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The Influence of Using Vertical Solar PV in Rationalization of Energy Consumption in Residential Buildings

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Abstract

As a result of repetitive terroristic attacks in Rafah city, the Egyptian government had to evacuate Rafah to eradicate terrorism. It is planned to build New Rafah city at a distance from the borders.

So if we are going to build a new settlement why not to build it right?

The aim of this research is to build new Rafah city convenient to their occupants by fulfilling both psychological and physical comfort.

This paper demonstrates a number of climatic and energy characteristics of building in the desert of the hot arid region. It presents proposed techniques for using vertical solar Photovoltaic Panels (PV) that installed on building facades. Designer can find out suitability for putting PVs installation in the façade surfaces of buildings using Google Earth imagery and ArcGIS software for spatial and attribute data of buildings in this defined urban study area. The approach entails modeling the solar irradiance characteristics of the site by fitting the probability distributions of the solar irradiance data measured during the day. Thereafter; it could be estimated the solar radiations factor according to analysis of different designs of PV modules. The module with the highest average factor is identified as the best suited module for the given site.

Key words

Photovoltaic (PV); Vertical Solar PV, 3D Modeling, Visualization., Geographical Information System (GIS).

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1. Introduction

Due to the fact that, roughly 50% of the energy consumed is used in the construction and operation of buildings, which account for 81% of the total Egypt electricity expenditures, architects play a major role in the reduction of energy consumption. [1]

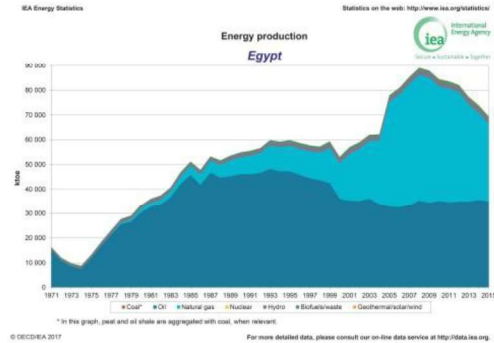
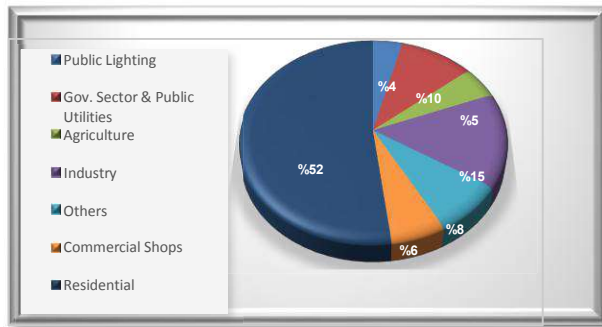


Figure- 1: Total Distribution of Energy Consumption in Egypt for 2014/2015. [2]

Figure- 2: Energy Production in Egypt for 2014/2015. [3]

Using vertical solar PV installed on building facades can potentially produce clean electricity to meet the energy demand of the buildings and also provides protection from weather. So the research presents the importance of studying the vertical solar PV for the architectural façade that is one of advanced technology aspect for contributing in optimal use of solar energy. It changes dynamically rather than being static or fixed, allowing movement to occur on a building’s façades. This helps to create a building's envelope that is an active system rather than just a container. Technological façade can be used to manage light, air, energy, and even information. They can act to reduce solar gain as well as allowing the passage of fresh air into the building, helping to alter the interior environment. The moving elements of the façade can be programmed to respond to climatic or other environmental factors, time, levels, type of occupancy and so on to improve performance and efficiency using vertical solar PVs. This combination is done with advances in sensors, materials and building management technology. So; designers are increasingly able to consider technological façade components as design solutions. [4] & [5]

This could be done using Geographical Information System (GIS) technology in analyzing automated spatial data of vertical solar PV potential and designing for an urban area in Rafah. GIS database would have records of each house for energy generation via connecting algorithms with theoretical formulas. Every house has its number, area size and selected area for panel installation. The energy generated through the vertical PV system is between 1.5GW and 5GW annually. [6]

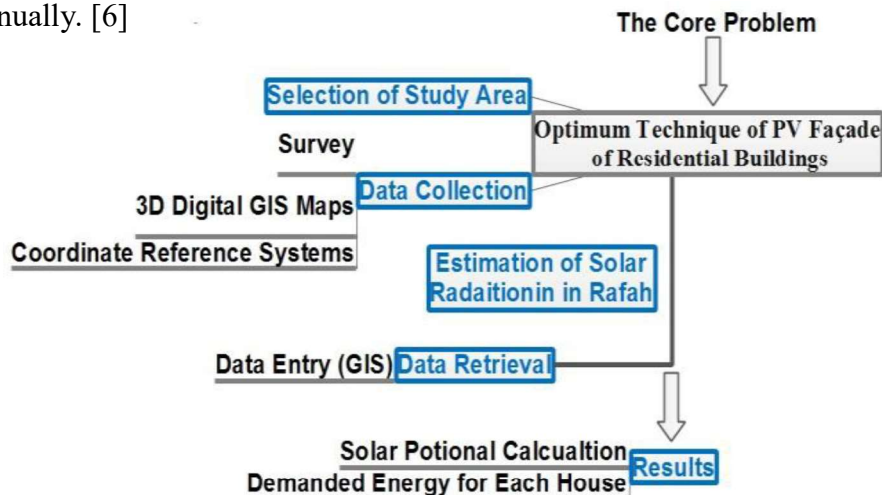


Figure- 3: Flow Chart of Current Study [7]

2. Criteria of Selected Area (New Rafah)

Site Selection

The study area is Rafah which locates in Sinai Peninsula. It is about 22 Acres that could be located in Google Earth software™ with a geo-referencing parameters (31° 17' 0" N, 34° 14' 0" E). The study area was chosen as it has unique design; it is bordered to the north by main road of Al Arish-Rafah. Rafah pertains various topographic variation and high suitability for vertical solar PV that could be installed on residential building facades. [7]



Figure- 4: Location of Study Area at Rafah in Arc Map Software According to Geo-Referencing in Google Earth. [7]

The Climate Criteria

Köppen-Geiger climate classification system classifies its climate as hot semi-arid. The pattern of weather and climate in Sinai are largely dictated by its position between the vast landmasses of Africa and Asia. Neither the Mediterranean nor the Red Sea significantly ameliorates the extremes of continentally inherited from its large land neighbors. The aridity dominates this environment. Rafah is characterized by hot dry summers and mild rainy winters.

Solar Radiation

The annual radiation for the entire region averages is more than 500 cal/cm²/day. A high percentage of Rafah’s daylight hours are cloud free time averages 74%.

Atmospheric Temperature

The temperature during summer can be around 30 °C during daytime, and rarely ‘exceeds 35 °C due to the influence of the sea. Winters range from mild to cool during the day and chilly during the night and temperatures dip below 6 °C. [8]

Table- 1: Climate data for Rafah, North Sinai. [8]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C	17.2	18	20.3	22.9	25.8	28.2	29.6	30.5	29	27.4	23.7	19.3	24.33
Daily mean °C	12.7	13.5	15.4	18	20.8	23.5	25.2	25.9	24.5	22.4	18.6	14.7	19.6
Average low °C	8.2	9	10.6	13.2	15.9	18.8	20.8	21.4	20	17.4	13.5	10.1	14.91
Av. precipitation mm	49	37	28	6	4	0	0	0	0	8	39	54	225

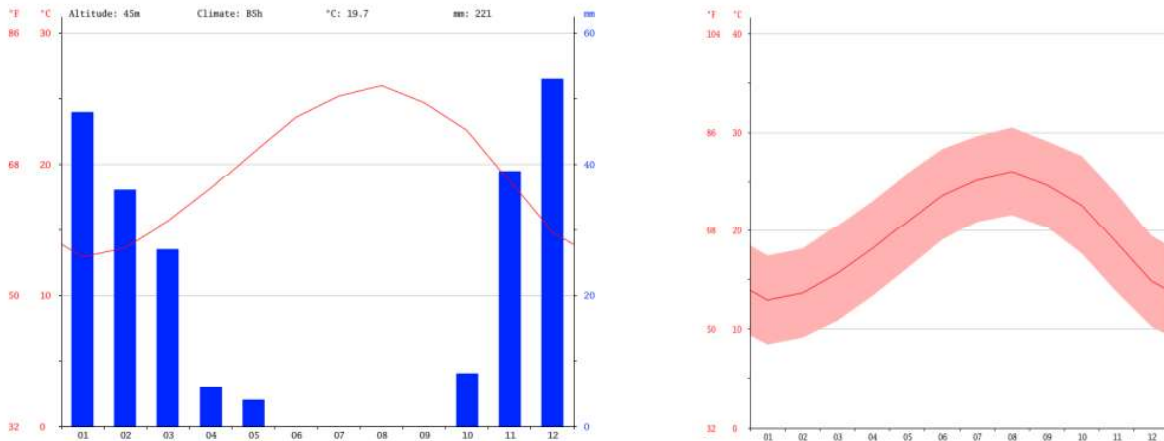


Figure-5&6: Temperature Graph Rafah. [8]

2.2.3. Wind

The prevailing winds of Sinai are from the north, however, mountain barriers and deep wadi channels often modify these winds locally. The general air flow from the Mediterranean is the source of nearly all precipitation, the bulk of which falls in winter. With the onset of spring there is an increased chance for strong winds, still predominantly from the north. But the south winds are the most dreaded. These tend to be abnormally hot and dry and accompanied by hazy atmosphere. Such a wind is, known as the “Khamasin” for the fifty days in which it is oppressive and frequently damages vegetation. Severe sand and dust storms often accompany the Khamasin.

2.2.4. Precipitation

There is a difference of 53 mm of precipitation between the driest and wettest months. The driest month is June, with 0 mm of rain. In December, the precipitation reaches its peak, with an average of 53 mm. Rainfall is average with sometimes hail, sleet and rarely snow takes place. [8]

3. Social Housing Building Model

A model for social residence has been chosen to the basic unit for a modern new settlement. Residential building has area 360 m²/ building. Each floor consists of (4) units. It was taken into consideration during designing that each building is multi-floor (ground, first), (ground, first, second), (ground, first, second, third). Residential loads are estimated by 30-50 VA/m² for moderate residential building loads.

$$P_{tot}=40 \times 360 \times 4=57600 \text{ KVA. [9]}$$

Where P total is (total output power of the PV module) Moreover; there are three apartments in the case study in the south and west directions that could be used to install the vertical solar Photovoltaic Panels (PV) on their facades as follow:

two apartments have eight PVs (250*8=2000 w)

one apartment has two PVs (250*2=500 w).

so; every apartment need (2500*4=10000 w).

The residential unit is composed of:

Room	Area	Unit model
Living & Dining room	21.4 m ²	
Master Bedroom	12 m ²	
Bedroom	10.8 m ²	
Bedroom	9.5 m ²	
Bathroom	2.6 m ²	
Kitchen	7.4m ²	



Figure-7: The Residential Model [7]

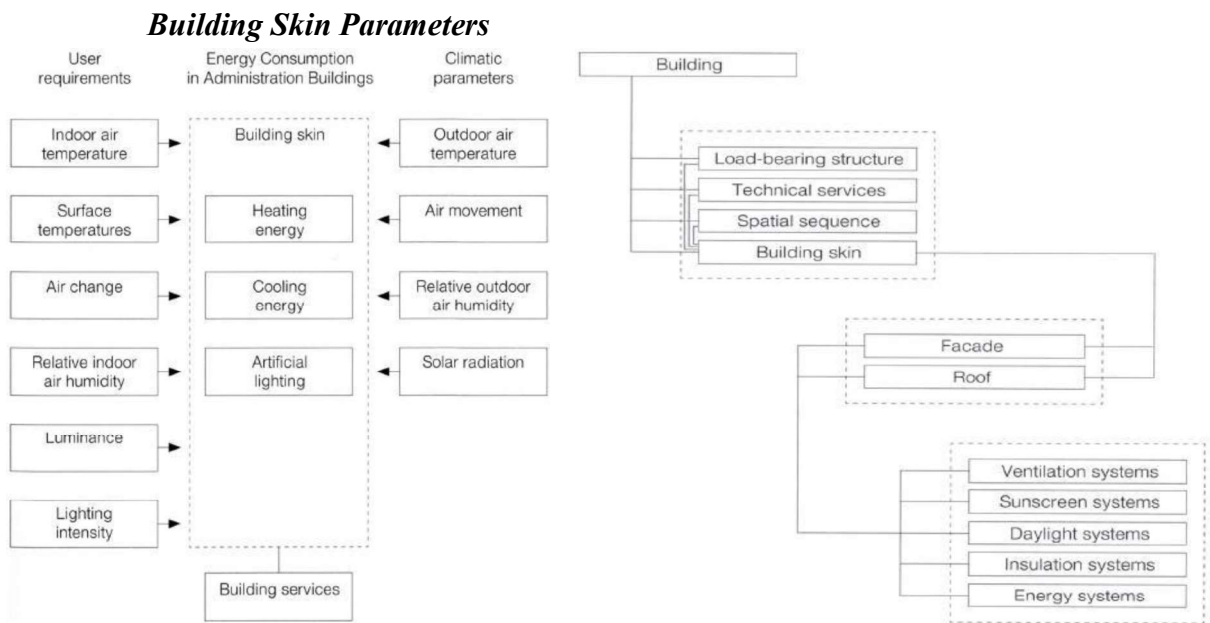


Figure-8: Building Skin Parameters for Proposing Vertical Façade of Solar PV System. [7]

Figure-9: Overall Building System for Proposing Vertical Façade of Solar PV System. [7]

Building Orientation

The buildings were oriented such that the openings are in east-west axis to decrease energy consumption by use of daylight.

The best four vertical façade orientations for PV application in climatic condition of Rafah are east, west, southeast and southwest as these façades received the highest incident irradiance. [6]

Table-2: The Simulation Results of the Building Orientation with Vertical Solar PV. [7]

Case/ Angle	Baseline/0°	Case (1)/ 45°	Case (2)/ -45°	Case (3)/ 90°	Case (4)/ -90°
Orientation					
Net Site Energy	116.27 kWh/m ²	120.11 kWh/m ²	126.63 kWh/m ²	130.76 kWh/m ²	124.23 kWh/m ²

4. Vertical Solar PV

The PV specifications assist builders in designing and constructing homes equipped with a set of features that make the installation of solar energy systems after the completion of the home's construction easier and less expensive. The specifications are based on best management practices and balanced with practical issues of cost.[10]

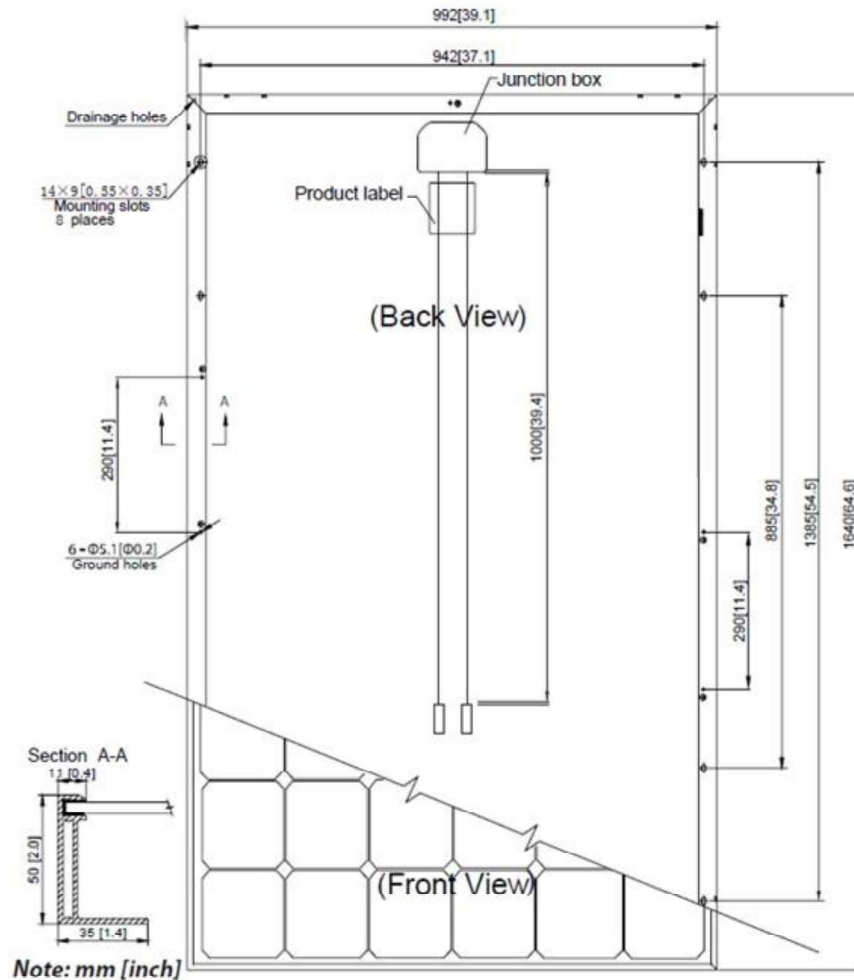


Figure-10: Detailed design of used Vertical Solar PV in the study area at Unit: mm.[10]

Vertical Solar PV (Performance)

1. High module conversion efficiency
Module efficiency up to 15.4% achieved through advanced cell technology and manufacturing capabilities.
2. Extended wind load tests
Module certified to withstand extreme wind (3800 Pascal).
3. Self-cleaning & anti-reflective
Higher module efficiency from anti-reflective, hydrophobic layer with higher light absorption and minimal surface dust.
4. Excellent weak light performance
Excellent performance under low light.
5. Suntech current sorting process
System output maximized by reducing mismatch losses up to 2% with modules sorted & packaged by amperage. [11]

Vertical Solar PV (Operating Condition)

Accordingly, the specifications of vertical solar PV are calculated and showing that the most preferable module belong to Max.

Electrical Characteristics

At Standard Test Conditions (STC): irradiance 1000 W/m², module temperature 25 °C, AM=1.5. power measurement uncertainty is within +/- 3%

Table-3: The Specifications of Vertical Solar PV module used in the case study. [10]

STC	STP250S-20/Wd
Optimum Operating Voltage (Vmp)	30.7 V
Optimum Operating Current (Imp)	8.15 A
Open Circuit Voltage (Voc)	37.4 V
Short Circuit Current (Isc)	8.63 A
Watt.hour /Day	124800.0 W
Operating Module Temperature	-40 °C to +85 °C
Maximum System Voltage	1000 V DC (IEC)
Maximum Series Fuse Rating	20 A
Power Tolerance	0/+5 %
Running hours	8
Select Size of Solar Panel	1.6 m ²
Number of String for Solar Panel	461
Total Watt of Each Solar Panel String	250 W
Total Watts of Solar Panels	115250 W

Temperature Characteristics

Table-4: The Temperature Characteristics of Vertical Solar PV. [10]

Nominal Operating Cell Temperature (NOCT)	45±2°C
Temperature Coefficient of Pmax	-0.45 %/°C
Temperature Coefficient of Voc	-0.34 %/°C
Temperature Coefficient of Isc	0.050 %/°C

Mechanical Characteristics

Table-5: The Mechanical Characteristics of Vertical Solar PV. [10]

Solar Cell	Monocrystalline silicon 156 × 156 mm
No. of Cells	60 (6 × 10)
Dimensions	1640 × 992 × 50mm
Weight	19.1 kgs
Front Glass	3.2 mm tempered glass
Frame	Anodized aluminium alloy
Output Cables	TUV (2Pfg1169:2007), UL 4703, UL44
	4.0 mm ² , symmetrical lengths (-) 1000mm and (+) 1000 mm

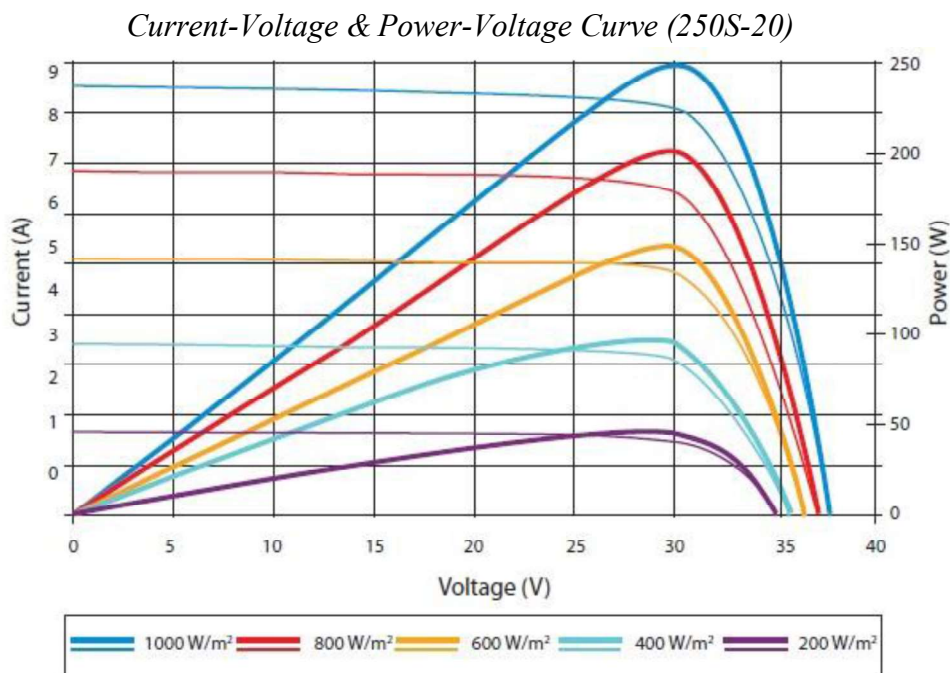


Figure-11: Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m², (AM 1.5, 25 °C), 95.5% or higher of the STC efficiency (1000 W/m²) is achieved.[1]

Suggested Building Model with Vertical PV.

In the case study, the vertical PVs are furnished over the south and west facades. The dimensional drawings illustrate the size of the two facades (which is given by 414 m² and 342m², respectively).

Grid-Tie application has been selected for the case study which so-called PV on-grid system. The proposed system is Parallel connected PV modules to an on-grid system. [12]

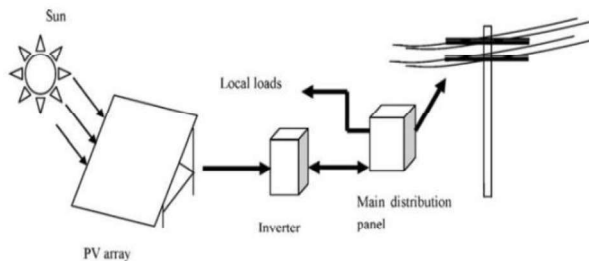


Figure-12: On-Grid PV system with no storage.[12]

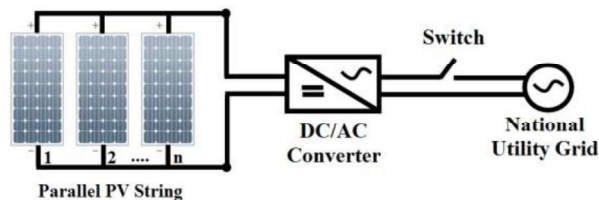


Figure-13: Parallel connected PV modules to an on-grid system.[13]

5. Digitizing Database

Spatial data was prepared with the help of Google Earth Map and ground surveys while attribute information for the proposed buildings and estimated electricity database is assigned by the researcher's studies and Rafah Electric Supply Company's website for the individual meteorological and irradiation data files for Rafah in Sinai at Egypt which recorded for every hour per day.

Three layers were created for database in the ArcGIS software. These layers consist of boundary of the study area, main road and raster layer for the calculation of solar energy potential. Google Earth satellite imagery was used as a base map to digitize area for vertical solar PV installation on façade of residential buildings.

South, south east and south west directions are best for PV installation. All buildings in the study area have flat surfaces at their façade which receives direct solar radiations without any shaded area.

In the study area, it could be estimated the solar radiation potential related to spatial relationship to other data using solar radiation spatial analyst tool in ArcScene software through the energy value [kWh/m²a] for a test area according to spatial and semantic properties.

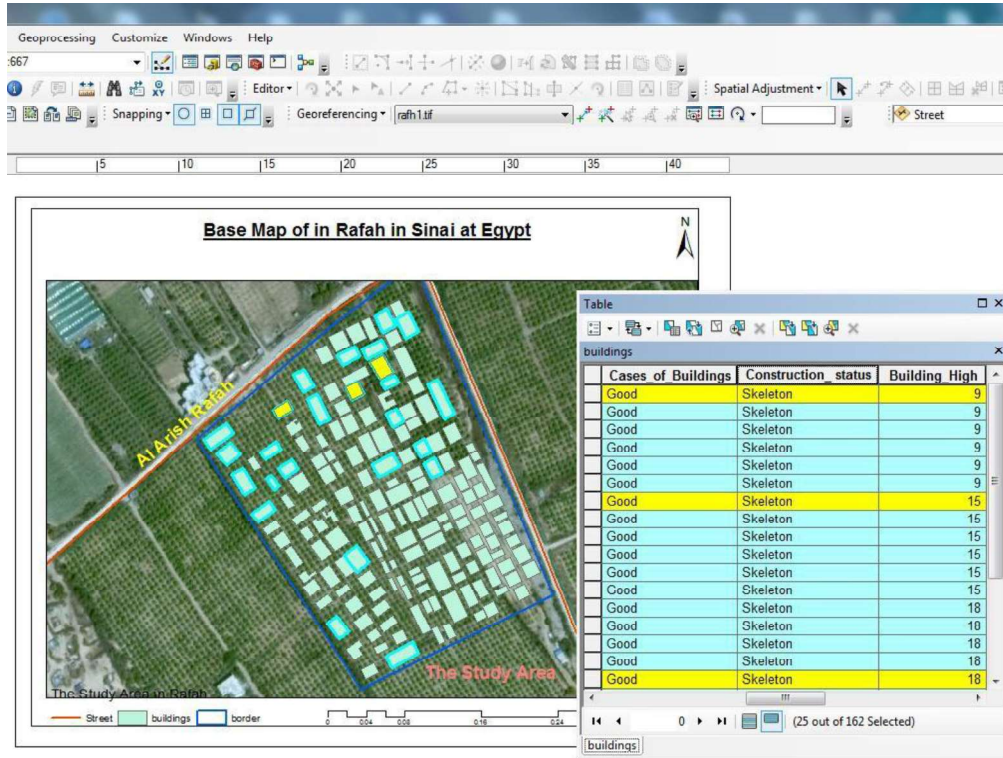


Figure-14: Visualizing the Georeferenced Buildings Model with all Attribute Data Table for all 2D Elements in a Base Map of Rafah in ArcMap Software According to WGS1984.[7]

Calculating The Solar Radiation

Calculating the solar radiation is a configuration of ArcGIS that can be evaluated for assessing if buildings have potential for solar panel installation. Visualize vertical solar PV for the architectural façade of buildings in a 3D scene and evaluate total solar radiation per selected surface area of the buildings.

Steps of The Calculation

The implementation of solar radiation consumption depends on geo-processing criteria as follows:

- a. The calculation of every building location factor according to Aspect (orientation), the surface azimuth angle, the building height, thematic hull surfaces that have been integrated and based on building typologies.
- b. The inserting of the solar radiation capacity factor according to the record of each house, its area selected for PV installation, its monthly, yearly electric energy generation.

Research Outcome

Consequently; the results for every building are written in new generic attributes in a geodatabase within the ArcScene file considering that all the building's façades have the same elevation. This calculation is using solar radiation spatial analyst tool in ArcScene software through the energy value [kWh/m²a] for a test area according to spatial and semantic properties.

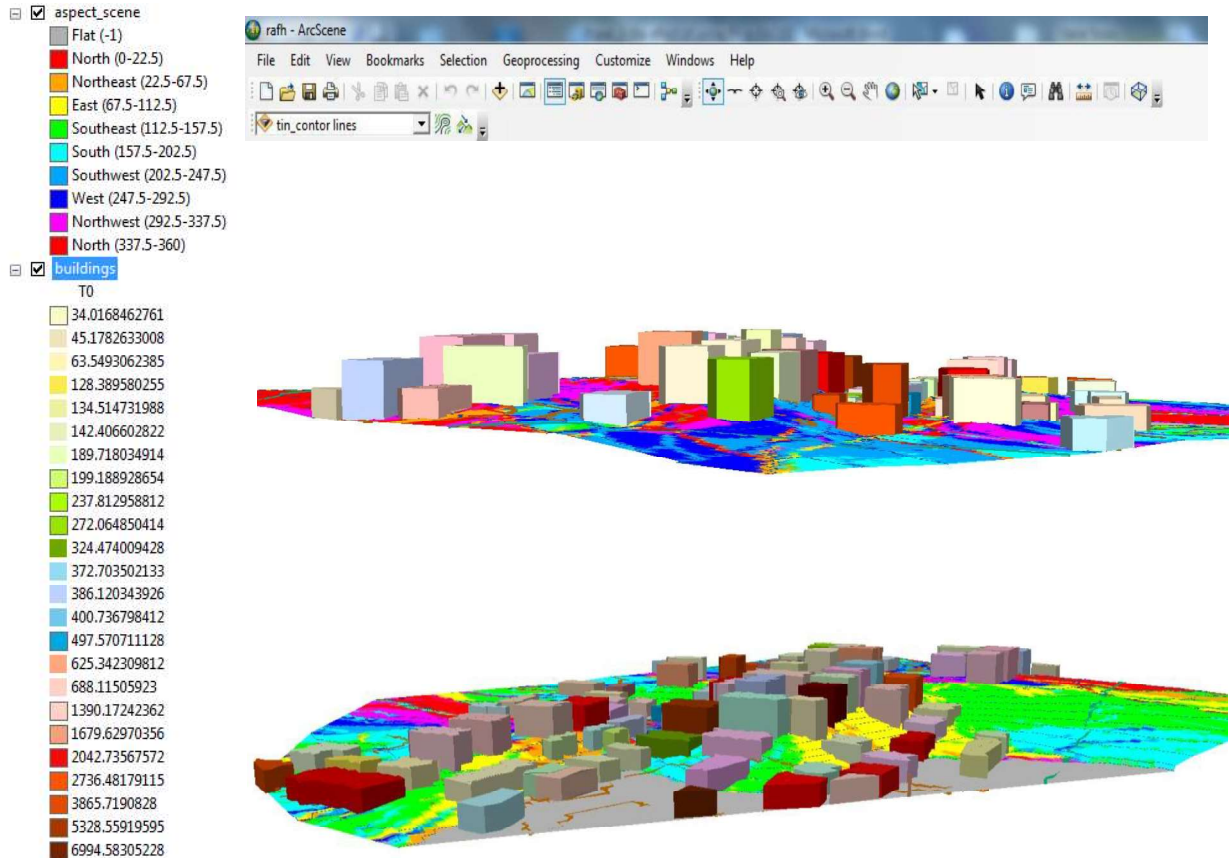


Figure-15: Visualizing the Estimated Solar Radiation Consumption for Each Colored 3D Building Using ArcScene Software.[7]

In this study, using of vertical solar PV for the architectural façade has been analyzed in accordance with the calculation of solar radiation for optimum selection façade. So; it could be reached to *the following points:*

- a. Building process of orientation of every building according to the projection system in 3D GIS model.
- b. Using the probability of optimistic location of PV panels in the building's façade by evaluating the optimum selection for a typical site related to estimated solar radiation consumption for each colored 3D building using ArcScene software.
- c. The optimum selection of PV panels depends on many other parameters, such as the PV Specifications as the Max. system voltage, Max. series fuse rating, Operating temperature range, Max. static load, front (e.g., snow and wind), Max. static load, back (e.g., wind), Max. hailstone impact (diameter / velocity).
- d. Accordingly, the Max. system voltage factor has been obtained at different seasons facilitating the selection of the best suited vertical solar PV module at the specified site location that is based on how much power could be extracted from the PV modules at any desired time to supplement the power demand.

- e. The results obtained from the distribution of vertical PVs have revealed that the south facade yield more efficient output power towards the on-grid systems in relevant to the west façade

6. Conclusion

The study presents the ability to define the using of vertical solar PV for the architectural façade of buildings model at a case study model of Rafah in Sinai at Egypt. This model is considered as generated simulation model according to spatial system as well. This could be done by modeling the solar radiation characteristics of the site to estimate it and measured at specific geographical location using ArcGIS software through 3D spatial database. The proposed PV panels can be used in local level with the available possibilities in Egypt that are effectually applicable in improving the exchange of urban data that is based on unified geodatabase. Also; the proposed PV panels is capable of improving the interoperability with urban data during various tasks such as designing and collaborating urban planning for developing any urban area according to proper characteristics of planning. Using vertical solar PV for the architectural façade by estimating the solar radiation would be very helpful for solving the lack of energy in every residential building. This study would benefit different stakeholders such as; expert urban planners and different local authorities. Indeed, the proposed model can be tested and evaluated before implementing it in the real site to achieve the most appropriate results for execute more sustainable buildings to save energy consumption. Moreover; reduction of 38.2% or more ratio in the total site energy consumption can be achieved on changing the design decisions and parameters; building orientation, location of windows which have a direct influence on energy use, and indoor environment. Energy simulation is an evaluation tools for the designer before deigning and executing the proposed building.

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