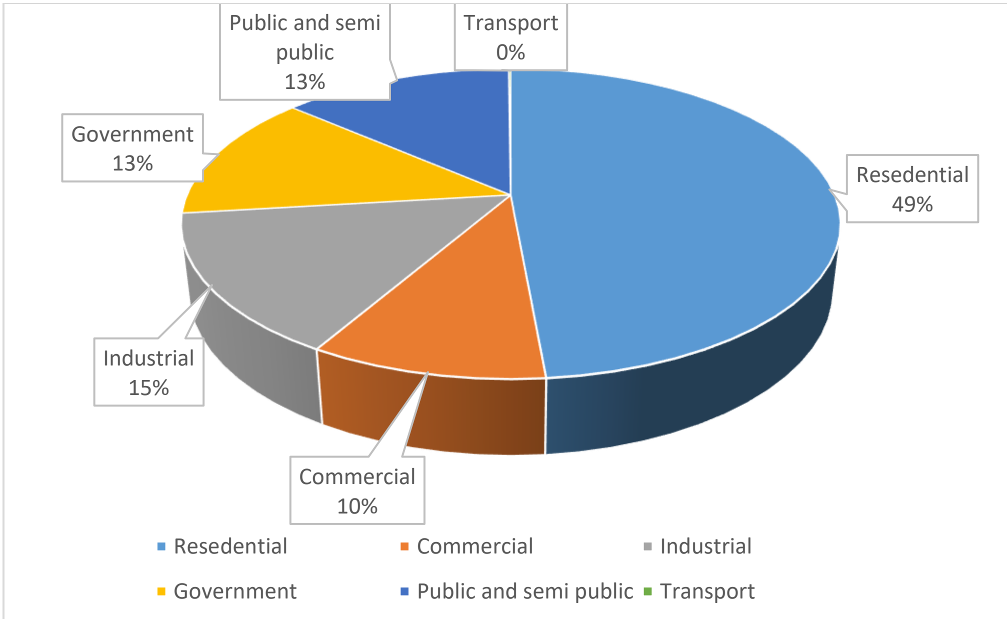

Figure 1.1 Solar Rooftop potential at different sector in Delhi (Source:DDA master plan 2021)

1.3 Solar Radiation Modeling

Incoming solar radiation (insolation) originates from the sun; is adjusted as it passes through the atmosphere; is further adjusted by topography and surface characteristics; and is intercepted at the earth's surface as immediate, diffuse and reflected elements. Direct radiation is intercepted unimpeded from the sun in a direct row. Diffuse radiation is dispersed by atmospheric constituents such as clouds and dust. Reflected radiation is reflected from surface characteristics. The sum of direct, diffuse and reflected radiation is referred to as total or global solar radiation.

Generally speaking, direct radiation is the biggest element of complete radiation, and diffuse radiation is the second biggest element. Reflected radiation generally represents only a small proportion of total radiation, except for locations surrounded by highly reflective surfaces such as snow cover. In Spatial Analyst, the solar radiation instruments do not include reflected radiation in the complete radiation calculation. The complete radiation is therefore calculated as the sum of the direct and diffuse radiation.

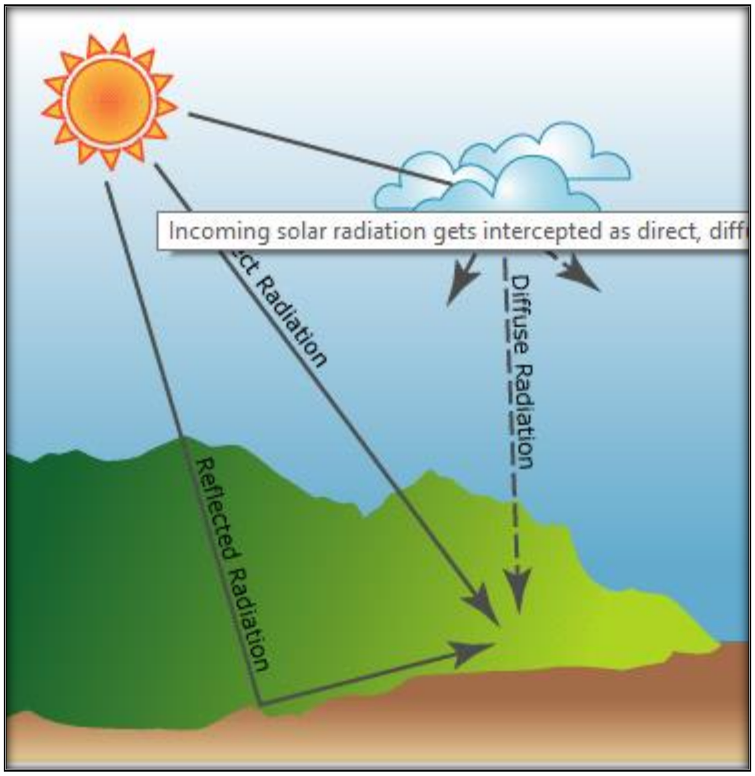

Figure1.2 Direct, diffuse and reflected part of incoming solar radiation

Solar radiation instruments can conduct calculations for point places or entire geographic regions.. This includes four steps:

1. Calculating a topography-based upward-looking hemispheric viewshed.
2. Overlay of the viewshed to estimate direct radiation on a direct sun map.
3. Overlay of the viewshed to estimate diffuse radiation on a diffuse sky map.
4. Repeat the process to generate an insolation map for each place of concern.

Since radiation can be greatly affected by topography and surface features, a key component of the calculation algorithm requires the generation of an upward-looking hemispheric viewpoint for each location in the Digital Elevation Model (DEM). The hemispheric views are comparable to upward-looking hemispheric (fisheye) photos that view the whole sky from the floor up, analogous to the perspective in a planetarium. The quantity of visible sky at a place plays an significant part in the insolation. For example, a sensor in an open field has higher insolation than a sensor in a deep canyon.

1.4 Objective of the study

To find the solar radiation map of the DTU campus using GIS tools.

To estimate the total ‘builtup area’ of the DTU campus using different web tools(such as Google Earth, ArcMap, SketchUp).

To Measure the ‘shade free region’ for each building and calculate the average plot area to shade free rooftop area ratio.

To create 3D models for the buildings at the plot level and calculate the rooftop solar potential of each building in Revit Software using SAR plugin.

1.5 Methodology adopted.

Use of Google Earth Pro:

The tool used for mapping the area is “polygon tool” in Google Earth Pro version , in google earth pro the measurement of area can be done by plotting the rooftop area in polygon shapes in high resolution satellite imagery.

Use of Autodesk’s Revit and Solar Analysis Plugin:

Revit is usually used by architects and structural engineers for Building Information Modeling (BIM). This software offers a plugin called Revit Solar Analysis (SAR). Using this plugin, we can visualize and quantify the distribution of solar radiation in different regions (roof, wall and ground) of a construction by taking into consideration the shading impacts of neighboring objects such as vegetation and surrounding structures in an urban environment.

The building’s 3D models were developed in Google SketchUp which is further imported to Revit at actual georeferenced axis and annual solar insolation on the roof top is calculated

Chapter 2

Literature Review

Bridge to India previously published a report in the year 2013 for Delhi City's rooftop solar potential. In this study, Google Earth is used to identify and estimate rooftop potential. Wikimapia has also been used to classify the construction category. The research widely categorized buildings and constructed regions in Delhi into three classifications–residential, commercial and industrial. The research found that the estimated rooftop potential of all these construction classifications is up to 2 GW. Similar methodology was applied to calculate Patna's rooftop solar potential by Bridge to India in its second report the rooftop solar PV capacity of the town of Patna was estimated at 759 MW.

2.1 Modeling of incoming solar radiation

It can be concluded that the most important factor influencing the generation of photovoltaic electricity is the amount of incoming solar radiation. Solar radiation, or insolation, is the energy of the sun touching the surface of the earth. It consists of three parts: direct beam, diffuse and ground-reflected radiation (Perez et al. 1987).

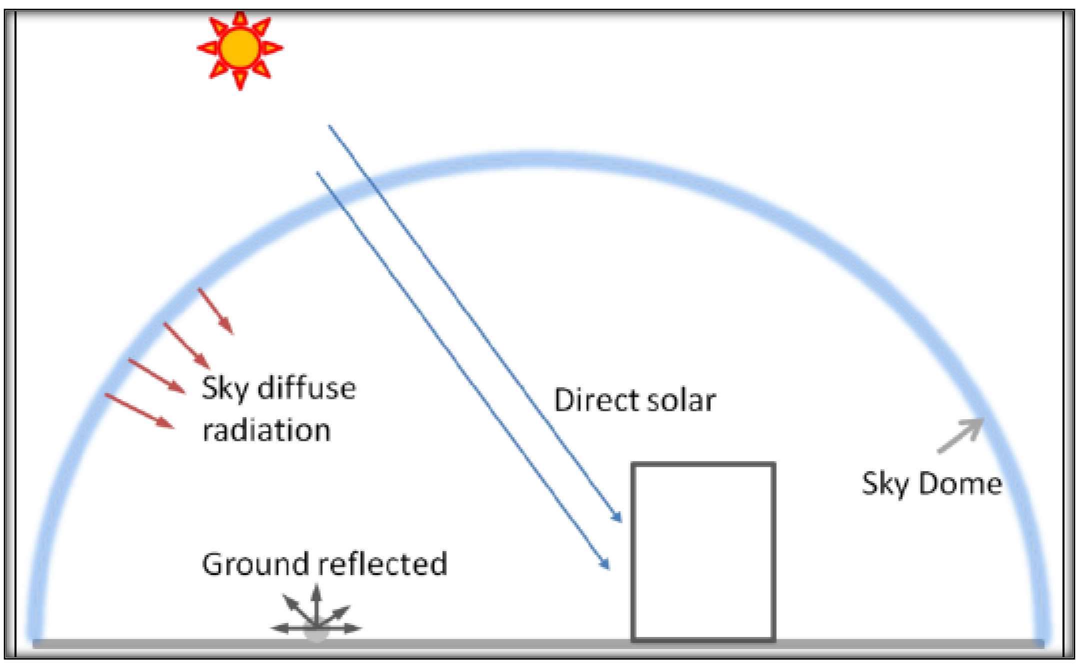

Figure 2.1Different component of incoming solar radiation(Source: International Building Performance Simulation Association 2011)

Direct radiation is the direct beam of solar energy that is intercepted by the ground without any interaction with particles in the air (Hetrick, Rich and Weiss 1993). Diffuse radiation is the intercepted radiation that is dispersed in the atmosphere by gases and aerosols (Hetrick et al. 1993; Kumar, Skidmore and Knowles 1997). Reflected radiation is reflected from the ground and surrounding surfaces (Kumar et al. 1997, Esri 2013a). Direct, diffuse and reflected radiations together constitute worldwide radiation or complete radiation reaching the surface.

The amount of solar radiation that reaches the surface depends on location, atmospheric effects, and topography. Solar radiation is influenced by the geometric rotation and revolution of the earth around the sun (Fu and Rich 1999). It also varies with environmental factors such as atmospheric attenuation effects including cloud cover and water vapor (Fu and Rich 1999). On the ground, topographic effects such as elevation, slope and orientation affect the amount of radiation reaching a surface (Kang, Kim and Lee 2002; Súri and Hofierka 2004).

Understanding the quantity of solar radiation reaching a surface is more crucial than just assessing the potential of renewable energy. Nearly all human actions rely on the strength of the sun (Fu and Rich 1999). Unfortunately, measured insolation information are incomplete for most geographical regions or are only accessible on a very coarse scale (Fu and Rich 1999). Solar radiation information are evaluated at a number of ground stations around the globe, but since solar irradiation concentrations can differ dramatically with terrain, vegetation, ground structures and climate, in most instances it is not precise to use the closest weather station in one's assessment.

2.2 Modeling of incoming solar radiation by GIS tool

Over the past two centuries, the use of geographic information systems tools has improved several empirical solar radiation models. The quicker processing capacities connected with GIS systems allow the inclusion of advanced solar radiation models and extra consideration of the impacts of topography on incoming solar radiation (Dubayah and Rich 1995). GIS instruments enable the user to examine the temporal and spatial variability of landscape-level incident solar radiation (Rich et al. 1994).

Integrating solar radiation models within GIS has helped eliminate the complexity of programming GIS functions into mathematical models (Nguyen and Pearce 2010). In addition, GIS solar radiation models can also incorporate environmental and socio-economic datasets for scenario modeling of interest to policymakers (Nguyen and Pearce 2010).

SolarFlux is one of the initial GIS based designs (Súri and Hofierka 2004). It was implemented as an ARC Macro Language (AML) program in the ARC / INFO platform (Dubayah and Rich 1995). This tool simulates the influence of shadow patterns on direct insolation at specific time intervals (Helios Environmental Modeling Institute, LLC 2000). It utilizes the input of a topographic surface with elevation values, latitude, calculation time interval, and atmospheric circumstances (Dubayah and Rich 1995). The output given displays direct radiation flux, direct radiation length, skyview factor, and diffuse radiation flux for each surface place (Dubayah and Rich 1995). While initially implemented on a multitude of temporal and spatial scales, Súri and Hofierka (2004) illustrate how Solarflux utilizes easy empirical formulas in which input parameters are averaged and therefore do not perform well when calculating over big fields.

Esri's Solar Analyst was created to draw on the strengths of precise point-specific radiation models while rapidly and accurately producing insolation maps over a landscape region (Helios Environmental Modeling Institute, LLC 2000). It is conveniently accessible as part of the Spatial Analyst expansion enabling simple integration with other analytical instruments available in Esri's ArcGIS.

Solar Analyst calculates solar radiation using the hemispheric viewshed model originally developed by Rich in 1990 and later enhanced by Fu and Rich (1999). A viewshed is the distribution of the obstruction of the sky or the view of the sky looking upward from each point on the floor (Helios Environmental Modeling Institute, LLC 2000).

The model calculates the viewshed for each cell in the digital elevation model input as the topography-based visible sky changes (Fu and Rich 1999).

2.3 Calculating Rooftop Area

As explained by Jakubiec and Reinhart (2012), two of the most important components for calculating PV potential include the amount of solar radiation reaching the surface and the amount of usable rooftop area that can be dedicated to photovoltaic panels.

A number of studies have outlined methods for analyzing building or rooftop shapes. In many cases, the methodologies relied heavily on the existence of high-resolution satellite or remotely sensed imagery. For the most advanced analysis, it is ideal to have 3D models in which individual buildings are represented next to other objects such as trees and man-made structures. Nguyen et al. (2012) clarify how precise construction generation from Light Detection and Ranging (LiDAR) information involves a number of procedures including construction detection, object segmentation, roof shape reconstruction, and performance modeling analysis. These methods are often only feasible with high price information and software for recognition of features. In some instances, current construction shape or outline data sets are also used to help with construction identification and segmentation (Nguyen et al. 2012).

I.Salvador, R.Marcos and F.Norberto created a rooftop solar potential assessment technique using a statistically representative stratified sample of vector GIS maps of metropolitan areas. They have suggested a three-level hierarchical methodology in which first the area's physical potential (how much solar energy is incident) is viewed followed by geographical potential (out of the complete geographical area, how much region can be regarded for the deployment of rooftop solar energy harnessing equipment) and technical potential (considers the equipment's technical capacity).

They also suggested the option of adding 2 more coefficient levels–for the discount region used for other uses such as aerials, HVAC facilities, etc.The research was conducted on the scale of the smallest administrative or municipal level and then aggregated the data to the main administrative divisions and eventually to the national level.

Jo and Otanicar (2011) propose a methodology for quantifying the usable rooftop surface by taking into account existing obstructions such as chimneys, air conditioning equipment and skylights that would limit the space available for PV panels. They use remotely sensed Quickbird pictures processed by Definiens Developer software along with current construction shapefiles for the four-square mile research region in Chandler, Arizona (Jo and Otanicar 2011). The object-oriented analysis uses brightness indices to define obstructions on the rooftops and then calculates the shadow impacts connected with these objects (Jo and Otanicar 2011).

2.4 Calculating Photovoltaic Potential from Solar Radiation

Understanding the accessible solar radiation and rooftop region are vital elements when calculating the potential of photovoltaic electricity, but there are also technological factors to be taken into consideration. These include efficacy, tilt, and proper maintenance of the photovoltaic panel. In addition, it is necessary to account for losses during conversion from direct current (DC) produced by photovoltaic to useable alternating current (AC).

A number of simulation tools have been developed to help understand the variability associated with PV potential. Some of these specifically complement the solar energy GIS models mentioned in the prior chapter, while others use interpolated solar radiation surface data sets. Choi et al. (2011) explain how these efforts have helped overcome existing barriers to implementing PV penetration by providing information needed for design, financing, and operation of PV systems.

Hofierka and Kanuk (2009) a used the PVGIS estimation utility for their evaluation of photovoltaic potential in metropolitan regions. They propose a comparable formula (given below) in which the complete annual electricity production in kWh for a scheme is evaluated by the following equation:

$E_{out} = A_e E_e G$

Where E_{out} is the annual electricity production in kWh, A_e is the total surface area of solar cells in square meters (m^2), E_e is the annual mean power conversion efficiency coefficient for each PV technology, and G is the annual total global irradiation (Wh/m^2).

Jakubiec and Reinhart (2012) suggest derating panel efficiency based on ambient temperature, as temperature is known to adversely affect panel production. In their latest research at the Massachusetts Institute of Technology, they integrated research conducted in the PVWatts Calculator Version 2 of the National Renewable Laboratory to construct the following equations for the approximate derivation of PV panels based on temperature.

and point irradiation data at an hourly time step (Marion et al. 2001; Luque and Hegedus 2011; and Jakubiec and Reinhart 2012).

$$T_C = T_{amb} + (T_0 - 20°C)E/800Wm^{-2}$$

Where T_C is the photovoltaic panel temperature °C, T_{amb} is ambient temperature in degrees Celsius (°C), T_0 is the nominal operating cell temperature at ideal conditions °C and E is the incident radiation in W/m^2 at each time step.

$$P_{mp} = P_{mp0} \text{ X } [1 + \gamma^* (T_C - T_0)]$$

Where P_{mp} is the derated panel max DC power in watts (W), P_{mp0} is the photovoltaic maximum power at ideal conditions (W) and **γ^*** is the temperature correction factor equal to 0.0038 °C.

Chapter 3

Methodology

3.1 TOTAL SOLAR INSOLATION

With landscape scales, topography is a significant factor that determines insolation's spatial variability. Variations in elevation, orientation (slope and aspect), and shadows cast by topographic characteristics all influence the quantity of insolation obtained at distinct places. This variability also changes with moment of day and time of year and in turn adds to microclimate variability including variables such as air and soil temperature regimes, evapotranspiration, snow melt patterns, soil moisture, and light required for photosynthesis.

The solar radiation assessment tools in the ArcGIS Spatial Analyst extension allows to map and evaluate the sun's impacts over a geographic region for particular time periods. It accounts for atmospheric impacts, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal sun angle changes, and shadow impacts cast by surrounding topography.

The total incoming solar radiation of entire DTU Campus is determined in Arc Map software by following these steps

- Input the DEM profile of the study area.
- Specifying the time setup (period) used to calculate solar radiation i.e the whole year for this study
- The time interval through the year (units: days) used to calculate sky areas for the sun map is set for a complete year default value of which is 14 days

The output of the analysis is in units of watt hours per square meter (WH/m^2) and the file data type is raster

The given figure represent the steps which is followed during analysis the numeric represent the steps no.

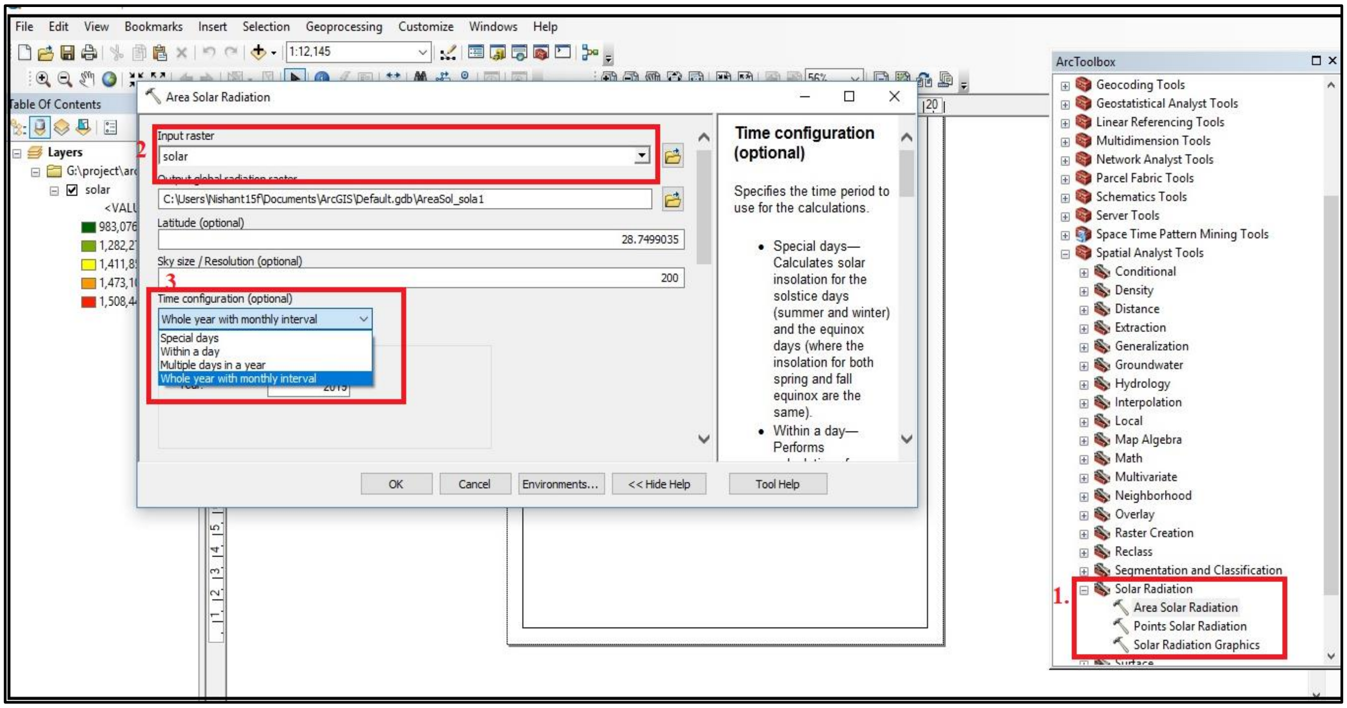

Figure 3.1 Steps for estimation of solar insolation over DTU Campus

3.2 ROOFTOP SOLAR RADIATION POTENTIAL

The methodology used in the study for rooftop solar radiation potential estimation do not include the existing utilisation of solar PV by various buildings in the campus.

Therefore, based on ideas from the review of literature on previous studies, a methodology is adopted that includes a three-step assessment to estimate the rooftop potential of the DTU campus. The first step of this methodology is to carry out a two-dimensional (top view) mapping of the campus using the Google Earth Pro. The mapping method involves manual sorting of the 2D top view satellite images into different kinds of buildings. Using appropriate sampling techniques, we ensure that all the buildings are represented in the mapping method. Building footprint area is thus obtained after the mapping.

Then the percentage contributing to the shadow free region appropriate for PV installation is calculated from this coverage area. For this the 3D model is built at actual georeferenced location in SketchUp software and the shape and size of determined by using shadow option in at different time of the day

The data obtained is then transmitted into the third stage, which is a 3D modeling and shading analysis of building clusters. This enables in figuring out the discounting factors to be regarded while calculating the rooftop PV potential owing to inter-building shading, particularly in densely built-up regions with variable building heights. A methodology flowchart is shown in Fig.   The different stages of the methodology and associated tools used and the methods of execution are explained in the sections following the flowchart.

3.2.1 MAPPING OF BUILDING STRUCTURE IN DTU CAMPUS

PLOT AREAS: A' plot' is generally a part of land with a physical border and one or more structures under single ownership. Plot area involves parking spaces, gardens, pools etc. within the limits of a developed plot. As an instance, Figure 3.2 shows the plot area of DTU campus mapped using Google Earth.

Figure3.2 Plot area of DTU Campus

COVERAGE AREAS: This involves the 'building footprint area ' of structures with appropriate rooftops for installation of solar PV systems within the plot limit. For instance, Figure 2.3 displays the coverage region for DTU campus within the plot region.

Figure3.3 Building footprint area of DTU Campus

USE OF GOOGLE EARTH POLYGON TOOL:

The most significant tool used in mapping is the Google Earth's polygon tool. This tool is accessible in Google Earth's professional version. We can access this tool by creating an account and then signing in. There are two benefits of Google Earth professional version. Firstly, region measurements can be done as polygons and secondly, high-resolution pictures can be accessed. Figure 3.3 demonstrates the sequence of plotting DTU Campus area using the polygon tool.

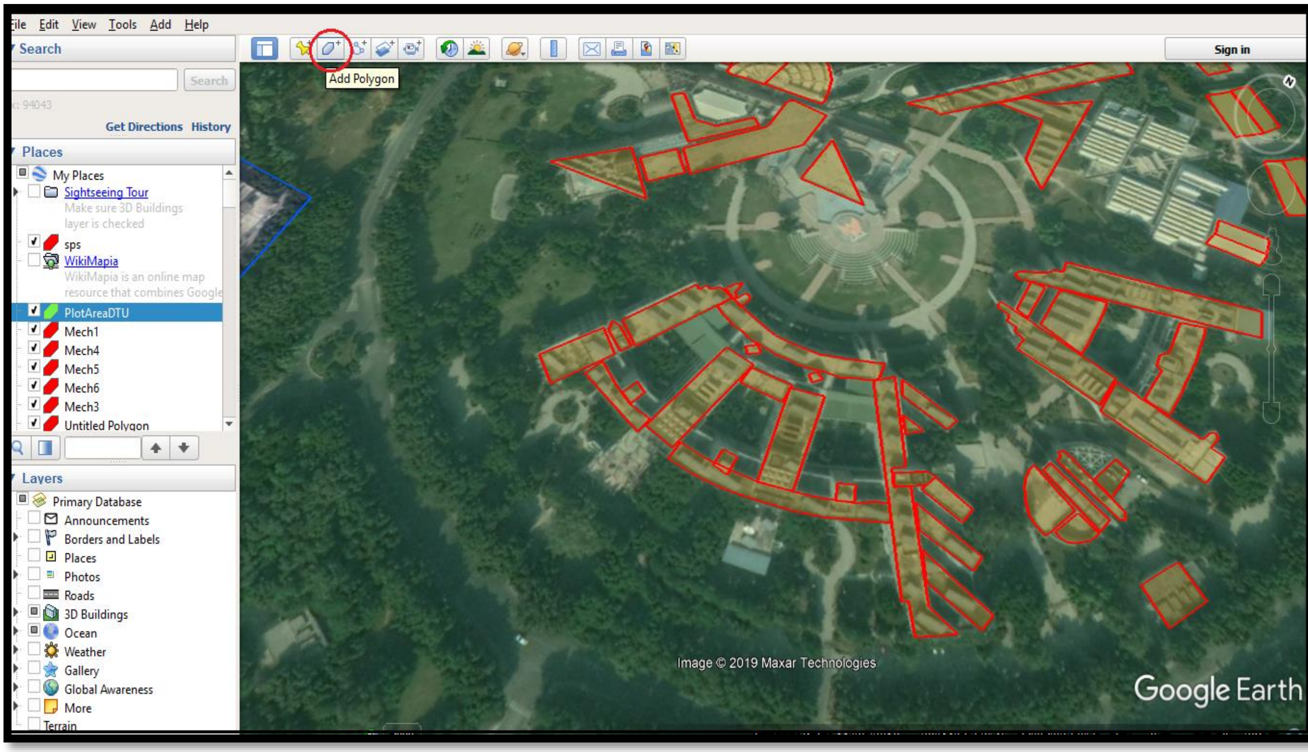

Figure3.3 *Step 1* Mapping using polygon tool in Google Earth

The mapped region area can be computed in square meter or square kilometre or in any of the 8 choices available in the tool drop-down list, for this study the area is measured in square meter. The region within the polygon can be filled with distinct colors (whose RGB value can be provided as input) and varying' opacity rate.

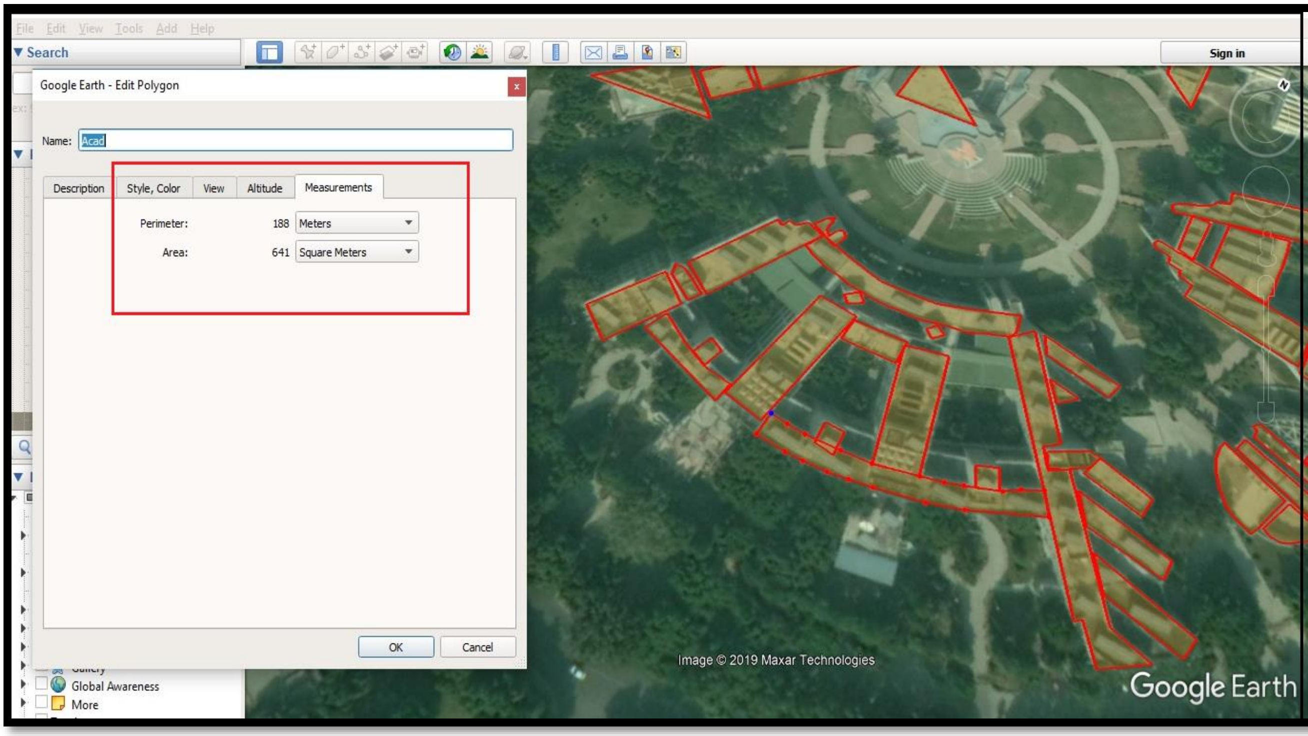

Figure 3.3 Step 2 Measurement of mapped area in square meter

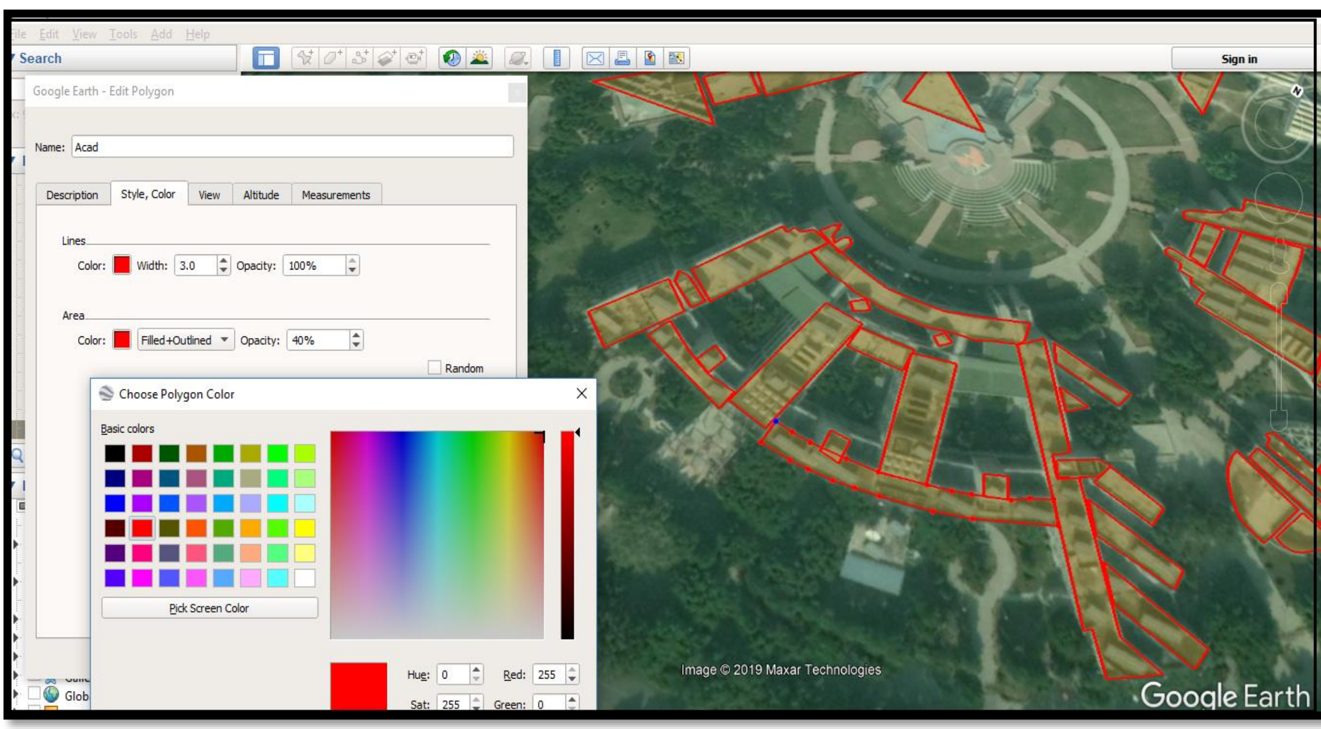

Figure3.3 Step 3 Applying area fill colour and outline colour to polygon

USING WIKIMAPIA PLUGIN IN GOOGLE EARTH:

Wikimapia is an open content collaborative mapping project that utilizes crowd-based collection of locations tagged by registered users and visitors to define locations on satellite maps[21]. Wikimapia offers a plugin file that can be incorporated into Google Earth Pro and can be activated and disabled by pressing the checkbox on its side. Once activated, the plugin overlays all the information and polygons mapped by users of Wikimapia about the region being found using Google Earth. Figure 2.12 displays overlaid polygons from Wikimapia for the DTU Campus. It can be seen that by clicking on the checkbox, the Wikimapia plugin is activated.

Figure 3.4 Overlay from Wikimapia on Google Earth Image

3.2.2 DETERMINING THE SHAPE AND AREA OF SHADOWS.

SHADE FREE AREAS: Shade free area is the real area appropriate for installing PV modules. This is the region acquired by excluding the rooftop shaded regions. We need to consider shading items such as ventilation of chillers and ACs, elevator shafts, water heater systems, water tanks, etc. and exclude the rooftop region around these objects while measuring the' shadow free area.'. If there is a shading object on the rooftop, then by using the shadow option in SketchUp software the shape and area of the shadows formed are calculated.

USING SketchUP

The 3D model of each building structure visible in satellite image is created at actual georeferenced location.

The plan or top view of each structure is created by outline the top view of the structure then "push/pull" option is exercised to create the final 3D structure

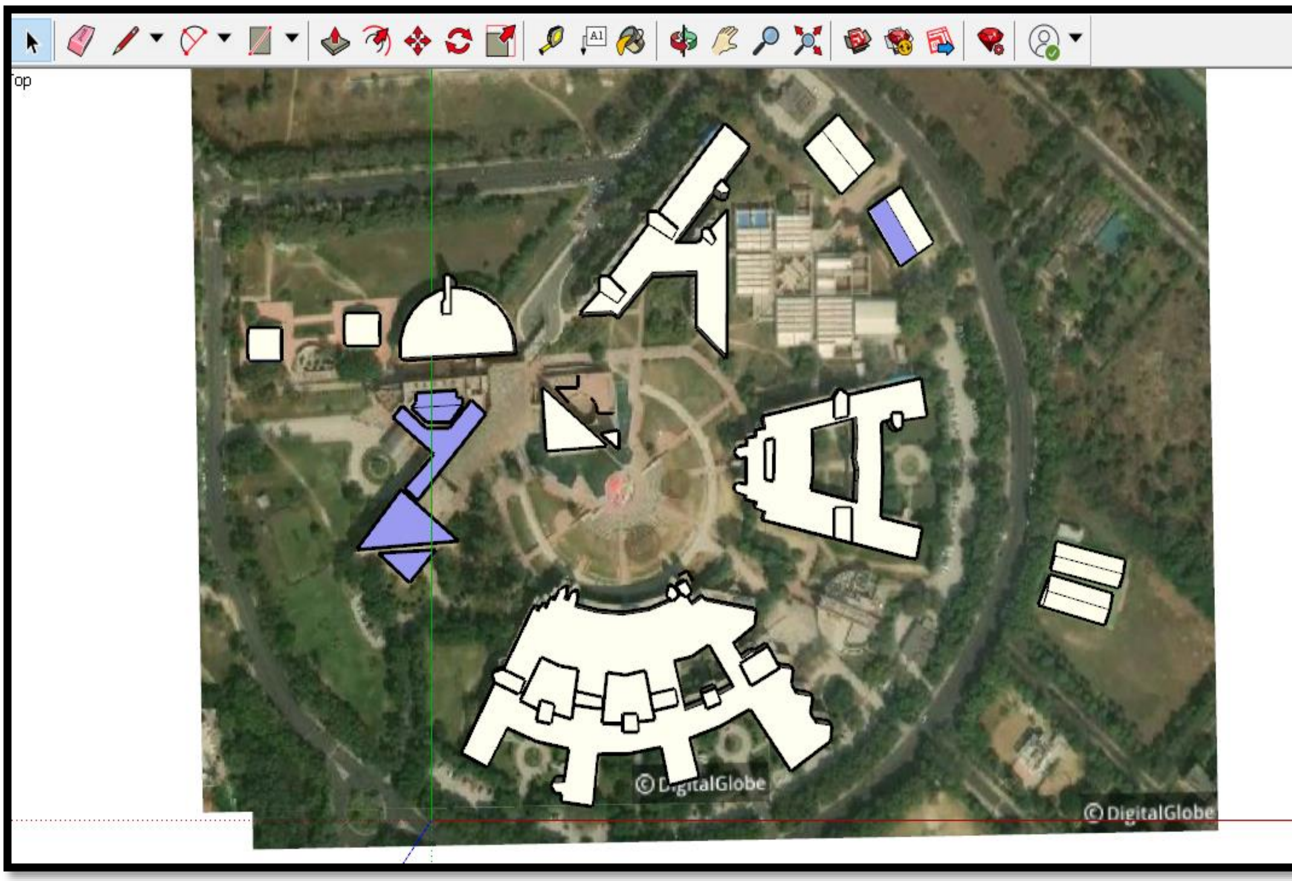

Figure3.5 Creating 3D model in sketchup over actual georefrenced satelite image

For calculating the shape and area of shadows formed the time zone corresponding to Delhi is chosen which is UTC+5:30 and the calculation was done at morning(900 hours) and evening(1700 hours) for a specific day in summer and winter.

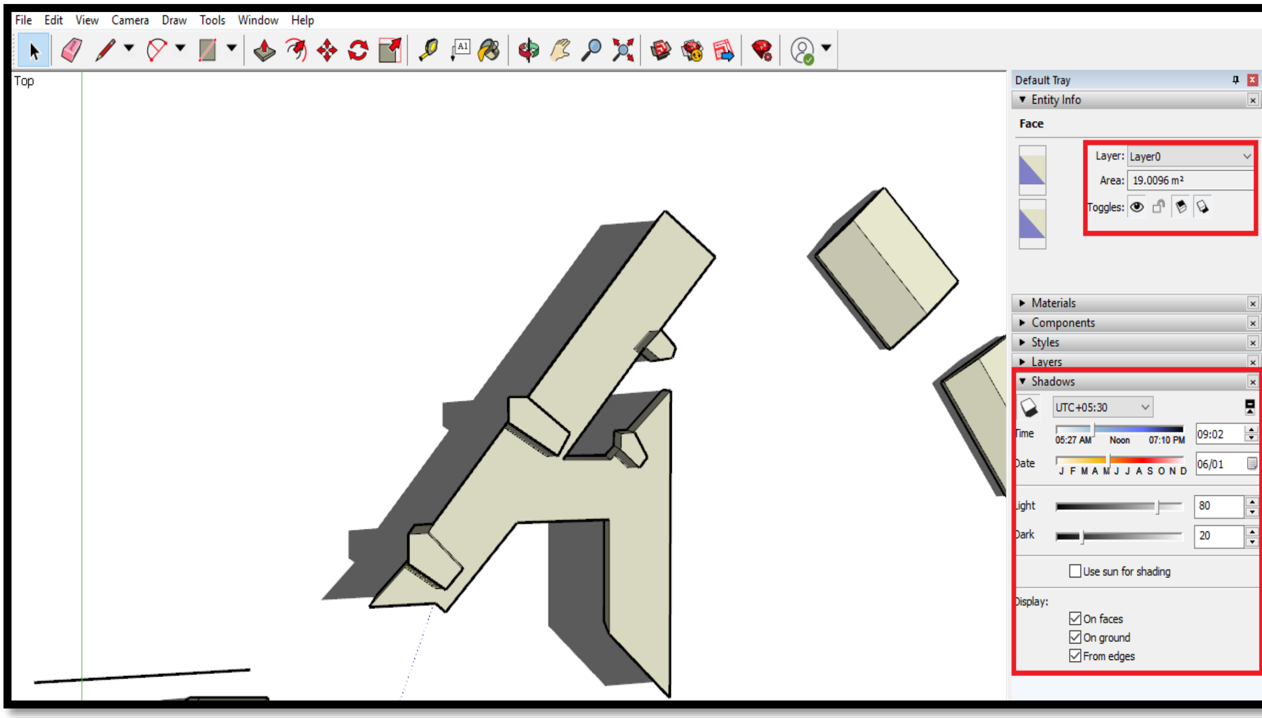

Figure 3.6 Determining the shape and area using shadow option in Sketchup

Calculation of coverage area to plot area ratio

The ratio of the total coverage area of all buildings within the plot to the total plot area is called ' Coverage area to Plot area ratio ' or ' C / P ratio. ' This enables the plot area to be converted to coverage region.

Calculation of shadow free area to coverage area ratio

The amount of shadow free area is calculated after discounting the shaded regions on each rooftop inside the plot area The proportion of the complete shadow free region to the complete coverage region within a plot provides an indication of how much rooftop area is translated into' solar appropriate' region. This ratio can be called' Shade free area to coverage zone ratio' or' S / C ratio.' The amount of the shade-free region from separate structures on the campus plot at DTU is 37400m^2. This demonstrates that nearly 90.9 percent of the university campus coverage region contributes to an region appropriate for rooftop PV installation. so we can consider the S / C ratio to be 0.909.

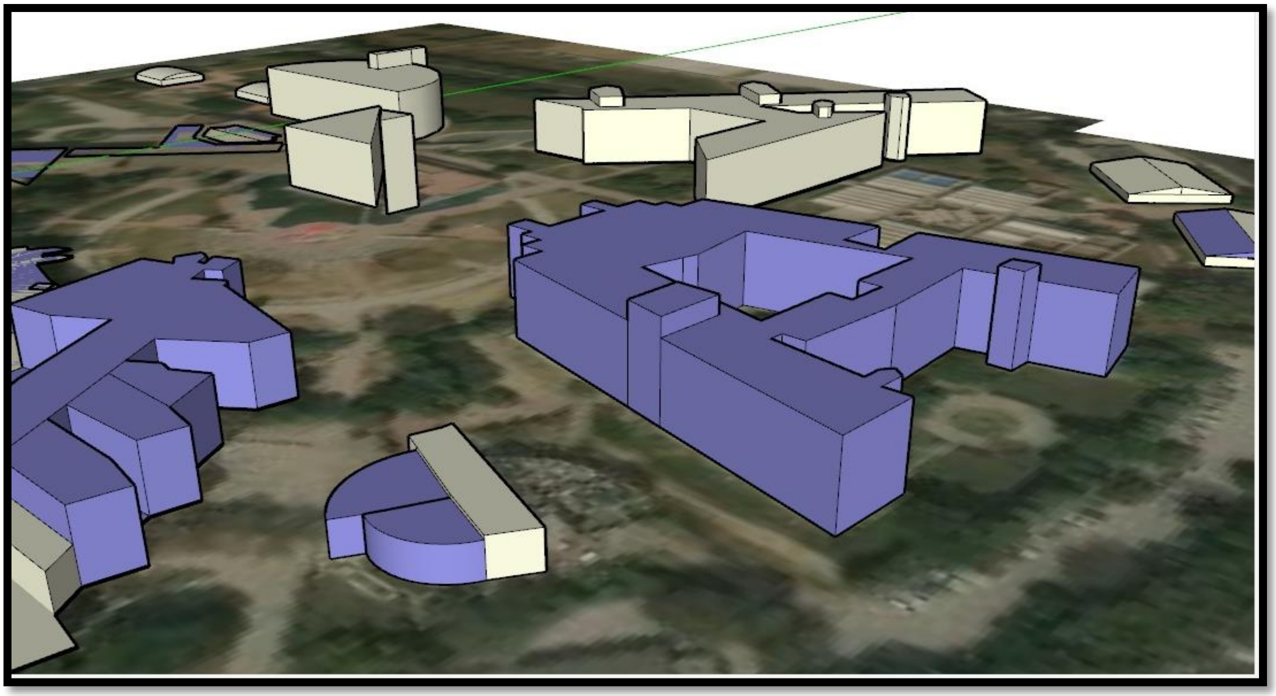

Figure 3.7 3D Model of Academic Blocks

Figure 3.8 3D Model of Hostel

3.2.3 3D MODELLING AND INTER BUILDING SHADING ANALYSIS

In the step 1, the probable rooftop region for entire DTU campus was calculated using only 2D mapping in Google Earth. Since this method does not consider the shading impacts of neighboring buildings on a specific rooftop (as opposed to shading induced by constructions on that rooftop itself), the region so far discovered would be an over-estimate. A 3D modeling and simulation analysis was carried out on almost each building structure of campus for better understanding. 3D modeling and shading simulation was carried out using the licensed student version of the Revit software created by Autodesk Inc.

USING AUTODESK REVIT AND SOLAR ANALYSIS PLUGIN

Revit is usually used by architects and structural engineers for Building Information Modeling (BIM). This software offers a plugin called Revit Solar Analysis (SAR). Using this plugin, we can visualize and quantify the distribution of solar radiation in different regions (roof, wall and ground) of a structure by taking into consideration the shading impacts of neighboring objects such as vegetation and surrounding structures in an urban environment.

3D model of each building in campus was developed in Google SketchUp. The 3D model developed were imported to Revit and georeferenced according to actual location and the total annual solar insolation is determined. Within a specified time period, insolation values can be incorporated over a year using this software. Simulation time period from 9 AM to 5PM was considered for the study. It was presumed that the irradiation concentrations are relatively high during this time period and that shadowing (if it occurs) will be prominent. The software also splits the region under simulation into grids of required cell area units. The plugin also helps to export the simulation results to an external spreadsheet (of CSV format) containing the insolation values information for each cell in the grid. Each grid size of 2 square meter is selected for simulation.

After simulation, we get insolation visualization with color coded rooftop region (insolation values are scaled, color coded and filled in each cell). Figure demonstrates the simulation output for an academic building.

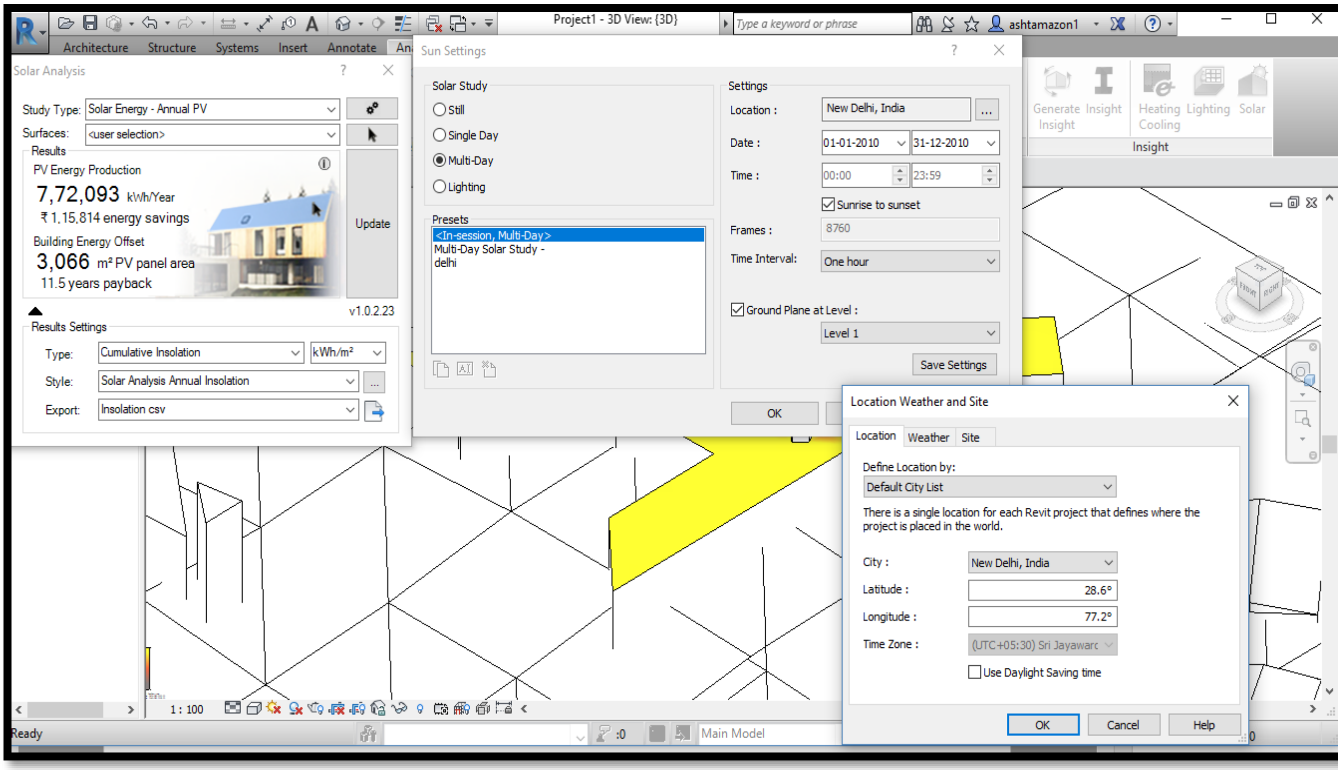

Figure 3.9 Use of SAR plugin to calculate PV energy of rooftop

The cells with this peak annual insolation value can be characterized as cells without much shading. If we count the number of cells with this maximum value, we can get the total shadow free area for the rooftop in square meter (From 1 cell= 2 sq. m).

The insolation values are scaled and color coded between grey and yellow in Figure 2.7. Grey refers to an insolation value of 800 kWh / square meter per year. Bright yellow refers to a value of 1618 kWh / square meter per year for academic block.

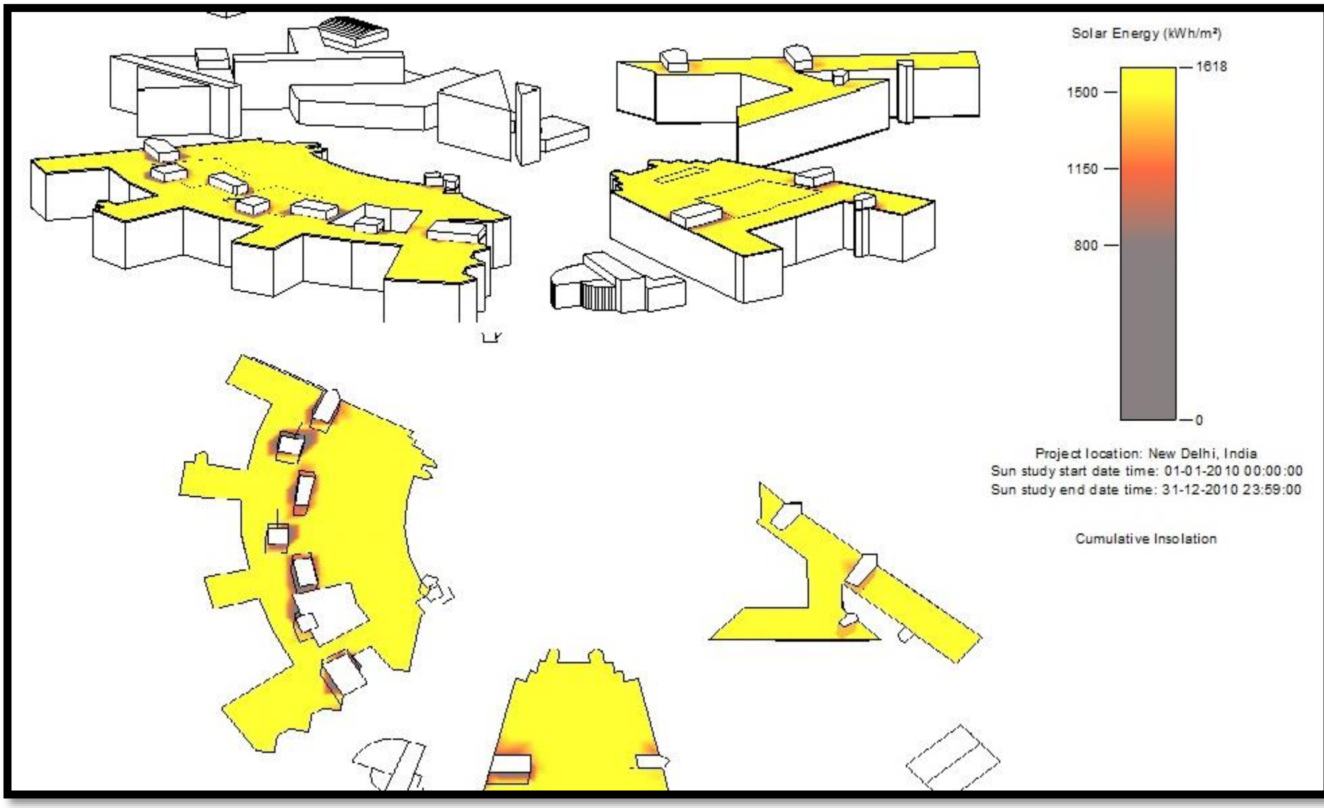

Figure 3.10 Solar simulation result for academic block in top and isometric view

When the heights of the buildings did not vary greatly between clusters, the shading on the roof is mainly due to the roof structures of the buildings themselves When there is a substantial distinction in the height of the structures within a cluster, the inter building shading becomes prominent as shown in Figure 3.11

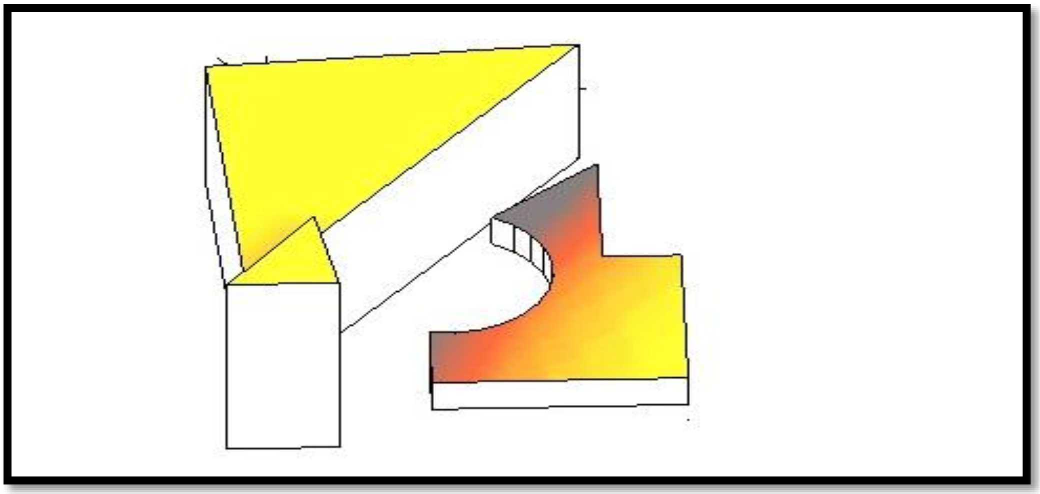

Figure 3.11 Solar simulation result for different building height

CHAPTER 4

RESULTS & DISCUSSION

The total solar radiation on the entire DTU campus is mapped in GIS environment using Area Solar radiation tool of Arc Map, the entire area is classified in 5 group of radiation value(in KWh/m2). The range of value of each group is represented in the Table 4.1 and the mapped area is represented in Figure 4.1

Table 4.1 Classification of solar radiation and its corresponding area

Classification	**Range(KWh/m^2)**	**Area(m^2)**
Very High radiation	1508.446 - 1583.835	82912.23
High radiation	1473.107 - 1508.446	487009.1
Medium radiation	1411.853 - 1473.107	60483.9
Low radiation	1282.278 - 1411.853	10234.2
Very Low radiation	983.076- 1282.278	1633.80

The minimum radiation in the study area is 983.07KWh/m^2 ,the maximum is 1583.8KWh/m^2 and the total radiation recived by the entire campus is 58.5 GWh. The mean solar radiation is 1490.83 KWh/m^2 and its standard deviation is 29.4 KWh/m^2

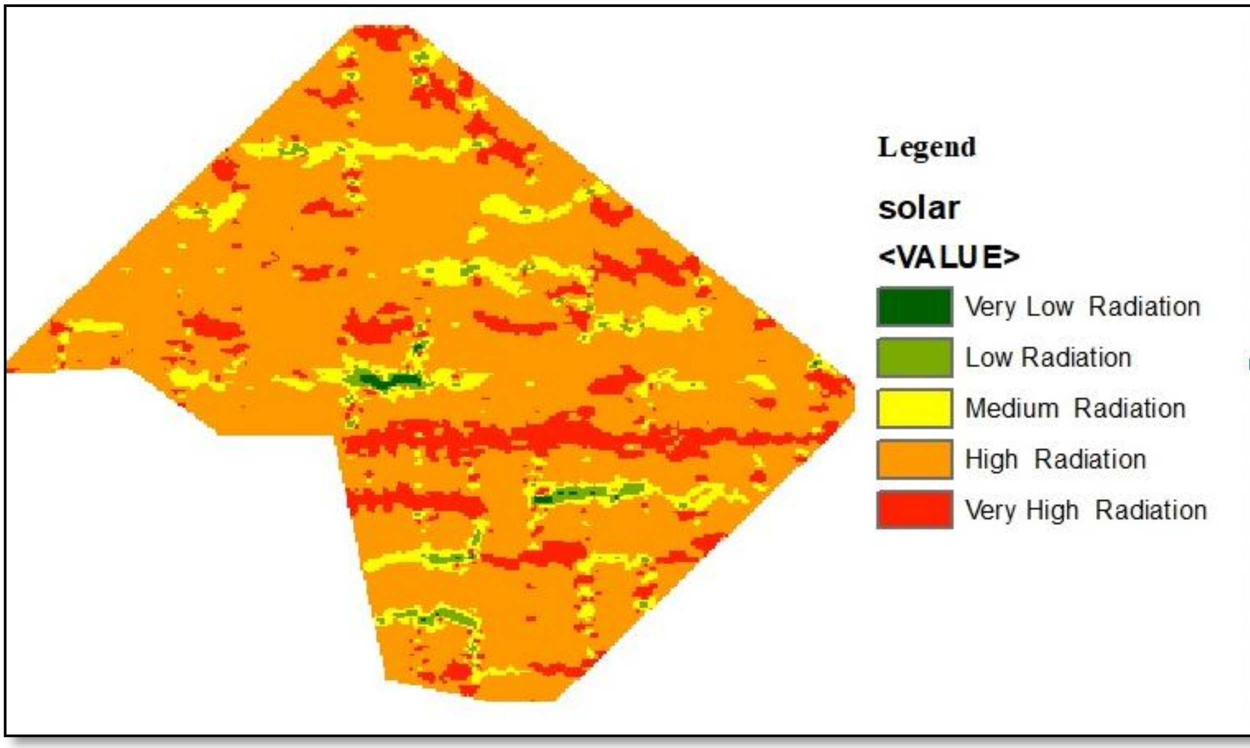

Figure4.1 Solar Radiation map of DTU Campus

The figure 4.2 shows the pie chart of area distribution of the solar radiation for the entire campus which shows that the maximum area receives high radiation (1473.107 - 1508.446 KWh/m^2) and it is 75% of the total area and less than 1% of the area receives very low radiation(983.076-1282.278 KWh/m^2)

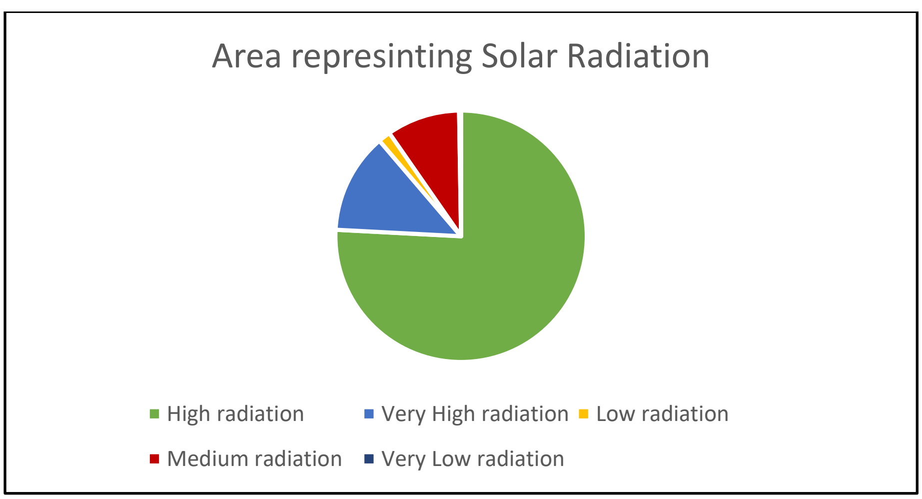

Figure4.2 Area representing different range of Solar Radiation

4.2 Estimation of rooftop solar radiation potential by 2D mapping

4.2.1 Plot area and building footprint area

The 2D mapping of entire DTU campus is done to find the total plot area as defined in previous section 2.2.1 the total plot area of the DTU is found to be 647394m^2, and having a perimeter of 3581meter.

The total 'building footprint area ' of structures with appropriate rooftops for installation of PV system is determined. The table 4.2 represents the building footprint area for each type of structure in the campus in square meter.

Table 4.2 Building Footprint area of Structure within campus

Building Structure	**Area from 2D mapping(m^2)**
Academic	18046
Administration	3457
Library	1656
Training & Placement	1000
Canteen	782
Hostel	3310.7
Residence Block	9794.8
Sps Hall	3086

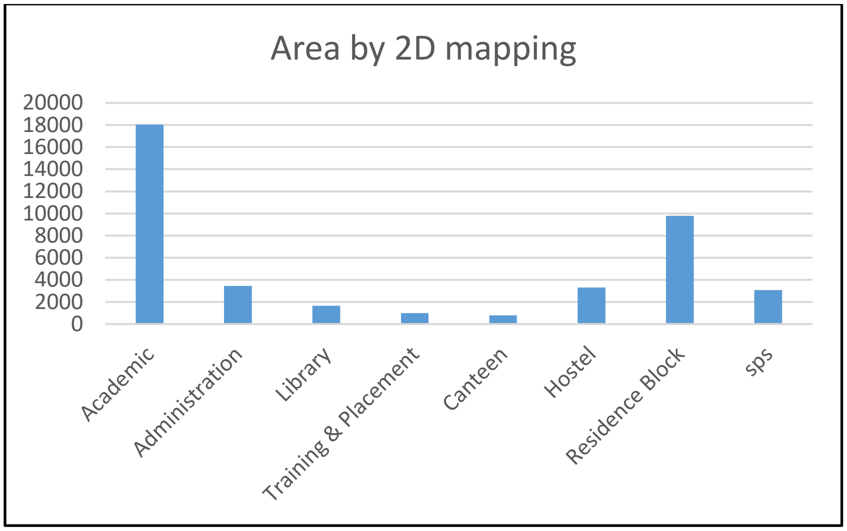

Figure 4.3 Area of different buildings from 2D sampling

From the figure we can conclude that Academic Block has maximum area(18046m^2) available for PV installation and the canteen has minimum area (782m^2) for PV installation.

4.2.2 Shade free area

The 3D model is created in the Sketchup software and the shape and size of shadow formed due to shading items such as ventilation of chillers and ACs, elevator shafts, water heater systems, water tanks, etc, After knowing the total shaded area the shade free region for installation of photovoltaic (PV) is also determined the table 4.3 represents the total shadow area and shade free region of each building structure in the campus. The figure 4.4 shows the percentage of shadow and shade free region.

Table 4.3 Shadow area and shade free region by 2D mapping

Building Structure	**Shadow Area**	**Shadow free Area**
Academic	1353.45	16692.55
Administration	641.75	2815.25
Library	162.03	1493.97

Training & Placement	67.1	932.9
Canteen	66.73	715.27
Hostel	421.67	2889.03
Residence Block	1019.46	8775.34
Sps Hall	0	3086

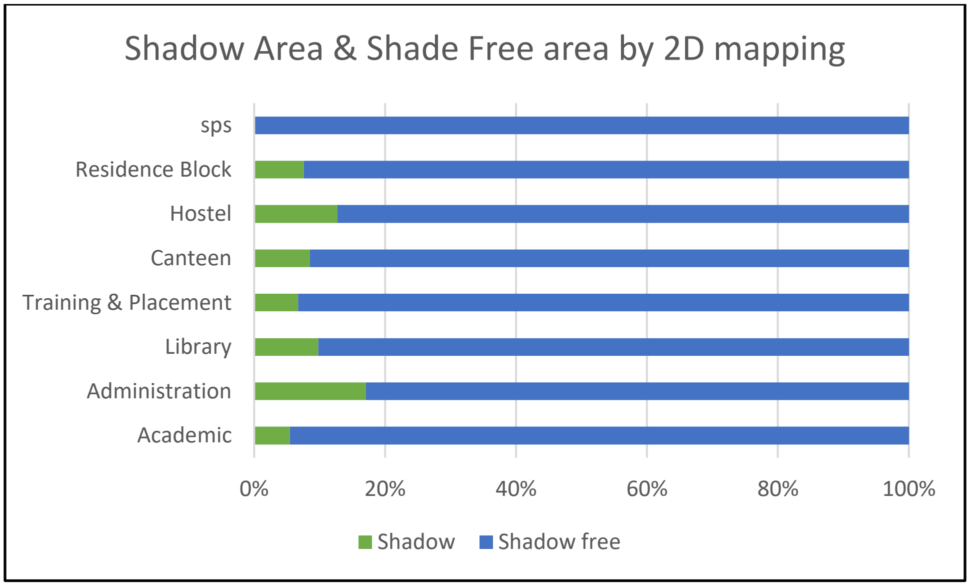

Figure 4.4 Shadow and shade free region by 2D mapping

From the analysis it is determined that the total building footprint area is 41132 m^2 and the shadow area is 3033m^2 and the shade free region is 38099.3m^2

Coverage area to plot area ratio (C/P) of DTU campus is 0.063535 and the shadow free area to coverage area ratio (S/C) is 0.909264.

4.3 3D MODELLING AND INTER BUILDING SHADING ANALYSIS

4.3.1 Rooftop area of Building by 3D simulation.

The SAR plugin export the simulation results to an external spreadsheet (of CSV format) containing the insolation values information for each cell in the grid which was analyzed for calculating the three parameter which are 1. Rooftop area 2. Shadow area 3.Shade free region in 3D simulation.

Rooftop Area: The roof top area of each building structure was determined by using the option to select the rooftop area in SAR plugin. The total rooftop area of each building structure excluding the disturbances such as water tanks AC shaft etc is represented as below

Table 4.4 Rooftop area by 3D simulation

Building Structure	Area by 3D Simmulation
Academic	17800
Administration	3430
Library	1690
Training & Placement	920
Canteen	813
Hostel	3350
Residence Block	9710
sps	3073

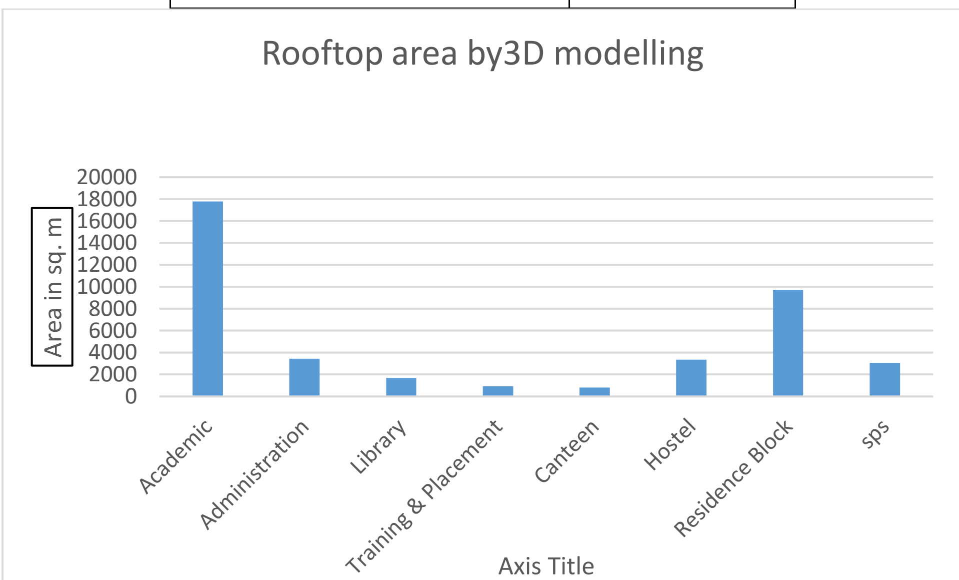

Figure 4.5 Rooftop area of each building structure by 3D simulation

4.3.2 Shadow and shade free reign by 3D simulation

From the exported CSV file output from the SAR plugin tool the area with insolation value of each grid the Data Analysis tool is used in excel sheet to exclude the grid with maximum insolation. The following table 4.5 and figure 4.6 represent the shadow area and shade free region for each building structure.

Table 4.5 Shadow and shade free region of rooftop

Building Structure	Shadow Area(m^2)	Shadefree region(m^2)
Academic	1435.2	16364.8
Administration	210	3220
Library	82	1608
Training & Placement	114	806
Canteen	156	657
Hostel	268	3082
Residence Block	800	8910
Sps hall	608	2465

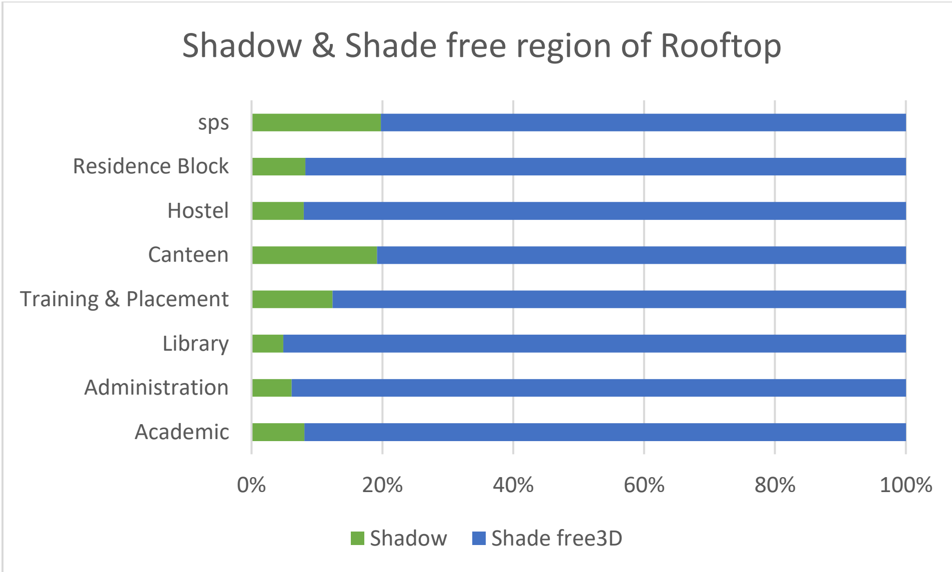

Figure 4.6 Shadow and Shade free region.

The shade free region by both 2D mapping and 3D simulation and the standard deviation from 2D mapping area is represented in the following table.

Table 4.6 Percentage deviation in Shade free region

Building ID	Shade free region from 2D Mapping	Shade free region from 3D Simulation	Percentage standard deviation
Academic	17063	16364.8	-4.09189
Administration	2867.36	3220	12.29842
Library	1493.97	1608	7.632683
Training & Placement	932.9	806	-13.6027
Canteen	715.27	657	-8.14657
Hostel	2889.03	3082	6.679405
Residence Block	9051.8	8910	-1.56654
Sps	3086	2465	-20.1231

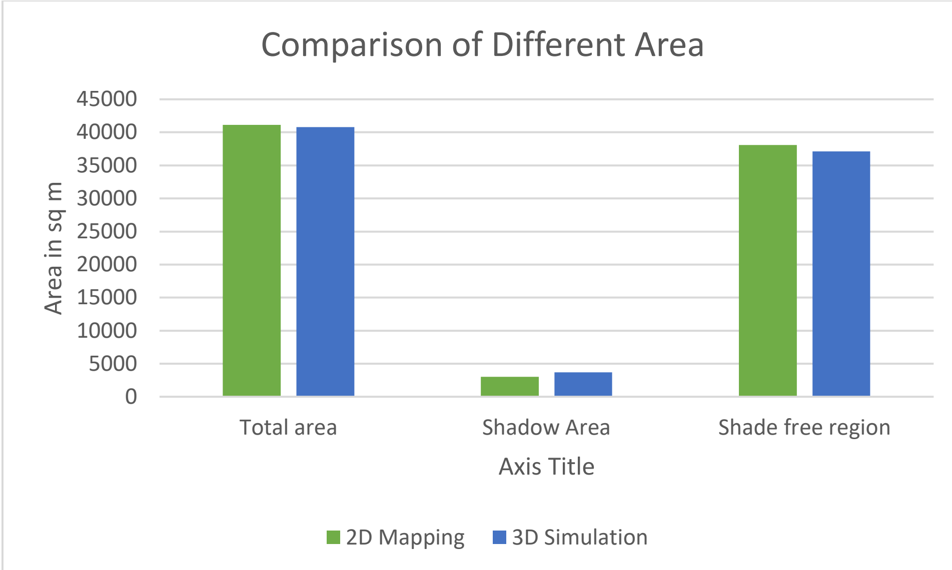

Figure4.7 Comparison of different area

4.3.3 Annual Solar Insolation on each Rooftop

The rooftop annual solar insolation of each building is reported and the corresponding table and figure is drawn below.

Table4.7 Annual solar insolation of rooftop

Building Id	annual insolation(MWh/year)
Academic	4936.52
Administration	917.863
Library	426.485
Training & Placement	231.578
Canteen	160.896
Hostel	817.898
Residence Block	1944.294
sps	765.793

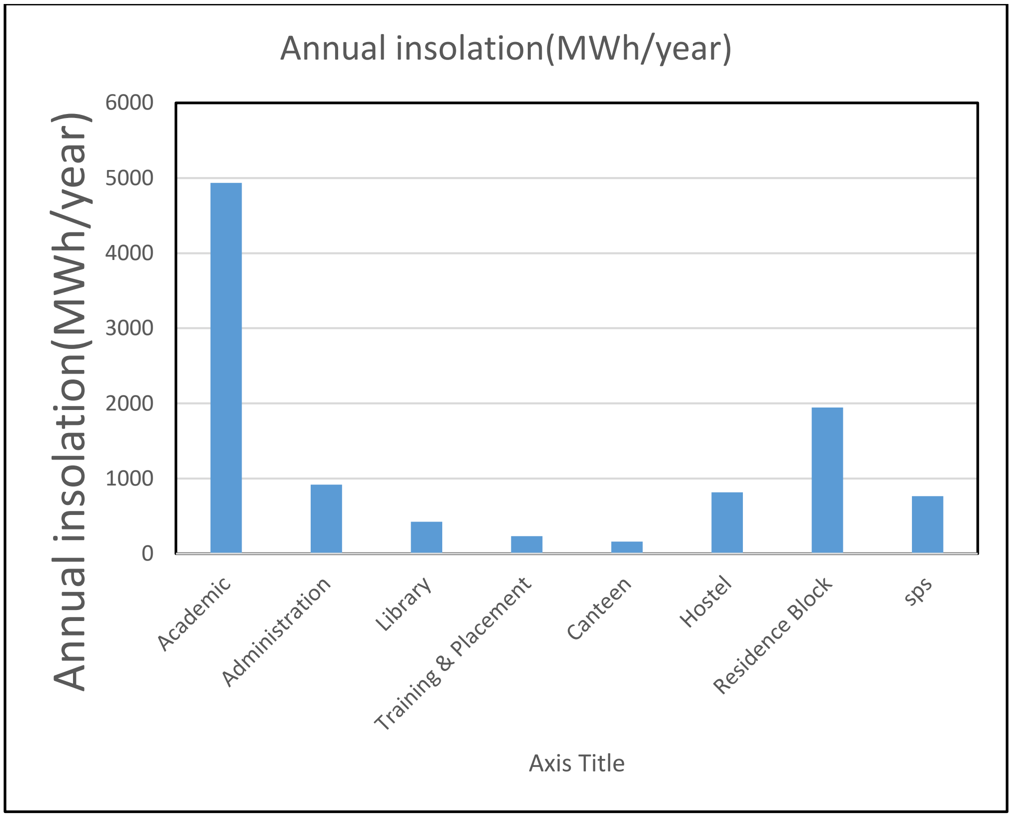

Figure4.8 Annual solar insolation of rooftop

The following figures shows the insolation map of rooftop and legend representing the insolation value of each grid.

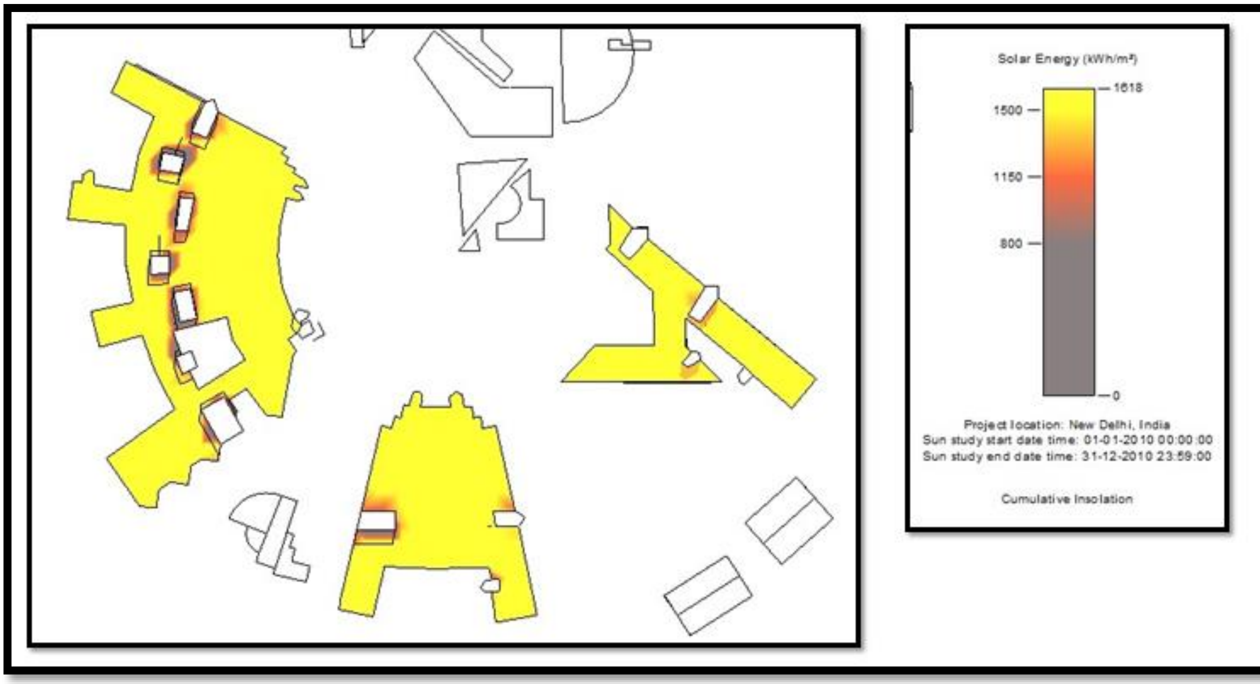

Figure 4.9 Colour Coded Insolation Map of Academic Blocks

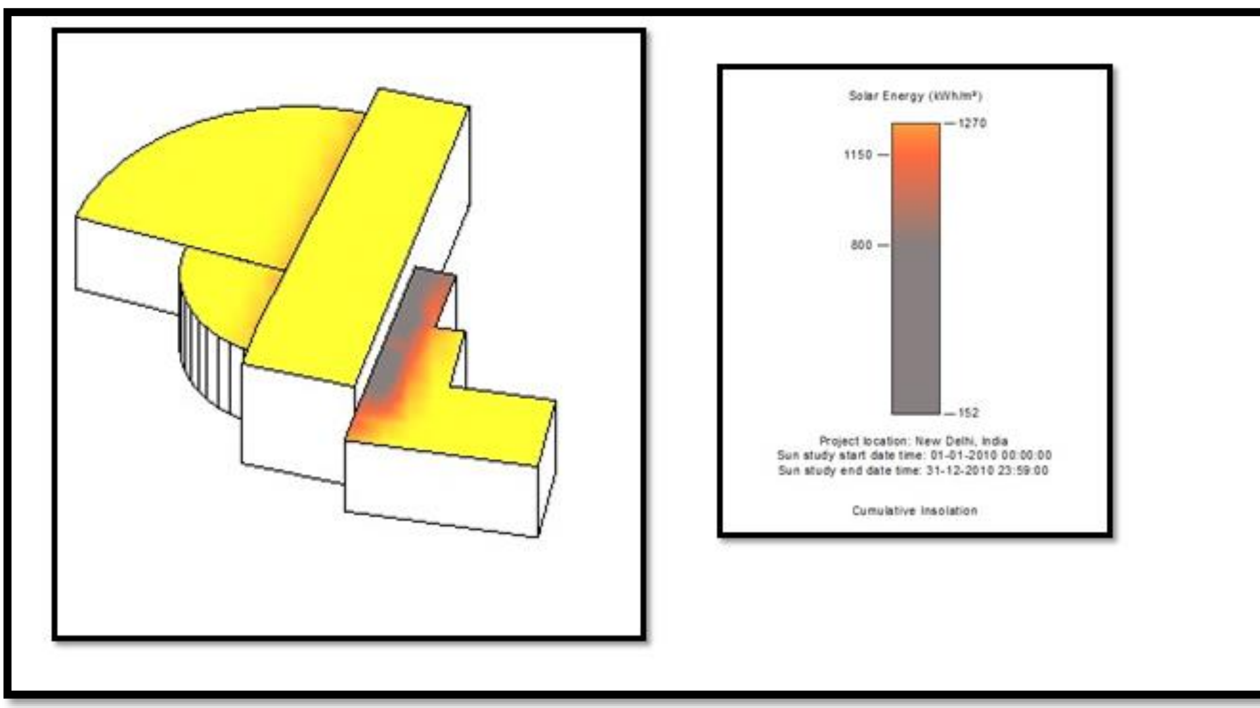

Figure 4.10 Colour Coded Insolation Map of Canteen

Figure 4.11 Colour Coded Insolation Map of Library

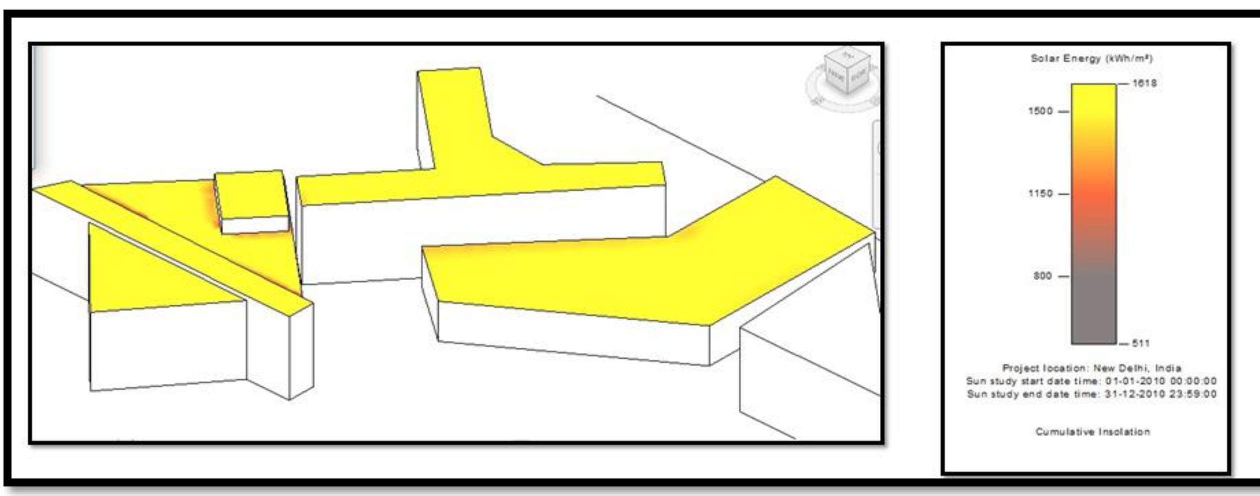

Figure 4.12 Colour Coded Insolation Map of Administrative Blocks

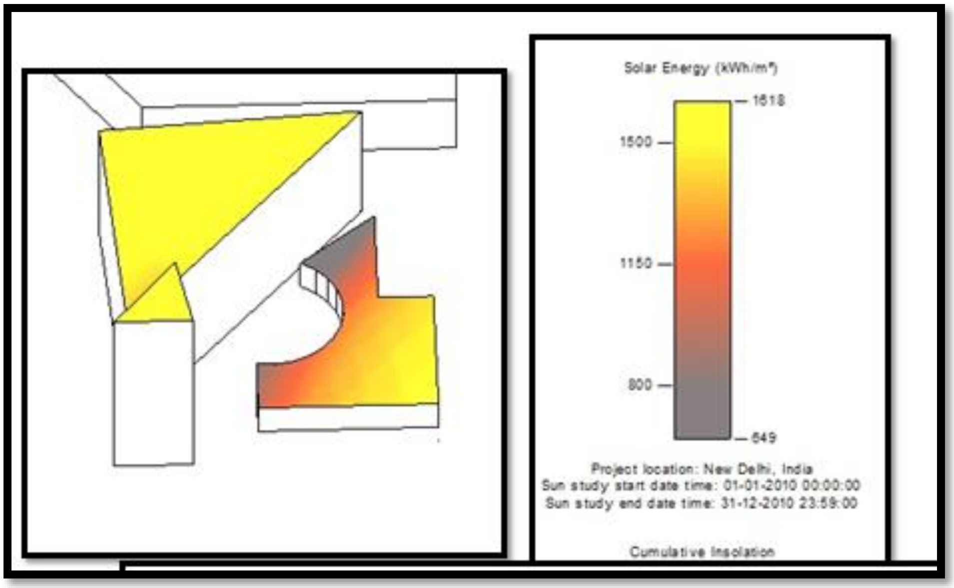

Figure 4.13 Colour Coded Insolation Map of Training & Placement Cell

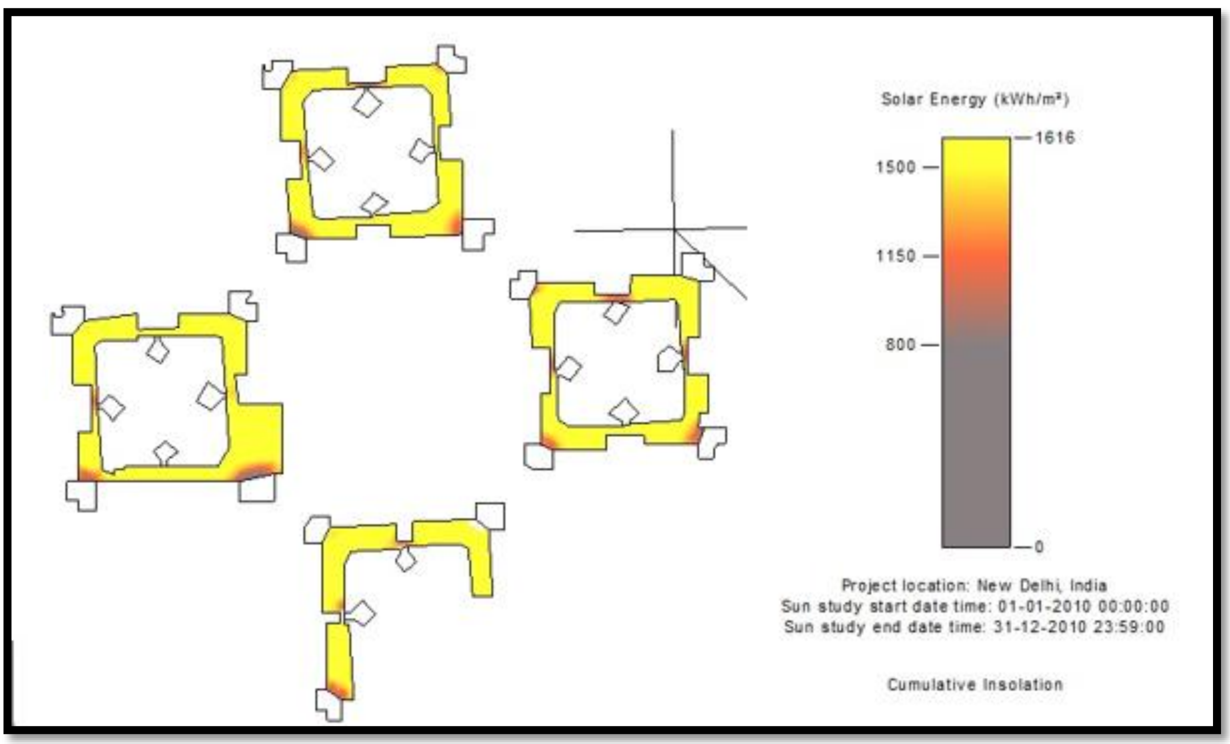

Figure 4.14 Colour Coded Insolation Map of Hostel

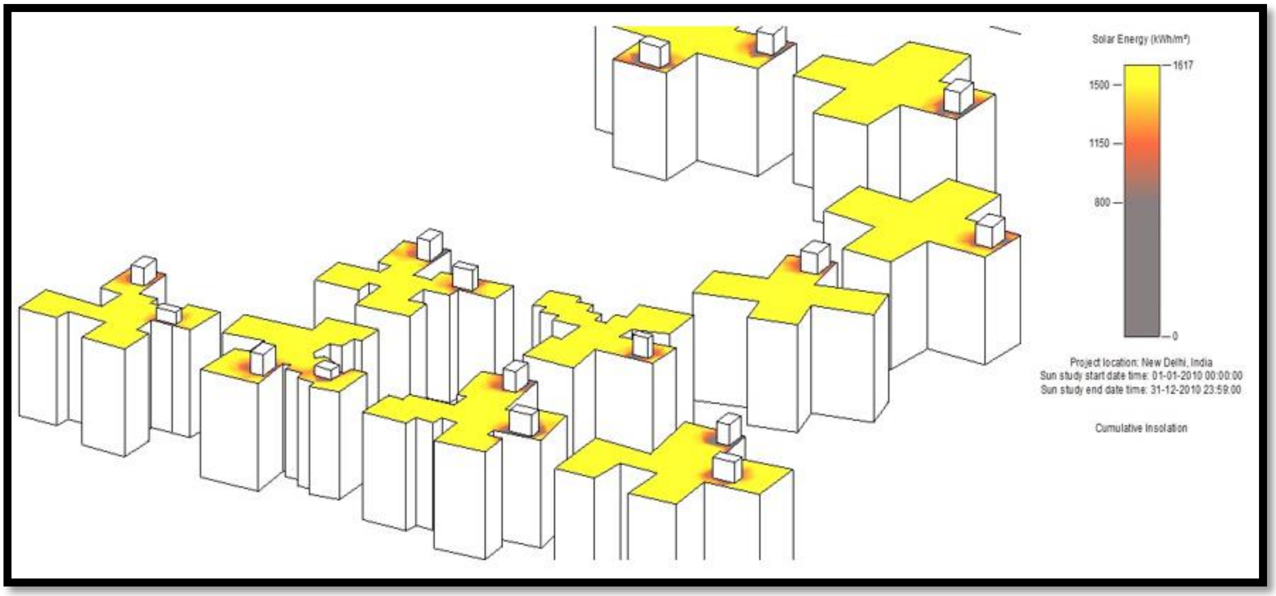

Figure 4.15 Colour Coded Insolation Map of Staff Quarter

4.3.4 Rooftop Photovoltaic(PV) potential.

The rooftop potential in terms of installed capacity (kWp) was calculated on the assumption that the area required for installing 1 kWp of PV modules is 10 square meter The typical dimension of a multi-crystalline modules of 250 Wp with the good efficiency is of1.6 m x 1 m. Therefore 4 such modules would create a system of 1 kWp that requires around 6.4 square meter We can count on another 50 percent area for inter-array spacing at an array level on roof mounted system. Therefore, the complete area requirement would be 9.6 sq. M(~10 square meter).

The following table and figure shows the PV potential of each building.

Table 4.8 The PV potential of Rooftop of each building

Building Id	PV potential(kWp)
Academic	1636.48
Administration	322
Library	160.8
Training & Placement	80.6

Canteen	65.7
Hostel	308.2
Residence Block	891
sps	246.5
Total PV potential	3711.28

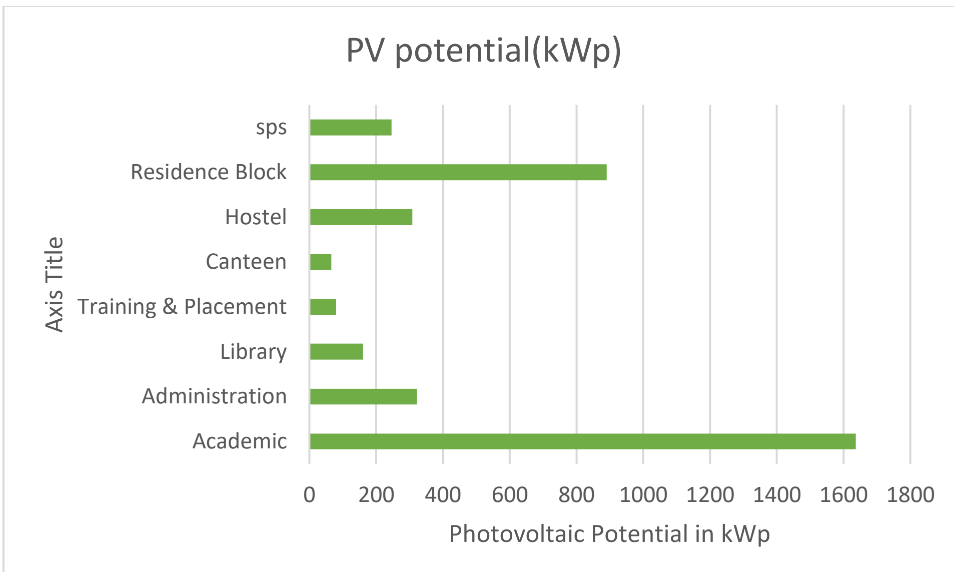

Figure4.16 The PV potential of Rooftop of each building

Chapter 5

Conclusion and Future Work.

The prime objective of this study was to determine for DTU campus the rooftop PV potential and solar insolation value. The study is intended to produce data in such a manner that the concerned authority could get an idea for using the solar energy as an alternate source of energy. The entire rooftop solar potential evaluation ranged from mapping and identifying building and calculating shade free region using Google Earth and other free online map sources. The 3D modeling and inter building simulation studies later improved the quality of the work.

From the area solar radiation analysis of the topography of the DTU campus it is concluded that the total radiation recived by the entire campus is 58.5 GWh. The mean solar radiation is 1490.83 KWh/m^2 and its standard deviation is 29.4 KWh/m^2.

From 2D mapping of the study area it found that at the total building footprint area is 41132 m^2 and the shadow area is 3033m^2 and the shade free region is 38099m^2

Coverage area to plot area ratio (C/P) of DTU campus is 0.063535 and the shadow free area to coverage area ratio (S/C) is 0.909264. From the S/C ratio we can suggest that nearly 90.9 percent of the university campus coverage region contributes to an region appropriate for rooftop PV installation. Thw C/P and S/C ratio could be used to get a rough estimate of shade free area for similar type of plot area.

From 3D simulation of the building structure it found that at the total building footprint area is 40786 m^2 and the shadow area is 3673.2m^2 and the shade free region is 37112m^2.

The shade free area from 2D mapping is more than that of 3D simulation because in 2D mapping, the impact of shading the neighboring building is not evident, we may have calculated more region as shade-free (because there may not be any shading structures on its own roofs such as water tanks, exhausts, etc.). But after 3D simulation, we see that the nearby buildings can cause heavy shading, resulting in a large reduction in shade-free area.

The maximum deviation in percentage from 2D mapping area is 12.3% for administrative building and minimum deviation is -13.60% for training and placement office.

The total annual solar insolation is 10201.3 MWh/year and maximum annual solar insolation is 4936.5 MWh/year for academic block followed by resident block (1944.3 MWh/year) the minimum annual solar insolation is 160.90 MWh/year for canteen building similarly the rooftop Photovoltaic potential is found to be maximum for academic block(1636 KWp) and minimum for canteen building(65.7 KWp).

Future Work

In addition to web-based(GIS) area calculations, the site surveys should also be conducted so that physical area measurements of the rooftops of chosen locations will substantiate the results .

Since the study is only done on the buildings which are visible clearly in the satellite imagery the site survey would help in analyzing the more building of the campus, site survey would also help in finding the actual disturbance on rooftop such as AC duct small water tank etc which is difficult to analyze in satellite image.

APPENDIX

Source	Date	Time	Model	Type	Study Average Insolation Value	Total Study Surface Area	Total Study Insolation Value	Study Date Range	Study Time Range	Long e
Revit 2016	########	17:02	Project1	Cumulative	1288.646	3351.935	4319459	01-01-2010,31-12-2010	Sunrise,Sunset	

Analysis Surface	Parent object type	Category	Parent object ID	Average Surface Insolation Value	Surface Area	Total Surface Insolation Value
-9E+08	FamilyInstance	Mass	2385	1529.648	706.2282	11628048
-4.5E+08	FamilyInstance	Mass	2385	1518.033	587.4013	9598127
-4.4E+08	FamilyInstance	Mass	2385	1521.063	565.0751	9251748
-4.4E+08	FamilyInstance	Mass	2385	1519.501	529.491	8660240
-4.4E+08	FamilyInstance	Mass	2385	1560.341	333.8994	5607967
-4.4E+08	FamilyInstance	Mass	2385	1516.682	100.1663	1635259
-4.5E+08	FamilyInstance	Mass	2385	-7.09E-06	529.6742	-0.04041

Analysis point index	Insolation value	Parent surface	point x	point y	point z	normal x	normal y	normal z
1	1564.212	-9E+08	-369.196	-61.0776	50.88583	0	0	1
2	1590.202	-9E+08	-362.162	-61.0776	50.88583	0	0	1
3	1592.75	-9E+08	-355.128	-61.0776	50.88583	0	0	1
4	1584.634	-9E+08	-348.094	-61.0776	50.88583	0	0	1
5	1597.386	-9E+08	-305.891	-61.0776	50.88583	0	0	1
6	1589.949	-9E+08	-298.857	-61.0776	50.88583	0	0	1
7	1577.739	-9E+08	-291.824	-61.0776	50.88583	0	0	1

8	1552.912	-9E+08	-284.79	-61.0776	50.88583	0	0	1
9	1514.388	-9E+08	-277.756	-61.0776	50.88583	0	0	1
10	1418.079	-9E+08	-270.722	-61.0776	50.88583	0	0	1
11	1444.848	-9E+08	-383.263	-68.2782	50.88583	0	0	1
12	1544.438	-9E+08	-376.23	-68.2782	50.88583	0	0	1
13	1579.47	-9E+08	-369.196	-68.2782	50.88583	0	0	1
14	1582.23	-9E+08	-362.162	-68.2782	50.88583	0	0	1
15	1585.132	-9E+08	-355.128	-68.2782	50.88583	0	0	1
16	1565.085	-9E+08	-348.094	-68.2782	50.88583	0	0	1
17	1584.759	-9E+08	-305.891	-68.2782	50.88583	0	0	1
18	1592.614	-9E+08	-298.857	-68.2782	50.88583	0	0	1
19	1593.407	-9E+08	-291.824	-68.2782	50.88583	0	0	1
20	1591.802	-9E+08	-284.79	-68.2782	50.88583	0	0	1
21	1583.503	-9E+08	-277.756	-68.2782	50.88583	0	0	1
22	1579.718	-9E+08	-270.722	-68.2782	50.88583	0	0	1
23	1574.565	-9E+08	-263.688	-68.2782	50.88583	0	0	1
24	1557.315	-9E+08	-390.297	-75.4788	50.88583	0	0	1
25	1576.673	-9E+08	-383.263	-75.4788	50.88583	0	0	1
26	1584.921	-9E+08	-376.23	-75.4788	50.88583	0	0	1
27	1594.939	-9E+08	-369.196	-75.4788	50.88583	0	0	1
28	1589.347	-9E+08	-362.162	-75.4788	50.88583	0	0	1
29	1574.792	-9E+08	-355.128	-75.4788	50.88583	0	0	1
30	1514.026	-9E+08	-348.094	-75.4788	50.88583	0	0	1
31	1602.528	-9E+08	-277.756	-75.4788	50.88583	0	0	1

32	1600.486	-9E+08	-270.722	-75.4788	50.88583	0	0	1
33	1598.629	-9E+08	-263.688	-75.4788	50.88583	0	0	1
34	1594.353	-9E+08	-390.297	-82.6794	50.88583	0	0	1
35	1598.278	-9E+08	-383.263	-82.6794	50.88583	0	0	1
36	1605.141	-9E+08	-277.756	-82.6794	50.88583	0	0	1
37	1605.968	-9E+08	-270.722	-82.6794	50.88583	0	0	1
38	1605.89	-9E+08	-263.688	-82.6794	50.88583	0	0	1
39	1603.391	-9E+08	-390.297	-89.8801	50.88583	0	0	1
40	1603.794	-9E+08	-383.263	-89.8801	50.88583	0	0	1
41	1606.811	-9E+08	-270.722	-89.8801	50.88583	0	0	1
42	1606.982	-9E+08	-263.688	-89.8801	50.88583	0	0	1
43	1607.014	-9E+08	-390.297	-97.0807	50.88583	0	0	1
44	1605.68	-9E+08	-383.263	-97.0807	50.88583	0	0	1
45	1602.322	-9E+08	-376.23	-97.0807	50.88583	0	0	1
46	1596.55	-9E+08	-270.722	-97.0807	50.88583	0	0	1
47	1603.246	-9E+08	-263.688	-97.0807	50.88583	0	0	1
48	1598.271	-9E+08	-390.297	-104.281	50.88583	0	0	1
49	1599.024	-9E+08	-383.263	-104.281	50.88583	0	0	1
50	1600.63	-9E+08	-376.23	-104.281	50.88583	0	0	1
51	1537.92	-9E+08	-270.722	-104.281	50.88583	0	0	1
52	1583.373	-9E+08	-263.688	-104.281	50.88583	0	0	1
53	1588	-9E+08	-390.297	-111.482	50.88583	0	0	1
54	1558.83	-9E+08	-383.263	-111.482	50.88583	0	0	1
55	1550.587	-9E+08	-376.23	-111.482	50.88583	0	0	1

56	1448.085	-9E+08	-270.722	-111.482	50.88583	0	0	1
57	1319.912	-9E+08	-376.23	-118.683	50.88583	0	0	1
58	1371.091	-9E+08	-270.722	-118.683	50.88583	0	0	1
59	1009.35	-9E+08	-376.23	-125.883	50.88583	0	0	1
60	1510.972	-9E+08	-270.722	-125.883	50.88583	0	0	1
61	1398.985	-9E+08	-376.23	-133.084	50.88583	0	0	1
62	1580.652	-9E+08	-270.722	-133.084	50.88583	0	0	1
63	1596.715	-9E+08	-263.688	-133.084	50.88583	0	0	1
64	1606.148	-9E+08	-256.654	-133.084	50.88583	0	0	1
65	1609.477	-9E+08	-249.621	-133.084	50.88583	0	0	1
66	1611.758	-9E+08	-242.587	-133.084	50.88583	0	0	1
67	1612.528	-9E+08	-235.553	-133.084	50.88583	0	0	1
68	1535.198	-9E+08	-376.23	-140.284	50.88583	0	0	1
69	1604.79	-9E+08	-270.722	-140.284	50.88583	0	0	1
70	1607.163	-9E+08	-263.688	-140.284	50.88583	0	0	1
71	1608.133	-9E+08	-256.654	-140.284	50.88583	0	0	1
72	1610.582	-9E+08	-249.621	-140.284	50.88583	0	0	1
73	1611.766	-9E+08	-242.587	-140.284	50.88583	0	0	1
74	1612.591	-9E+08	-235.553	-140.284	50.88583	0	0	1
75	1599.891	-9E+08	-376.23	-147.485	50.88583	0	0	1
76	1606.634	-9E+08	-270.722	-147.485	50.88583	0	0	1
77	1609.205	-9E+08	-263.688	-147.485	50.88583	0	0	1
78	1608.112	-9E+08	-256.654	-147.485	50.88583	0	0	1
79	1610.802	-9E+08	-249.621	-147.485	50.88583	0	0	1

80	1611.036	-9E+08	-242.587	-147.485	50.88583	0	0	1
81	1612.514	-9E+08	-235.553	-147.485	50.88583	0	0	1
82	1607.102	-9E+08	-383.263	-154.686	50.88583	0	0	1
83	1605.583	-9E+08	-376.23	-154.686	50.88583	0	0	1
84	1607.457	-9E+08	-270.722	-154.686	50.88583	0	0	1
85	1606.452	-9E+08	-263.688	-154.686	50.88583	0	0	1
86	1607.052	-9E+08	-256.654	-154.686	50.88583	0	0	1
87	1606.986	-9E+08	-249.621	-154.686	50.88583	0	0	1

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