

Development of a Photo Voltaic Building Rooftop Integration Analysis Tool for GIS for Dokki District, Cairo, Egypt

Ahmed Mohamed El Saeid Mustafa

2012
Department of
Physical Geography and Ecosystem Analysis
Centre for Geographical Information Systems
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden



**Development of a Photo Voltaic Building Rooftop
Integration Analysis Tool for GIS for Dokki District,
Cairo, Egypt**

By: Ahmed Mohamed El Saeid Mustafa

Master thesis, 30 credits, in Geographical Information
Sciences

Supervisor: Dr. Ulrik Mårtensson
Research Assistant and Teacher in GIS, Dept. of Physical
Geography and Ecosystem Analysis, Lund University.

Dedication

I dedicate this work to my parents, siblings, Mohamed M. El Saeid, Nourhan Khalifa and Ayman M. Lotfy.

Acknowledgements

I wish to express my gratitude to my supervisor, Dr. Ulrik Mårtensson at the Department of Physical Geography and Ecosystem Analysis, Lund University for good advice, patience and encouragement.

I wish to express my special thanks to Dr. Micael Runnstöm, Dr. Roger Groth and Dr. Petter Pilesjö for their assistance throughout LUMA program. Special thanks also to my colleagues Anne Njoroge and David Kanyari for their valuable suggestions and discussions throughout the LUMA program.

Information Technology Institute/ Egypt, which provides intensive courses in GIS for one academic year. Thank you.

A special thank you goes to Dr. Moamen Afify at the Department of Architecture, Cairo University, for providing a good knowledge of energy simulation in buildings using Ecotect software.

Friends, colleagues and family, thank you, without you this would never have been possible.

Abstract

This study describes the development and implementation of a Photo Voltaic (PV) Roof Integration Analysis Tool integrated into a GIS system in order to be used in conducting research within alternative energy field.

The tool was developed in ArcMap using Visual Basic for Applications (VBA). In order to manage tables, map, etc. in ArcMap the ArcObjects COM-library was used. The different functions of the tool are: show address, find building rooftop suitability for using PV system, find installable modules area, find expected maximum electricity output, find reduction of CO₂ emission and find how many people can utilize PV system output.

Nowadays, the reduction of greenhouse gases is playing most important role around the world. By using other energy sources instead of ordinary fossil fuels, such as renewable energies, we can help to meet the greenhouse gas reduction targets and supports the goals of the Ministry of Environment in Egypt.

The results of the study encourage the installation of the PV systems to electrify suitable buildings.

The most important conclusion of this thesis is that GIS can be an advantageous tool in alternative energy fields. The Photo Voltaic Roof Integration Analysis Tool is an example of a user-friendly tool that can be used in researches within renewable energy sector.

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1 Introduction

1.1 Background

There are many changes after the Egypt's revolution, including the tendency of governmental authorities to work on the development of alternative energy sources and reduce the dependence on fossil fuels.

Experts can take part in the planning procedures for new urban areas to state the specifications for integrating Photo Voltaic (PV) modules into buildings but for the existing urban collections, if there are needs to install the PV modules in the buildings' rooftops, we will face several problems including the differences in heights of buildings, guidance and the formation of the roofs and other factors which urges the work of a detailed study from which to assess the roofs of buildings on the basis of the possibility for the use of photovoltaic modules.

Stakeholders in Egypt, such as the Ministry of Environment, the Ministry of Electricity & Energy and the Ministry of Finance, can achieve several benefits when using renewable energy technologies, for instance, slow greenhouse gas emissions, expand our energy options, establish new companies and create new job vacancies.

This study focuses on the Dokki district in Greater Cairo that was used as a case for developing the idea of a tool to assess the possibility of the roofs of existing buildings to install PV modules in order to electrify building through developing a tool that works within the environment of ArcGIS software.

1.2 Purposes

The main aim of the thesis project is to introduce a set of analytical functions in a software application with the purpose of obtaining a suite of analysis functions, where they code is fully available and it can be accessed with the possibility of modifying or even adding more functions. The toolbox was developed on VBA because of the VBA allows modify the code with anyone with basic programming skills.

The project aims to produce a tool that might help energy planners to assess whether the specific building rooftop is suitable for using solar energy by installing PV modules on rooftops or not. Also to find approximately how much CO₂ will be reduced by using PV system on rooftops and how many people can benefit from the amount of electricity that may be produced by the PV rooftop system.

1.3 Structure of the Thesis Report

This thesis report is organised in main seven chapters. Chapter 1 is the introduction part of the thesis. Chapter 2 gives a brief background of PV physics and installation considerations along with brief description of the Sun. Chapter 3 introduces technical fundamentals of GIS, ArcGIS, VBA, ArcObjects and Ecotect analysis tool. Chapter 4 describes the toolbox of the software detailing all the functions and codes used by the application. Chapter 5 contains the results of the software suite for all study area. Chapter 6 includes general discussion about the study's results and evaluation of the tool. Chapter 7 is a conclusion and proposed future work.

1.4 The Study Area: Facts about Egypt

1.4.1 Location

Egypt is situated in northern Africa, bordering the Mediterranean Sea. Libya is on its western border, the Gaza Strip & the Red Sea make up the eastern border and the Sudan lies on Egypt's southern border [20].

1.4.2 Geography

Egypt area is about 1,001,450 km² [21]. It has a desert climate with hot, very dry summers, moderate winters and there is almost no rainfall on a regular circumstances [20].

The country is basically a vast desert plateau interrupted by the Nile Valley and Delta. The lowest point is at the Qattara Depression -133 m, and the highest point is Mount Catherine at 2,629 m. Natural hazards that afflict the country are: Periodic droughts, frequent earthquakes, flash floods, landslides and a hot, driving windstorm called khamasin which occurs in the spring [20].

Egypt controls the Sinai Peninsula and the Suez Canal. Its size and juxtaposition to Israel establish its major role in The Middle Eastern geopolitics [20].

1.4.3 Fast Facts

Egypt is Africa's second most populous country after Nigeria, and it has the highest population in the Arab world [19]. Total population is 82,079,636 (July 2011) with median age 24.3 years [21]. About 94% of populations are Muslims (mostly Sunni) and 6% are Coptic Christian and other [20].

Egypt's ethnic groups are consisted of about 99.6% Egyptian and 0.4% other (2006 census) [21]. The official language is Arabic also English and French widely understood by educated classes [21].

1.4.4 A Quick History

The regularity and richness of the annual Nile River flood that begins in June and end in October had created urban collections along the Nile banks. Without the Nile, there would likely be no Egypt. A unified kingdom arose circa 3200 B.C. and a series of dynasties ruled in Egypt for the next three millennia. The last native dynasty fell to the Persians in 341 B.C., who in turn were replaced by the Greeks, Romans, and Byzantines. It was the Arabs who introduced Islam and the Arabic language in the 7th century and who ruled for the next six centuries. A local military caste, the Mamluks took control about 1250 and continued to govern after the conquest of Egypt by the Ottoman Turks in 1517. Following the completion of the Suez Canal in 1869, Egypt became an important world transportation hub, but also fell heavily into debt. Ostensibly to protect its investments, Britain seized control of Egypt's government in 1882, but nominal allegiance to the Ottoman Empire continued until 1914. Partially independent from the UK in 1922, Egypt acquired full sovereignty following World War II. The completion of the Aswan High Dam in 1971 and the resultant Lake Nasser have altered the time-honored place of the Nile River in the agriculture and



Fig. 1.1 Egypt map, source [28]

ecology of Egypt. A rapidly growing population (the largest in the Arab world), limited arable land, and dependence on the Nile all continue to overtax resources and stress society. The government has struggled to ready the economy for the new millennium through economic reform and massive investment in communications and physical infrastructure [21].

1.4.5 Economic Overview

Egypt's economy was highly centralized during the rule of former President Gamal Abdel NASSER but opened up considerably under former Presidents Anwar EL-SADAT and Mohamed Hosni MUBARAK [21]. Lack of substantial progress on economic reform since the mid 1990s has limited foreign direct investment in Egypt and kept annual GDP growth in the range of 2-3 percent in 2001-03 [20]. Cairo from 2004 to 2008 aggressively pursued economic reforms to attract foreign investment and facilitate GDP growth [21]. In 2010, the government spent more on infrastructure and public projects, and exports drove GDP growth to more than 5%, but GDP growth in 2011 is unlikely to bounce back to pre-global financial recession levels, when it stood at 7% [21].

GDP main sectors are industry, which includes textiles, food processing, tourism and chemicals; agriculture, which includes cotton, rice, corn, wheat and cattle; exports, which include crude oil and petroleum products, cotton, textiles, metal products and chemicals; tourism revenues and Suez Canal revenues [19].

1.4.6 Greater Cairo

Greater Cairo, the capital of Egypt, lies on the south edge of the Nile delta. Cairo has the largest population in Africa and the Middle East and is considered as one of the world's 15 largest cities in urban and population growth, home to almost a quarter of the total population of Egypt. Its population exceeds 14 million (2010 statistics, source: CAPMAS) concentrated over an area of about 214 km².

There are over 4,500,000 cars on the streets of Cairo, 60% of which are over 10 years old and therefore lack modern emission cutting features like catalytic converters. Cairo has many unregistered lead and copper smelters which heavily pollute the city. The results of this have been a permanent haze over the city with particulate matter in the air reaching over three times normal levels. It is estimated that 10,000 to 25,000 people a year in Cairo die due to air pollution-related diseases [26].

Cairo has an arid desert climate, where the days are hot but the nights are relatively cool [25].

Egypt is located in the world's Sun Belt area and has a high solar radiation level throughout the year. The average solar radiation ranges from about 1950 kWh/m²/year on the Mediterranean coast to more than 2600 kWh/m²/year in Upper Egypt [8].

1.4.7 Dokki District

The detailed data that contains height of the buildings costs too much, therefore we have selected one of the most famous districts in Greater Cairo that is Dokki district, Giza. Dokki is situated at the western bank of the Nile, directly across from Downtown Cairo [24]. Dokki covers about 5 km² and has about 5700 buildings.

Dokki population exceeds 122 thousand (2011 statistics, source: official website for the judicial committee

supervising Egyptian's elections [31]).

Dokki is urbanized area and big portion of populations are working on trade and services sectors.

Many landmarks are located in Dokki, the German school DEO and approximately 56 foreign embassies of many countries including Russia, France, Chad, the Czech Republic, Somalia and Ethiopia.

1.5 Data and Software

The data is used in the study are: district's buildings layer, landmarks layer, streets layer and metro stations layer. The most important layer is buildings layer. The data was provided by Connection-maps Company (working on surveying and GIS data collection field in Egypt); updating date is December 2008 (based on provider). The data coordinate system is WGS 1984 UTM zone 36N.

Cairo Intl Airport 623660 weather data file (using ETMY method) is used in the study. This is the climatic data file mainly used to find shadow percentage per roof via Autodesk Ecotect software.

Weather file details:

World Meteorological Organization station number 623660.

Location: Cairo International Airport

Elevation: 74m above sea level

Standard Pressure at Elevation -- 100439Pa

Egyptian Typical Meteorological Year (ETMY) method is developed for standards development and energy simulation by Joe Huang from data provided by U. S. National Climatic Data Center for periods of record from 12 to 21 years, all ending in 2003 [22].

Software used: ESRI ArcGIS "ArcView 9.3", Autodesk Ecotect Analysis 2011 and Microsoft office 2007.

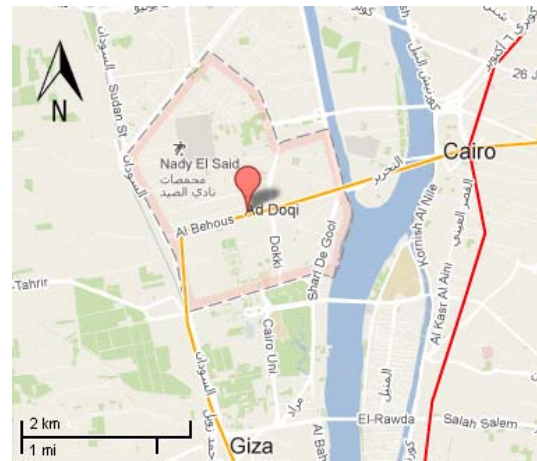


Fig. 1.2 Study area, source [Google Maps]

2 Theoretical Fundamentals

2.1 Photovoltaic Systems Engineering Background

The word Photovoltaic (PV) is composed of two terms: Photo - Photon which means "light" and Voltaic from "Volt" which is the unit used to measure electric potential at a given point. The PV power technology uses semiconductor cells (wafers), generally several square centimeters in size [2]. PV system converts sun radiation directly into direct current electricity. It works any time the sun is shining, but more electricity is produced when the sunlight is more intense and strikes the PV modules directly (as when rays of sunlight are perpendicular to the PV modules) [1].

This part looks at PVs and examines a number of issues of interest to designers including the photoelectric process, the PV cells, PV modules and PV arrays.

2.1.1 The Photoelectric Process

The PV process works by the photovoltaic effect in semiconductor materials [5]. When light strikes the cell, a portion of it is absorbed within the semiconductor material and "knocks" electrons loose, enabling an electrical charge to flow freely within the material [5]. Figure 2.1 shows PV cells have an in-built electric field that acts to force electrons, freed by light absorption, to flow in a certain direction. The field is created by doping in silicon with elements such as phosphorus or boron to create n-type or p-type zones [5].

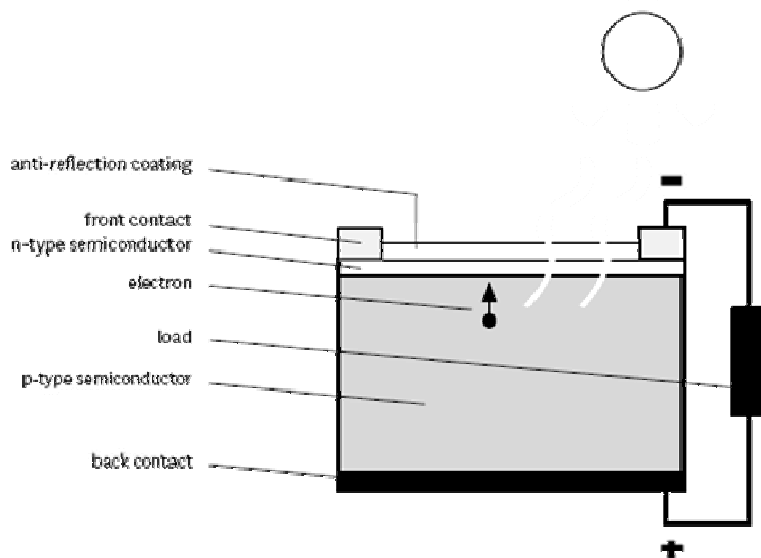


Fig. 2.1 Schematic of a single PV cell showing the main functional parts for conversion of light to electrical energy. The thickness of the absorbing layer is exaggerated to show an electron carrier, source [5]

By placing metal contacts on the top and bottom of the PV cell, the current generated can be put to work by passing through an external circuit. The current is generated silently with no moving parts; no emissions and the cells need no maintenance, apart from keeping the top surface of the module clean for the passage of light [5].

In a graph of the spectrum (Figure 2.2), the visible part corresponds to the wavelength range, 400–700 nm. The overall curve in the figure shows the solar spectrum stretching into the infra-red beyond 2000 nm. Silicon PV cells absorb most of the visible spectrum and the near infra-red up to 1100 nm [5].

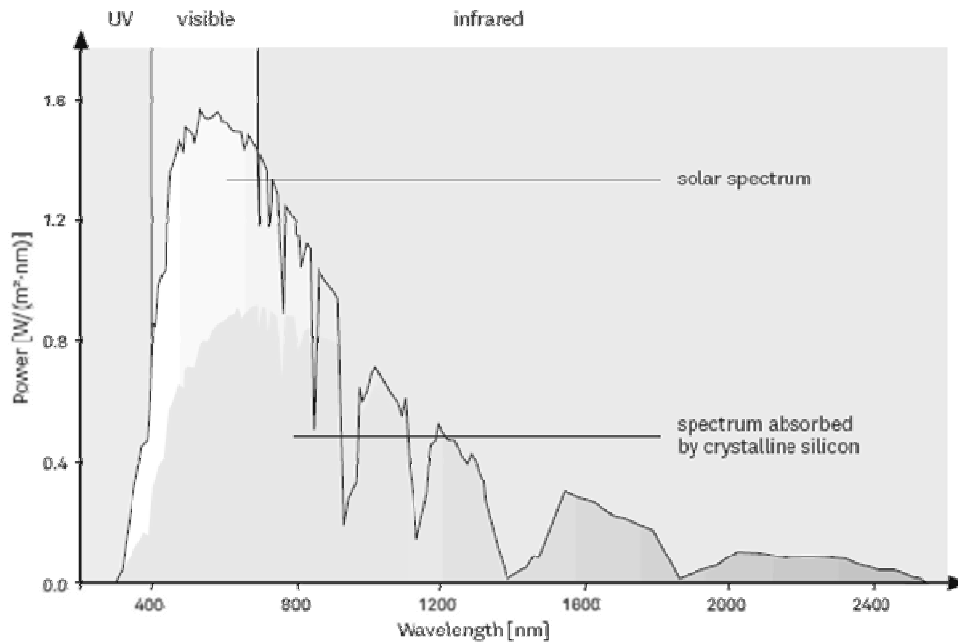


Fig. 2.2 Comparative spectra for solar input (including atmospheric losses) and the spectral parts absorbed by crystalline silicon PV cells. The solar spectrum is AM 1.5 at an irradiance of 1000 W/m^2 , source [5]

2.1.2 The PV Cell

Photovoltaic cells consist of a junction between two thin layers (positive P and negative N) of dissimilar semi conducting materials. When a photon of light is absorbed by a valance electron of an atom, the energy of the electron is increased by the amount of energy of the photon [3].

When the cells are exposed to the sun, direct current (DC) flows as shown in Figure 2.3. PVs respond to both direct and diffuse radiation and their output increases with increasing sunshine or, more technically, irradiance [4]. Cell efficiency relies on two main factors, the efficiency of conversion and the ability to absorb solar radiation.

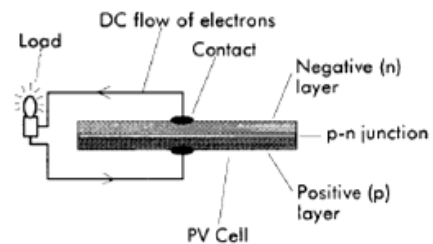


Fig. 2.3 Diagram of PV principles, source [4]

Comparisons between alternative power technologies, the most important measure is the energy cost per kWh delivered.

Most important cell technologies are single-crystalline Silicon, polycrystalline Silicon and thin films. Single-Crystalline Silicon is the most common method of producing this material, the silicon raw material is first melted and purified in a crucible. A seed crystal is then placed in the liquid silicon and drawn at a slow constant rate. Typical module efficiency for this type is 12-15% [2, 5]. Polycrystalline Silicon is relatively a fast and low cost process to manufacture thick crystalline cells. Instead of drawing single crystals using seeds, the molten silicon is cast into ingots. In the process, it forms multiple crystals. The conversion efficiency is lower, but the cost is much lower. Typical module efficiency for this type is 11-14% [2, 5]. A thin film is available as solid forms like others or as flexible films with small thickness. Typical module efficiency relies on manufacture material type as follows [11]

- A. Thin-film amorphous silicon: 7-9%.
- B. Thin-film Cadmium Telluride: 7-10%.
- C. Thin-film Copper Indium Diselenide: 18% “not available for commercial purposes”.
- D. Thin-film Gallium Arsenide: 35.6% “not available for commercial purposes”.

2.1.3 The PV Module

In order to obtain adequate output voltage, PV cells are connected in series to form a PV module [6]. The modules are constructed like a sandwich (and sometimes referred to as laminates) and have a backing sheet and a cover of low-iron glass which protects the front surface of the material while maintaining a high transmissivity. A structural frame is used in a number of designs to protect the glass [4].

The design goal is to connect a sufficient number of cells in series to preserve V_m of the module within a comfortable range of the battery/system voltage under conditions of average irradiance. If this is done, the power output of the module can be maintained close to maximum [6].

When connecting a module into a system, one consideration is what happens when the module is not illuminated. This can happen at night, but can also happen during the day if any cell or portion of a cell is shaded by any means [6].

Under night time conditions, when none of the cells are generating appreciable photocurrent, it is necessary to consider the module as a series connection of diodes that may be forward biased by the system storage batteries, as shown in Figure 2.4 below [6].

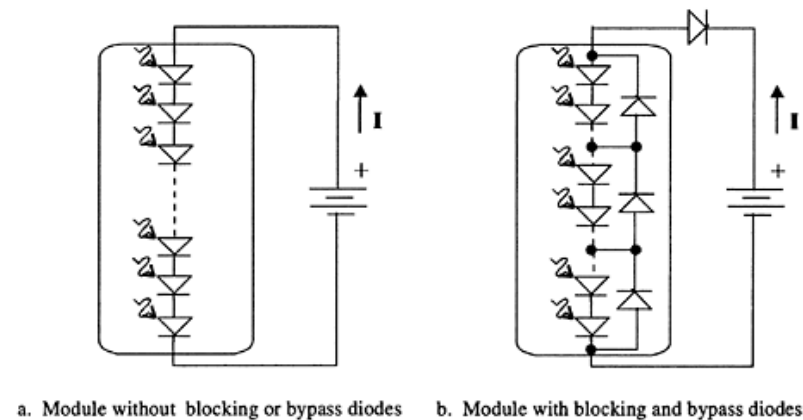


Fig. 2.4 Battery discharge path through PV module with and without blocking diode, source [6]

Another important observation relating to the series connection of PV cells relates to shading of individual cells. If any one of the cells in a module should be shaded, the performance of that cell will be degraded. Since the cells are in series, this means that the cell may become forward biased if other un-shaded modules are connected in parallel, resulting in heating of the cell [6]. This phenomenon can cause premature cell failure. To protect the system against such failure, modules are generally protected with bypass diodes. If PV current cannot flow through one or more the PV cells in the module, it will flow through the bypass diode instead [6].

Standard module dimensions are 1.0×0.5 m, 1.33×0.33 m or 1.2×0.7 m. Many producers design modules in other dimensions if required by the client [11].

2.1.4 The PV Array

Array is a series of connected PV modules. The output from building-integrated PV installations is the output of the PV arrays less the losses in the rest of the system [4]. There are normally two types of connections, Series and Parallel connections. Series connections result in higher voltages, while parallel connections result in higher currents [6].

Figure 2.5 below shows two common module configurations.

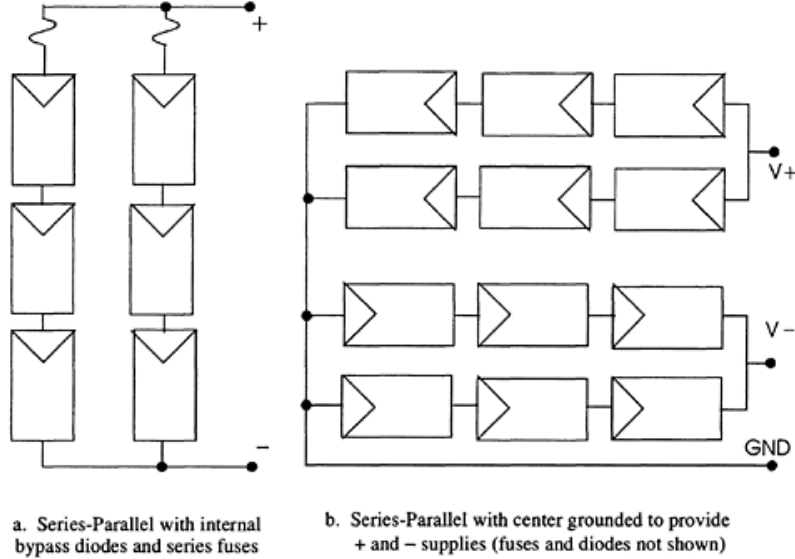


Fig. 2.5 Examples of PV arrays, source [6]

2.2 PVs in Buildings

One of the attractive features of the PV system is that its power output can match with the peak load demand for standard family uses [2]. PVs offer enormous potential to building designers. If architect take into consider the PVs as an integral part of the energy strategy of the building and of its functioning in this case the PVs can influence building's orientation, footprint, layout and form; they will affect the building fabric and will be an important element of the environmental and building systems. The integration of PVs with the other building elements is critical to success. Appearance and aesthetics are, as ever, especially important [4].

2.2.1 Location Constraints

It is desirable to have a site with as little shading as possible as this reduces the electrical output.

Because of the way PV modules are wired, shadowing from any source can have what might seem to be a disproportionate effect. In urban areas overshadowing by other buildings is common, Figure 2.6. Computer programs are available to assist in analysing these losses [4].

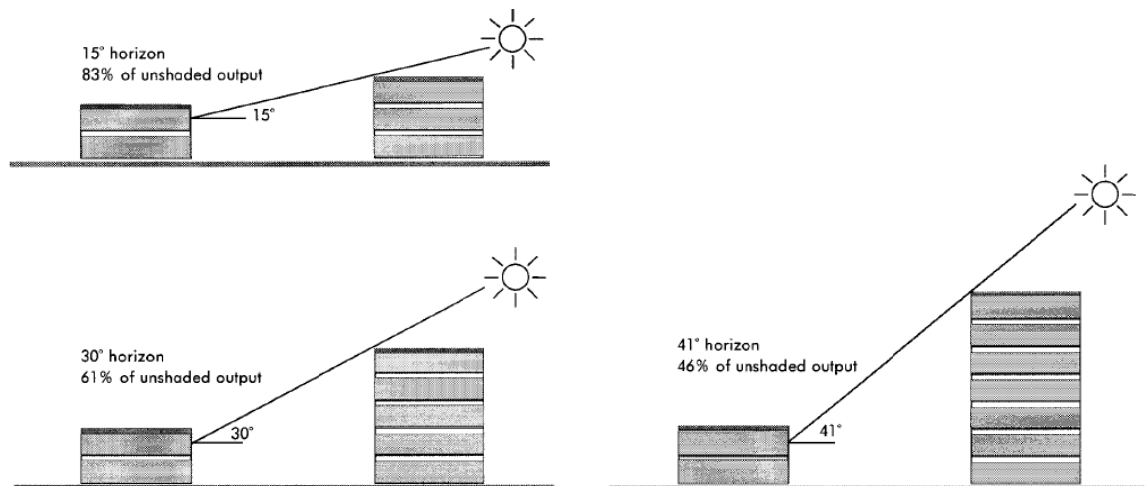


Fig. 2.6 very approximate estimate of losses due to shading by neighbouring buildings, source [4]

2.2.2 Forms and Systems

The three basic ways of integrating PVs into buildings are roof-based systems, facade systems and sunshades/sunscreens [4].

2.2.3 Ventilating Roof Systems

Roof systems are likely to be easier to ventilate than facade systems and any unwanted heat gains, being above the occupancy height, are likely to have less effect than for facade systems.

One of the common ways to ventilate roof system is shown in Figure 2.7. This allows an air space (100mm if possible) between the modules and the roof structure (which incorporates the insulation). For many saw-toothed roof designs, opening north lights can take away the heat [4].

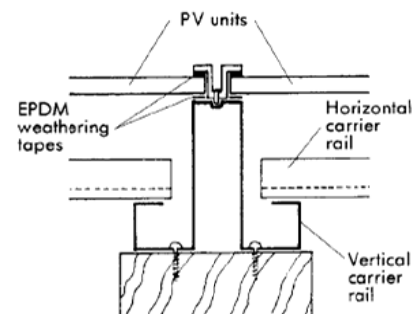


Fig. 2.7 Ventilating PV roof using sub frame for mounting the PV modules onto the roof structure. This allows an air space (100mm if possible) between the modules and the roof structure, source [4]

2.2.4 PV System Units in Buildings

The main elements of PV system are PV modules, inverter to convert Direct Current (DC) into Alternating Current (AC), cabling and components used for electrical protection, meter to record the quantity of electric power fed into the grid (grid connected systems) and in case of off-grid systems charge controllers and a storage battery will be used for supplying the electric energy when there is no sunlight e.g. during night hours.

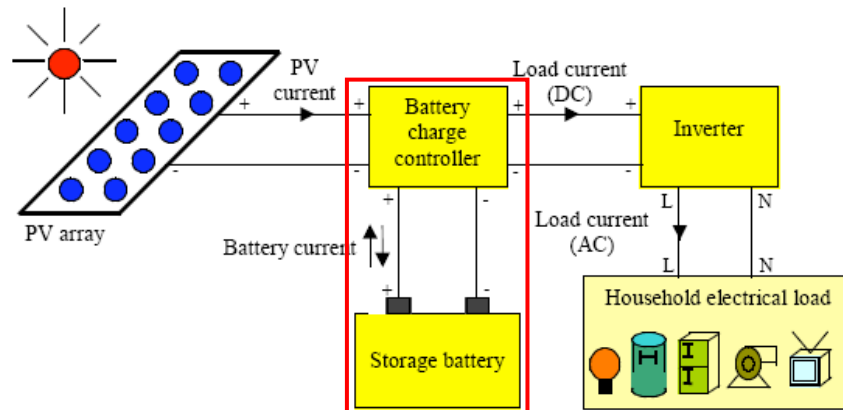


Fig. 2.8 The PV integration building systems' units, source [8]

2.2.5 Safety

The PVs building integration system should be considered in terms of construction and access for maintenance, in the normal way following the CDM (Construction Design and Management) Regulations [4].

Safety is a standard consideration with all electrical installations. There are particular issues that apply to PVs. Firstly, current is produced during a wide variety of light conditions and so to switch off the installation one needs, for example, to cover the modules with something opaque. Secondly, there is less familiarity within the building industry with DC compared with AC. Thirdly, Voltages can be higher than the familiar 240V single phase AC [4].

2.3 The Sun

The sun has played an important role since time immemorial for all natural activities in the earth in particular for the formation of fossil and renewable energy sources. Solar radiation emission from the sun into every corner of space appears in the form of electromagnetic waves that carry energy at the speed of light [3].

This chapter provides a synopsis of important solar phenomena, including the solar spectrum, determination of sun position and measurement of solar parameters.

2.3.1 Electromagnetic (EM) Spectrum

In one hour, the Earth receives enough energy from the sun to meet its energy needs for nearly a year. In other words, this is about 5000 times the input to the Earth's energy budget from all other sources. In order to maximize the utilization of this important energy resource, it is advantageous to understand some of the properties of this "ball of fire" in the sky [3, 6].

The interaction of matter with the area of the electromagnetic (EM) spectrum that is known as light gives it color, perceived through the eyes. EM waves consist of

electric and magnetic fields, which are perpendicular to each other and perpendicular to the direction of travel as shown in Figure 2.9 [3].

The range of the visible spectrum is very small with red light having a longer wavelength (7×10^{-7} m) than blue light (4×10^{-7} m) Figure 2.10 [3].

Knowledge of the spectral composition of the sun is important for understanding the effects of the atmosphere on the radiation from the sun and for understanding which materials should offer the best performance in the conversion of sunlight to electricity [6]. For example, depending on the color temperature of the light source, photographic film must be compensated to obtain true colors. At lower temperatures, nearly the entire spectrum lies outside the visible range in the infrared range the characteristic white color of the sun is obtained due to the mix of wavelengths in the visible spectral range. At even higher temperatures, the color shifts toward blue, and at lower temperatures, the color shifts toward red.

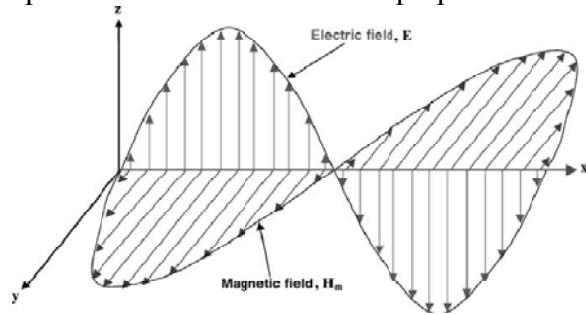


Fig. 2.9 EM waves “electric and magnetic fields”, source [3]

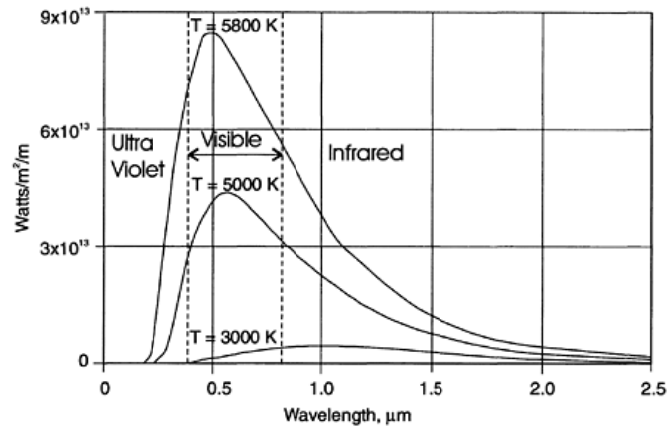


Fig. 2.10 Blackbody radiation spectra for temperatures of 3000 K, 5000 K and 5800 K, source [6]

2.3.2 Finding the Sun's Position

To specify the sun position it is necessary to specify three coordinates. If we assume the distance from the sun to the Earth to be constant, the position of the sun can be specified using two coordinates the solar altitude and the azimuth. The complement of the zenith angle (the zenith is a line perpendicular to the Earth), θ_z , is called the solar altitude, α , and represents the angle between the horizon and the incident solar beam in a plane determined by the zenith and the sun, see Figure 2.11. The air mass is proportional to $\sec \theta_z$ [6].

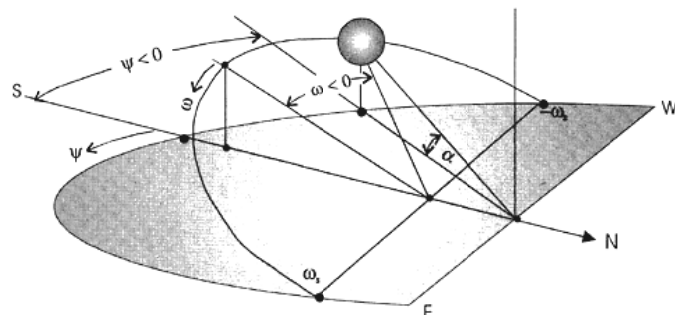


Fig. 2.11 Sun angles, showing altitude, azimuth and hour angle, source [6]

The angular deviation of the sun from directly south can be described by the azimuth angle, ψ , which measures the sun's angular position east or west of south. It is the angle between the intersection of the vertical plane determined by the observer and the sun with the horizontal and the horizontal line facing directly south from the observer, assuming the path of the sun to be south of the observer [6].

The angle of deviation of the sun from directly above the equator is called the declination, δ . If angles north of the equator are considered as positive and angles south of the equator are considered negative, then at any given day of the year, n , the declination can be found from [6]

$$\delta = 23.45^\circ \sin [(360(n-80))/365] \quad (2.1)$$

Another advantageous angle in describing the position of the sun is the angular displacement of the sun from solar noon in the plane of apparent travel of the sun. The hour angle is the difference between noon and the desired time of day in terms of a 360° rotation in 24 hours [6]. To compute that [6]

$$\omega = ((12-T)/24) \times 360^\circ = 15 (12-T)^\circ \quad (2.2)$$

Where T is the time of day expressed with respect to solar midnight, on a 24-hour clock. For example, for $T=0$ or 24 (midnight), $\omega=\pm 180^\circ$ and for $T=9$ a.m., $\omega=45^\circ$.

It is possible to show that the sunrise angle is given by [6]

$$\omega_s = \cos^{-1}(-\tan \Phi \tan \delta) \quad (2.3)$$

Where Φ represents the latitude or angular distance from the equator. By convert the sunrise angle to hours from sunrise to solar noon, and then multiplying by 2 to include the hours from solar noon to sunset, yields the number of hours of daylight can be computed as [6]

$$DH = (48/360) \times \omega_s = (\cos^{-1}(-\tan \Phi \tan \delta))/7.5 \text{ hr} \quad (2.4)$$

Note that if δ , Φ and ω are known, then the position of the sun, in terms of α and ψ at this location at this date and time, can be determined from [6]:

$$\sin \alpha = \sin \delta \sin \Phi + \cos \delta \cos \Phi \cos \omega \quad (2.5)$$

$$\cos \psi = (\sin \alpha \sin \Phi - \sin \delta) / (\cos \alpha \cos \Phi) \quad (2.6)$$

Please note all angles above are measured in degrees.

2.3.3 Egypt's Solar Resources Potential

Egypt lies among the Sun Belt countries with annual global solar insolation ranging from 1750 to 2680 kwh/m²/year from North to South and annual direct normal solar irradiance ranging from 1970 to 3200 kwh/m²/year also from North to South with relatively steady daily profile and small variations making it very favorable for utilization. Such conditions of favorite solar resource utilization are supported by other conditions of sunshine duration ranging from 9 – 11 hours with few cloudy days over the year [15].

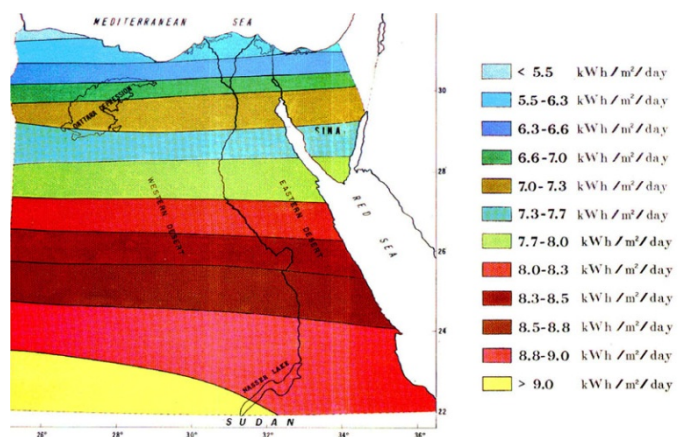


Fig. 2.12 annual average of direct solar radiation over Egypt, source [15]

Using Egypt's sun radiation Atlas the annual average of direct sun radiation in Cairo, Egypt, can be determined which is about $6.7 \times 365 = 2445 \text{KWh}/(\text{m}^2\text{-y})$.

2.3.3.1 Egypt's Sun Path Diagram

Sun-path diagrams are a convenient way of representing the annual changes in the path of the Sun through the sky on a single 2D diagram. They provide a unique summary of solar position that the designer can refer to when considering shading requirements and design options [16].

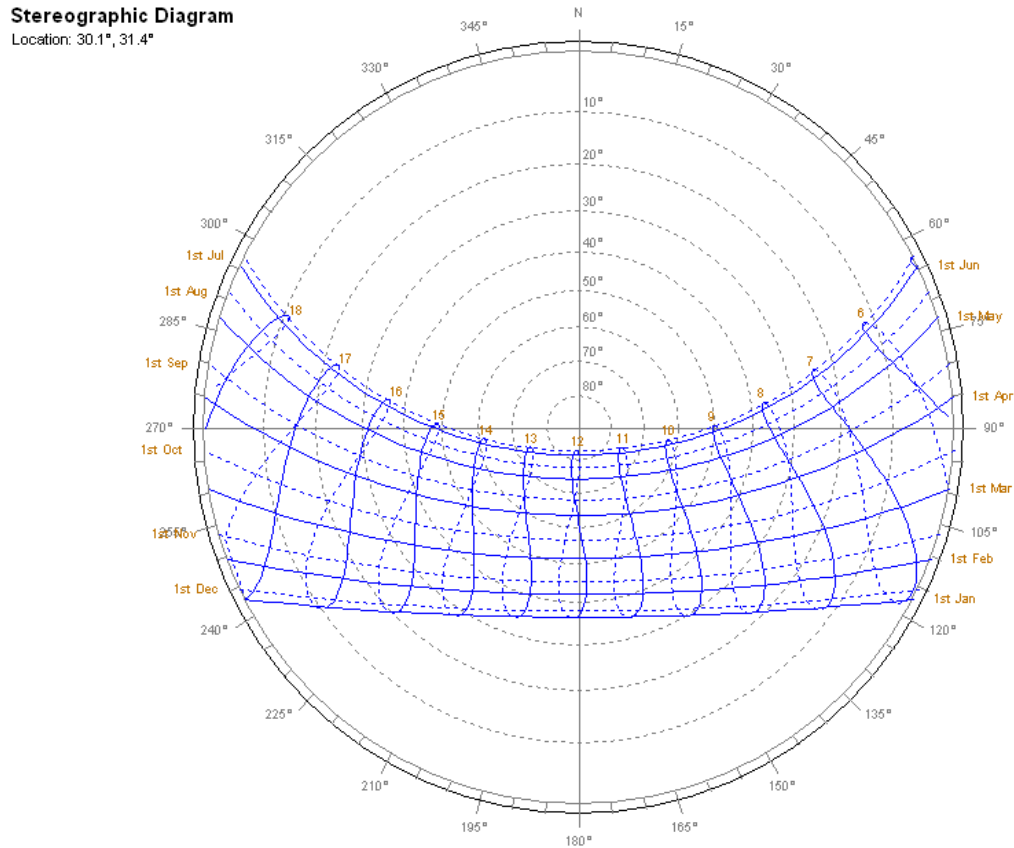


Fig. 2.13 Cairo 2D Sun-path diagram. Produced by Autodisk® Ecotect.

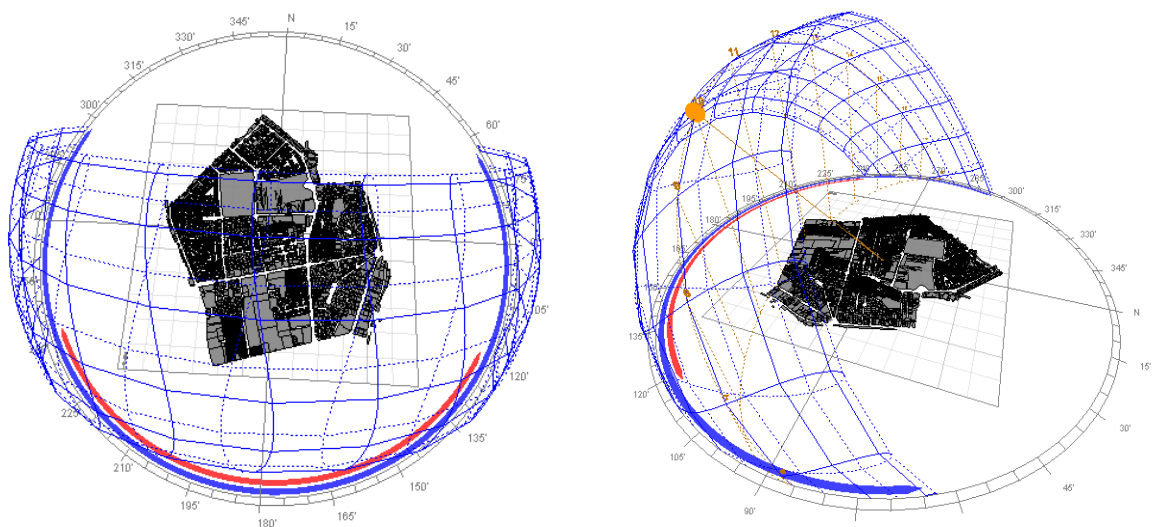


Fig. 2.14 3D Sun-path diagram. Produced by Autodisk® Ecotect.

In order to find the exact Sun's position in the sky the Sun-path diagram is needed to be read correctly. There are main four lines in Sun-path diagram (Figures 2.13, 2.14) azimuth Lines, altitude lines, date Lines and hour Lines [16]. Azimuth angles run around the edge of the diagram in 15° increments. A point's azimuth from the reference position is measured in a clockwise direction from True North on the horizontal plane. True North on the stereographic diagram is the

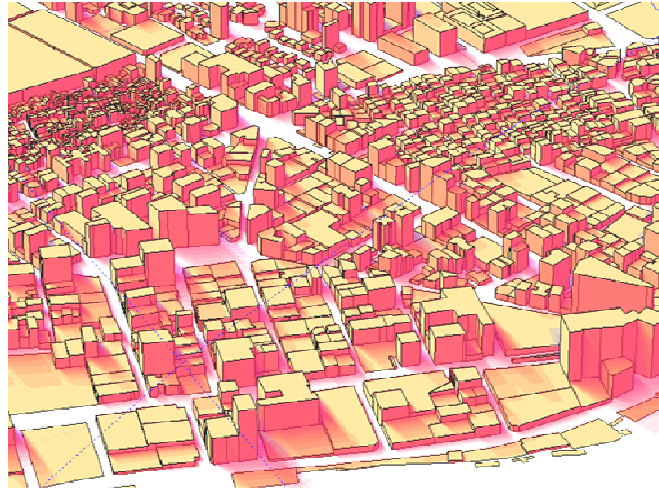


Fig. 2.15. Study area 3D annual shadows presentation

positive Y axis (straight up) and is marked with an N. Altitude angles are represented as concentric circular dotted lines that run from the centre of the diagram out, in 10° increments from 90 to 0 . A point's altitude from the reference position is measured from the horizontal plane up. Date lines represent the path of the sun through the sky on one particular day of the year. They commence on the eastern side of the graph and run to the western side. There are twelve of these lines shown, for the 1st day of each month. The first six months are shown as solid lines (Jan-Jun) whilst the last six months are shown as dotted (Jul-Dec), to allow a clear distinction even though the path of the Sun is cyclical. Hour lines represent the position of the sun at a specific hour of the day, throughout the year. They are shown as figure-2.13 type lines (*Analemma*) that intersect the date lines. The intersection points between date and hour lines give the position of the sun. Half of each hour line is shown as dotted, to indicate that this is during the latter six months of the year.

3 Technical Fundamentals

3.1 GIS and GIS Applications

3.1.1 What is GIS?

A Geographical Information System is an integration of computer hardware and software which can create, manipulate and analyze a geographically referenced database to produce new maps and tabular data. GIS includes the capabilities of Computer Aided Design (CAD) and DataBase Management Systems (DBMS), but is more than just a combination of those systems. In a GIS, a relationship between the graphic map data and the tabular database is maintained so that changes to the map are reflected in the database, and vice versa [10].

3.1.2 ArcGIS

ArcGIS is an integrated family of GIS software products for building a complete GIS. ArcGIS provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field [27].

Esri's ArcGIS consists of several primary frameworks for deploying GIS. Firstly, ArcGIS Desktop: an integrated suite of professional GIS applications, most users recognize this as three products ArcView, ArcEditor, and ArcInfo. Secondly, server GIS: which includes ArcIMS, ArcGIS Server, and ArcGIS Image Server. Thirdly, mobile GIS: which includes ArcPad and ArcGIS Mobile for field computing. Fourthly, developer GIS: which includes ArcGIS Engine plus software development kits for Desktop, Server and Mobile that enable software developers to customize and extend the ArcGIS framework [27].

3.1.2.1 ArcGIS Desktop

This product is a complete system divided into three desktop applications: ArcMap, ArcCatalog, and ArcToolbox. All of the desktop applications can be reached from any of the three software products ArcView, ArcEditor or ArcInfo [7].

3.2 Visual Basic

Microsoft Visual Basic (VB) consists of tools for designing interface and a simplified software programming language. Examples of interfaces are menus, texts and graphics. VB is frequently used for interface development in Windows environment, but the programming language is not very suitable for heavy calculations [7].

VB programming language build around objects, each object has some methods "actions" and some properties. The methods are used to perform actions with the objects. A property is something that characterizes the object, e.g. its name. VB is so-called event-oriented programming, which means that something is executed when the user for example clicks a command-button [7].

VB application can be built from several forms. The forms are simply connected to each other in the code.

3.2.1 Visual Basic for Applications

Microsoft Visual Basic for Applications (VBA) contains a set of programming tools that can be embedded in applications based on the Microsoft Visual Basic development system and is designed to enable developers to build custom solutions using the full power of Microsoft Visual Basic. Software that includes VBA is called customizable applications, which mean applications that can be suited to fit specific

business requirements. When using applications that host VBA, e.g. ArcMap, automation and extension of the application functionality can be done. An example of this is creating tools with new or simplified functions in ArcMap. With VBA, customers can buy software and tailor it to meet a specific requirement, rather than building solutions from scratch [7].

3.2.1.1 VBA and ArcObjects

ArcObjects is based on Microsoft's Component Object Model (COM). VBA is used in ArcGIS together with the COM-library ArcObjects. In the VBA environment it is possible to reach data, such as table data, using ArcObjects. VBA can be reached from e.g. ArcMap through the Visual Basic Editor. The Visual Basic Editor lets you write a VB macro and then debug it right away in ArcMap [7].

The COM-library ArcObjects is visualized in a diagram that shows all the objects, its properties, interfaces and methods. The components are grouped into subsystems. Each subsystem has its own component object model diagram. Examples of sub systems are ArcMap, ArcCatalog, Geodatabase, IMS, and Spatial Analyst extension. Figure 3.1 shows a component from the sub system Geodatabase [7].

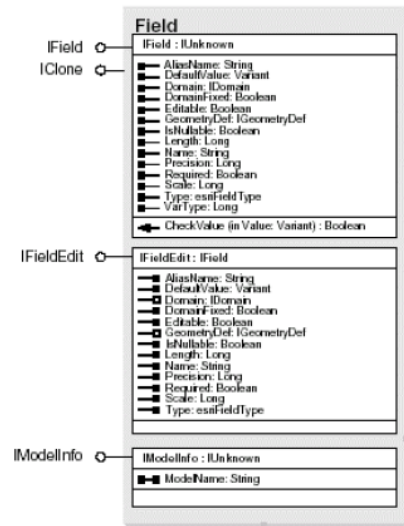


Fig. 3.1 COM-library

ArcObjects consists of objects and classes. An object represents a spatial feature such as a road or a vegetation stand. In a geodatabase, an object corresponds to a row in a table and the object's attributes appear in columns. A class is a set of objects with similar attributes. An ArcObjects class can have built-in interfaces, properties, and methods [9].

ArcObjects includes three types of classes. The most common type is the coclass. A coclass can be used to create new objects. For example, FeatureClass is a coclass that allows new feature class objects to be created as instances of the coclass. The second type is the abstract class. An abstract class cannot be used to create new objects, but it exists so that other classes (i.e., subclasses) can use or share the properties and methods that the class supports. For example, GeoDataset is an abstract class. The class exists so that geographic datasets such as feature classes and raster datasets can all share the properties of extent and spatial reference that the GeoDataset class supports. The third type is the class. A class cannot be used directly to create new objects; instead, objects of a class can only be created from another class. For example, EnumInvalidObject is a non creatable class because an EnumInvalidObject can only be obtained from another object such as a data conversion object. When converting a shape-file from one coordinate system to another, for example, a data conversion object automatically creates an EnumInvalidObject to preserve track of those objects that have failed to be converted [9].

3.3 Autodesk Ecotect

Complete environmental design tool which couples an intuitive 3D modeling interface with extensive solar, thermal, lighting, acoustic and cost analysis functions. Ecotect is one of the few tools in which performance analysis is simple, accurate and most importantly, visually responsive [23].

Ecotect is driven by the concept that environmental design principles are most effectively addressed during the conceptual stages of design [23]. It offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs [29].

Ecotect can be used to find the azimuth and altitude of the Sun at a particular time or annual average sun radiation and average shade for buildings on architecture and urban levels [16].

3.3.1 Ecotect Solar Exposure Analysis Tool

Ecotect Solar exposure analysis tool can be used to find how each surface will be affected by surrounding buildings' shadows [16].

There are main parameters those should be taken into account when using this tool (Figure 3.2) [16].

Firstly, total monthly calculations: which calculates the total amount of solar radiation falling on selected surfaces for each month of the year.

Geometric overshadowing, reflective effects and available radiation are

calculated separately for each day within the month. Secondly, Sun-Path: which uses the detailed Sun-Path shading calculation functions for each object. If multiple objects are selected, their shading is accumulated into one complex mask. This detailed shading will need to be recalculated each time we select different objects for analysis in the 3D Editor page. Ecotect will automatically detect this and recalculate the shading. Thirdly, direct light only: using this toggle to isolate only the direct component of the available solar radiation, all diffuse and reflected energy is ignored. Fourthly, shading: which means the average percentage of the surface in shade. Fifthly, weather Data File: this file contains hourly data for both diffuse and direct solar radiation as well as temperature, wind speed and direction, relative humidity and rainfall.

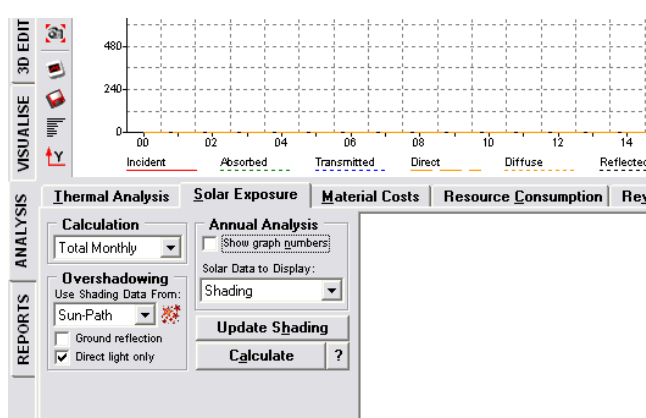


Fig. 3.2 Ecotect Solar Exposure analysis

4 Methodology

The project is divided into two parts

Part 1: This part of the project deals with the building of the Dokki area geo-database, which includes assigning coordinate system, building new Esri personal geo-database and export all shape files into new geo-database, calculating the area of building's roof and calculating the annual average shadow from surrounding buildings.

Part 2: This part of the project deals with the development of The Photo Voltaic Roof Integration Analysis Tool as an application to ArcView. The application has been developed in the Visual Basic for Applications to ArcMap by using the ArcObjects COM-library.

Literature treating Visual Basic for Applications and further literature in ArcObjects was studied. To make the tool user-friendly directions from Software Engineering book (Sommerville, 2001) were used. Help menu for each step of the functions were also included in the tool, to make it more user-friendly.

Tool includes six functions: zoom in and show selected building address, find solar surface suitability class, find installable modules area, calculate expected maximum electricity output per year, find CO₂ reduction by using the PV system per year and find how many people can use PV system

4.1 Dokki Area Geo-database

Geo-database used in this study is composed of four layers. Mainly one layer "buildings" is used and others for presentation purposes only. The four layers are buildings "main layer", buildingLandmarks, streets and metroStations.

The attributes of district buildings layer are (building number, second number "in case of building has two streets", street name, second street name "in case of building has two streets", parcel name, mark and floors number). Annual average shadow percentage is calculated and added as a new attribute in layer "buildings" with name "Avg_shadow".

Because of data limitations we don't have the exact height of buildings. Floor height always depends on age of the building and the building's functionality. On the other hand we have the floors sum for each building provided by the data provider, which can be used to roughly produce building height by multiply floor sum by 3 (in meter), average floor height in Egypt.

3D model was created using ArcScene and exported to a proper file format that can be imported in Ecotect such as VRML, thereafter the 3D model was imported into Ecotect in order to find the shadow percentage.

4.1.1 Calculate the Shadow Percentage for Each Roof

Computer programs are available now to assist in the analysis of the losses of the Sun radiations by shadow. Autodesk Ecotect Analysis 2011 can be used to find the average shadow percentage. User should select building's roof as Figure 4.1 and should make sure that the selected element type is ceiling.

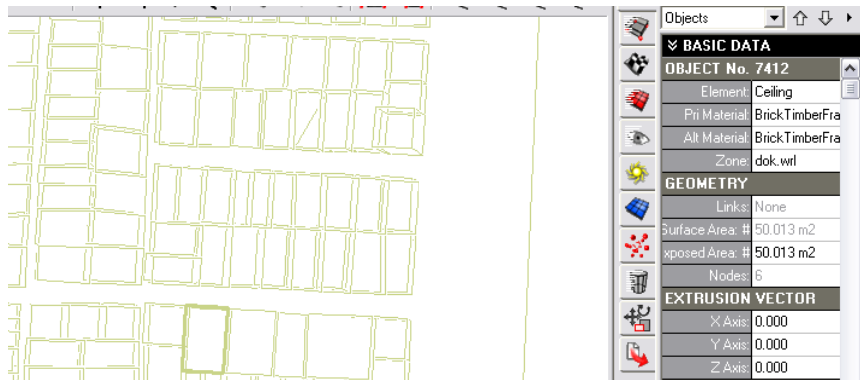


Fig. 4.1 Ecotect select ceiling object

By using solar exposure tool the average shadow percentage per month can be calculated as Figure 4.2, spreadsheet programs, for instance, Microsoft Excel can be used to calculate annual average shadow percentage value then this value will be added manually to a proper building attribute in ArcMap.

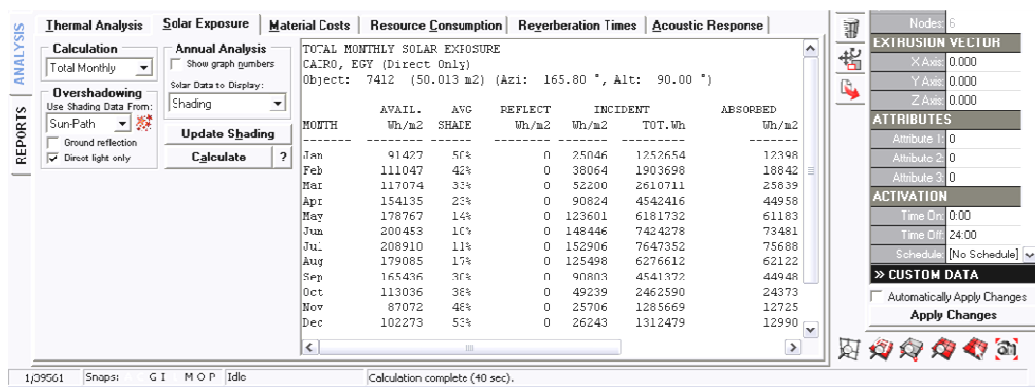


Fig. 4.2 Solar exposure tool calculations

Solar exposure tool creates test points, Figure 4.3, on selected object to find average overshadowing for each month. Overshadowing accuracy relies on test points' numbers, Figure 4.4. More accuracy rate creates more test points and takes more time to produce calculations, level 6 take about 10 minutes per roof to finalize calculation also rely on PC performance. The overshadowing percentage varies between one level to the next by + or - 3% in average, because of time limitation the second accuracy level was used to find average overshadowing percentage and in some cases third level used specially if roof shape is complex to produce more accurate results then fill in the shadow field in building attribute table manually.

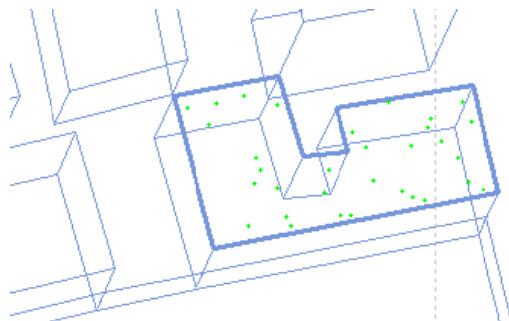


Fig. 4.3 Ecotect select ceiling object test points

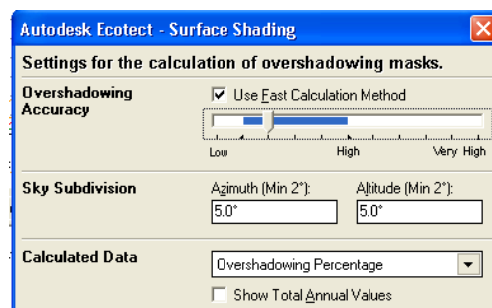


Fig. 4.4 Ecotect surface shading settings

Examples of annual average shadow for 22 buildings as a sample of calculations

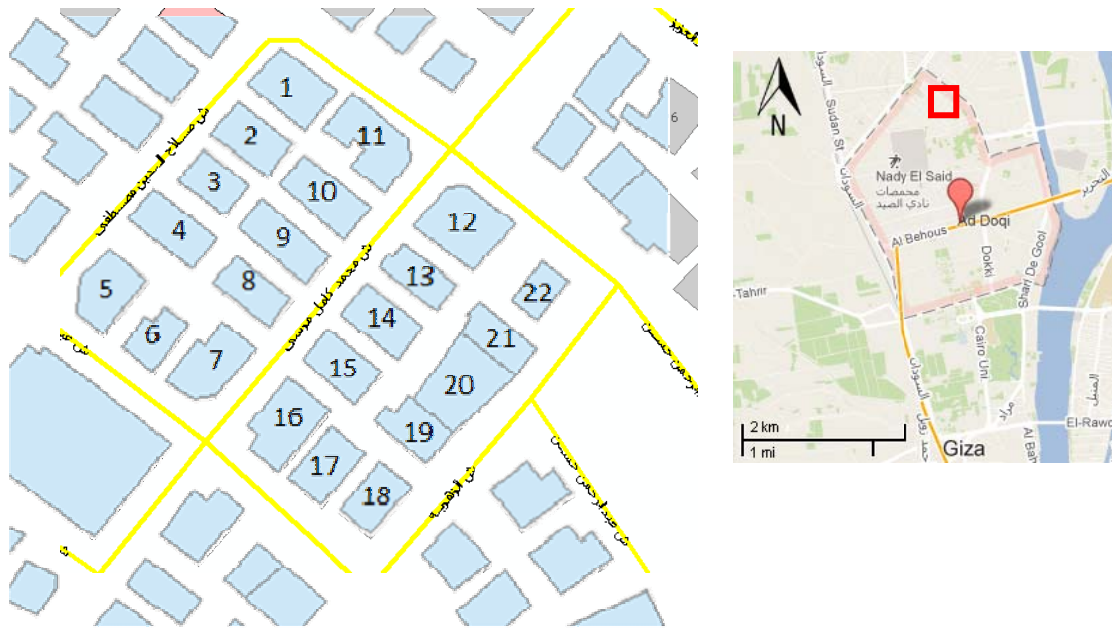
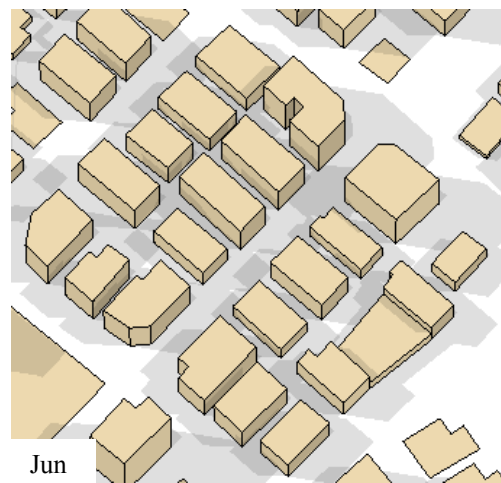
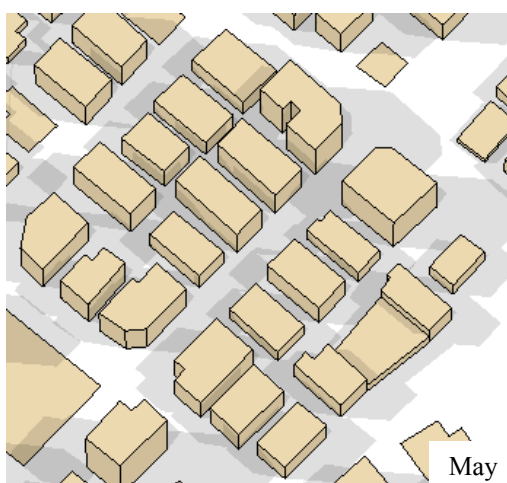
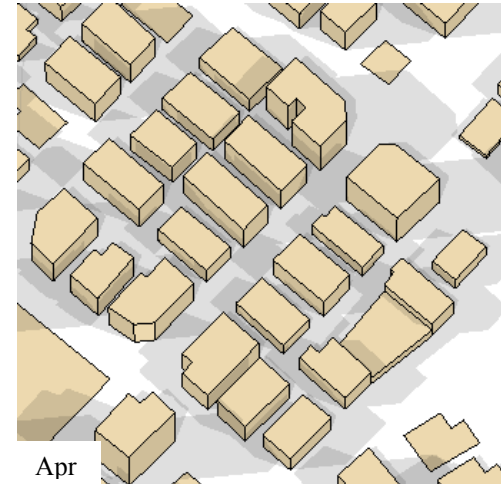
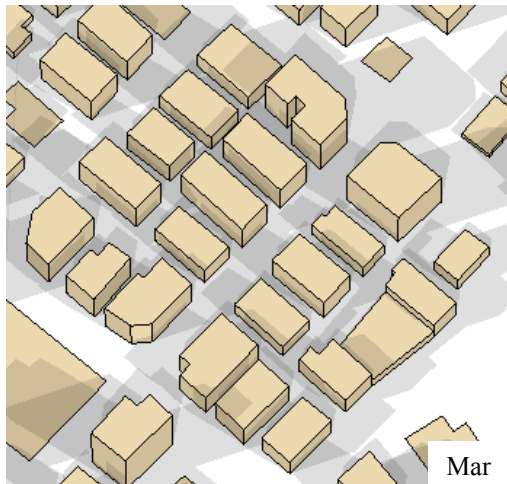
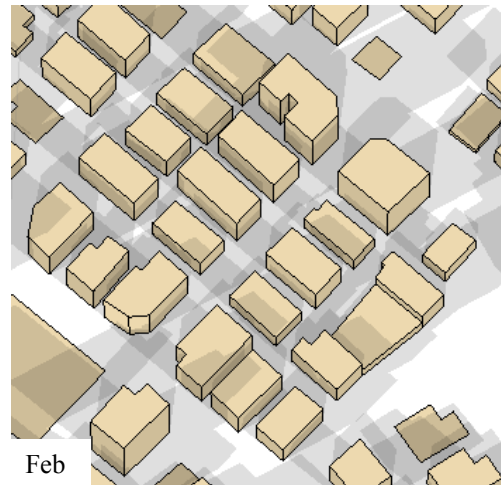
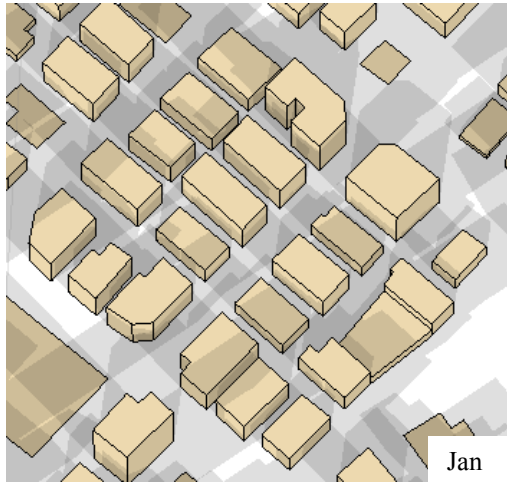


Fig. 4.5 Sample of shadow calculations

Table 4.1 Average shadows in per cent for 22 building rooftops “sample for shadows calculations”

Building ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
01	32	30	25	17	11	9	10	15	22	26	32	33	21.83
02	31	24	18	17	13	13	12	16	20	19	24	32	19.92
03	18	12	5	8	5	6	5	8	8	7	12	16	9.17
04	9	7	2	3	1	2	0	0	6	3	2	9	3.67
05	10	11	4	1	1	2	0	0	5	11	3	8	4.67
06	6	4	5	3	0	1	0	1	8	4	0	9	3.416
07	6	5	5	4	1	2	0	1	9	1	0	9	3.58
08	15	12	8	10	11	13	11	11	9	8	6	17	10.92
09	5	8	3	6	2	2	2	5	7	2	1	8	4.25
10	6	10	8	11	10	11	9	11	11	6	7	8	9.00
11	4	1	0	0	0	0	0	0	0	0	1	8	1.166
12	6	5	0	0	0	0	0	0	0	0	7	9	2.25
13	25	20	15	15	16	18	17	15	14	20	21	29	18.75
14	6	9	6	3	1	3	2	1	7	2	2	9	4.25
15	20	15	13	15	10	10	8	13	14	10	15	22	13.75
16	19	10	2	6	1	0	0	3	7	4	10	22	7
17	13	15	9	10	1	0	1	8	10	14	6	10	8.08
18	6	8	5	12	7	4	5	12	10	4	6	9	7.33
19	8	8	4	8	2	0	3	8	7	4	8	9	5.75
20	31	30	26	30	28	27	27	29	30	24	31	31	28.67
21	6	10	10	8	2	0	0	5	12	9	9	9	6.67
22	14	20	14	8	3	5	2	4	16	14	13	12	10.42

Next figures, Figure 4.6, demonstrate the monthly shadows for buildings, the selected month's day is 15 and hours range from 9:00 to 17:00 to cover most hours those have high average intensity of the Sun's radiation during the summer and winter months.



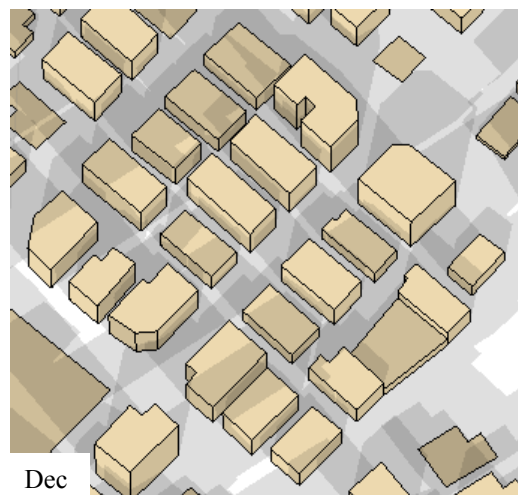
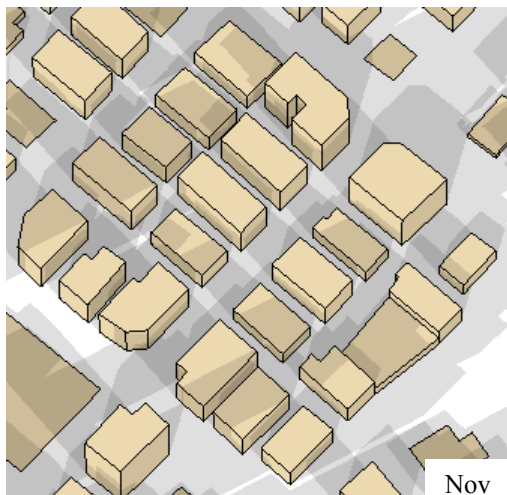
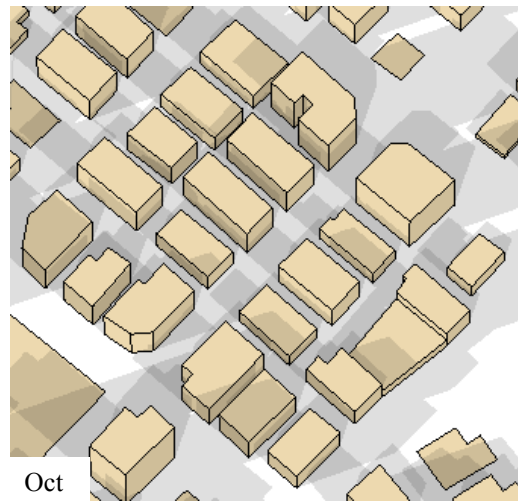
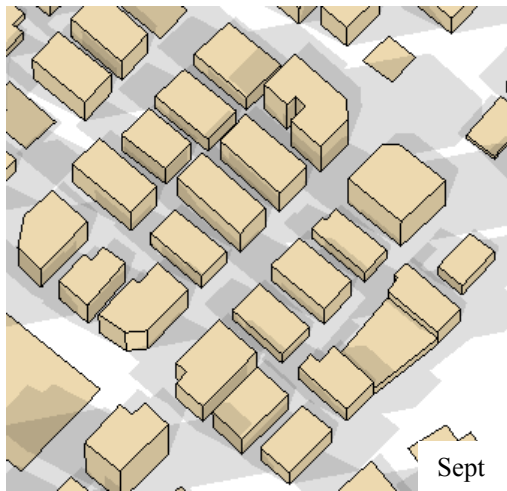
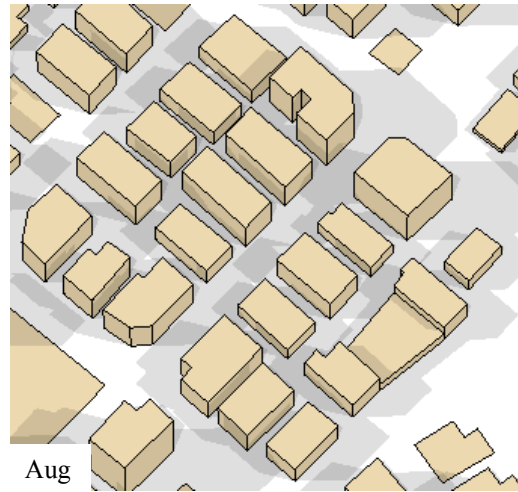
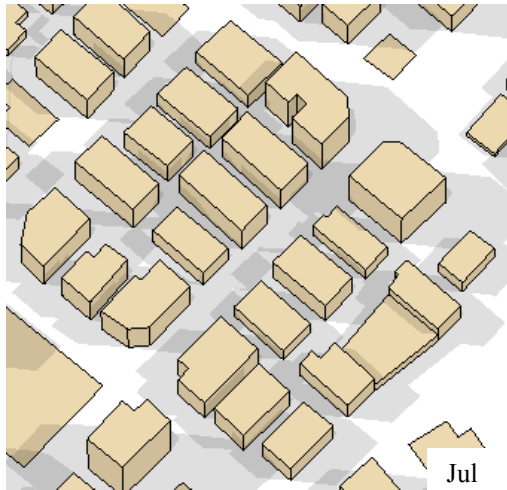


Fig. 4.6 Selected buildings shadow presentation

As one can obviously notice that the maximum shadow percentage values have been occurred in the autumn and the winter months that's because the Sun's altitude is lower than the summer months, Figure 4.7 presents that more clearly.

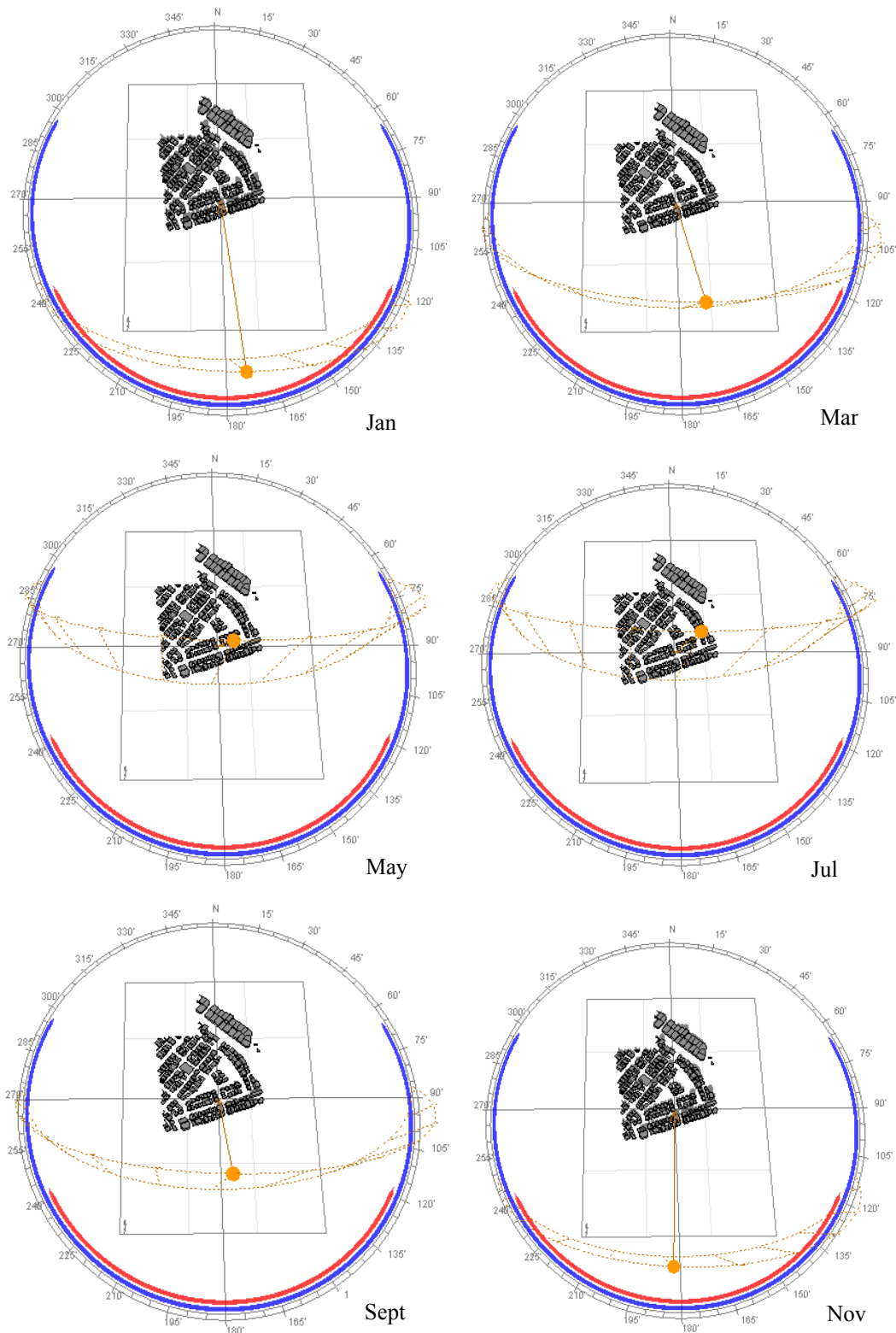


Fig. 4.9 Monthly Sun path diagram (Sun altitude), selected day is 15 and time is 12

4.2 The PV Roof Integration Analysis Tool

4.2.1 Introduction

The The Photo Voltaic Roof Integration Analysis Tool is a geographical analysis tool produced for analyses of geometrical data and attribute data together. It is built as an application to the ESRI GIS component ArcMap using VBA. The tool has been developed within The Lund University Master Program for GIS “LUMA” and is produced for planners and researchers as a spatial decision support tool to help find the suitability class for using PV modules on rooftops of existing buildings. The tool is placed in a GIS to enable easy access to databases containing geographical information.

The tool calculates the sun power potential of each roof in the study area and may be in the future applying for each district, city and province in Egypt. With geographical information systems, the solar potential of all roof areas is precisely calculated fully automatically on the basis of collected data. This is done by calculating shadow and, in case if roof is tilted, the angle of the roof and its alignment.

An essential point of developing the tool is to make it user-friendly for people who have not much experience in working with a GIS environment; on the other hand the specialists should prepare the data to be compatible with the tool before the end user uses the tool. For this task, VBA is suitable since it is easy to learn and enables development of user-friendly applications.

The tool is partly tailored for data within thesis project, but only some adjustments are required to make it general.

4.2.2 Description

The tool can be reached by opening the project document (mxd-file) containing the tool in ArcMap. To access the PV tool a certain button, called PV roof tool, is used (see Figure 4.10).

Main layer should be found when one opens mxd file is buildings, shape file or from geo-database.

This layer should contain next attributes BUILDNO, this field contains building number that will be used when the show address function is working, FIRST_STR, this field contains building street name that will be used in show address function, Avg_shadow, this field contains annual average building rooftop shadow as percentage calculated by Ecotect solar exposure tool and Area, which contains area of the roof.

Tool functions are: show selected building address, find solar surface suitability class, find installable modules area, calculate expected maximum electricity output, find reduction of CO₂ emissions and find how many people can utilize the PV system outputs.

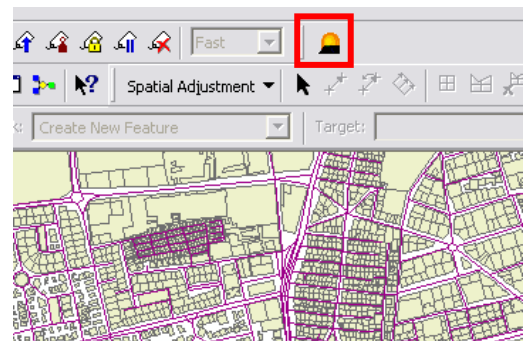


Fig. 4.10 PV roof integration analysis tool

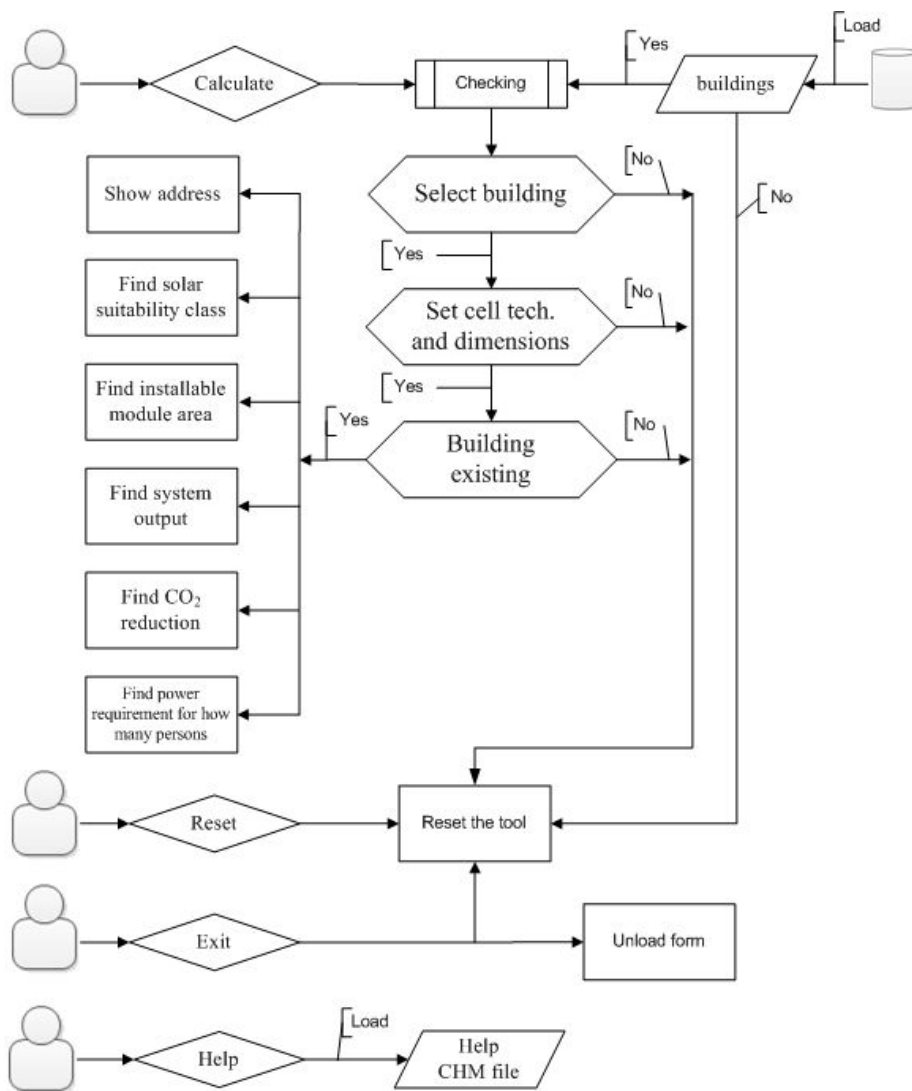


Fig. 4.11 Scheme with the structure of the tool

4.2.3 Graphical User Interface

The user interface is the part of a software program that is visible for the user. The user interface of the tool is an ordinary form with command buttons, compo-boxes and textboxes that lead the user through the program.

The software is developed in ArcMap using the graphical user interface, GUI, for the VBA programming environment.

Recommendations of how to make user friendly tool have been considered during the development. The recommendations are taken from the book Software Engineering (Sommerville, 2001). Examples of how the recommendations have been affected the design: the user can always cancel an operation or go to a help, the form has a little and simple text to describe to the user what to fill-in or what to select, if the user needs more detailed information he/she is requested to use the help menus, terms have been used in a consequent way and the tool not blocks the rest of the functions in ArcMap. The user can for example select any building or open table when the tool is in use.

In order to create a VBA GUI two major elements are need and they are detailed below.

Components: Pushbuttons, labels and combo boxes are graphical components of VBA. Composing these features in the right way we can make an easy interface for the end users.

Call-backs: This is the most important element since it produces the function to call a specific function when an event occurs. A mouse click or a key press are type events, and VBA must respond to each event performing a specific function. This component is the code executed in response to an event is known.

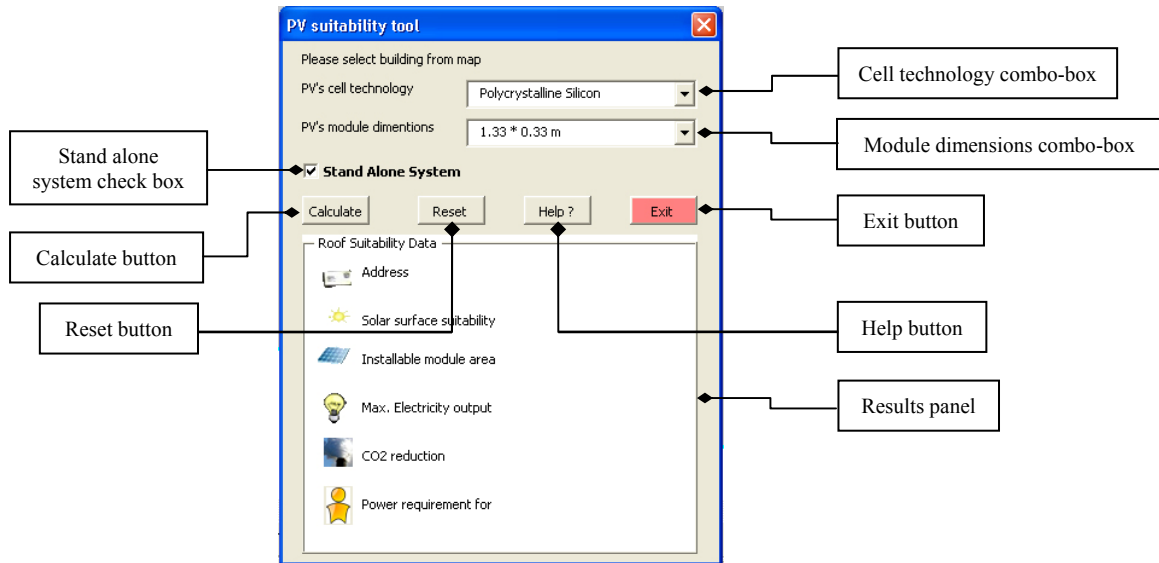


Fig. 4.12 PV roof integration analysis tool interface

4.2.4 The Functionality of the Tool

The following section will be describing each one of the tool's functionalities and customized commands. VBA code is commenced with the declaration of the general variables which are used throughout the tool, see code 4.1.

```
'General declaration of ArcObjects variables
'These variables is used at more than one function
Dim pDoc As IMxDocument
Dim pMap As IMap
Dim pFeature As IFeature
Dim pGeom As IGeometry
'Others
Dim mArea As Double
Dim mdlNum As Double
Dim sysOutput As Double
Dim pvEfficiencyRate As Double
Dim pvLCEm As Double
Dim stopeExcution As Boolean
```

Code 4.1.code for variables' declaration

The code starts with creating new objects from ArcObjects COM classes then declared new public variables those will be used at a number of code pieces.

The *pDoc* is an object from *IMxDocument* interface which is the starting point for all the other objects in ArcMap. *pDoc* is used to set the mxd document file and set the map that will be used to define map layers. *pMap* gives access for many tasks those control the map, for instance, it used to provide access for map layers. The *pFeature* returns and sets properties of the feature. *pGeom* defines a spatial location and geometric shape and it is mainly used here to zoom in selected object.

Other variables are defined publically because they are used at more than one function throughout the tool's functions.

Basically, tool's functions work when the user click on calculate button. Calculate button calls seven functions, see code 4.2.

```
'Calculate button
Private Sub calcBtn_Click()
    checkingFunction()
    'check if checking function called reset function and stopped the
    'execution of the code
    If stopeExcution = fales Then
        zoomAndShowAdressFunction()
        findInstallableAreaFunction()
        findMaxOutputFunction()
        co2RedFunction()
        consumptionSufficient()
        setSuitabilityClassFunction()
    End If
End Sub
```

Code 4.2.code for calculate button

These functions have been designed to perform the basic tasks of the tool. Code starts with checking function then checks if checking function called reset function therefore the execution of the code will be stopped. Checking function makes possible checking of the data before other functions start working, please see code 4.3.

```

Private Sub checkingFunction()
    'Declaration of ArcObjects variables
    Dim pEnumLayer As IEnumLayer
    Dim pLayer As ILayer
    Dim pFeatureSelection As IFeatureSelection
    Dim pFCursor As IFeatureCursor
    Dim pEnumGeom As IEnumGeometry
    Dim pEnumGeomBind As IEnumGeometryBind
    Dim pGeomFactory As IGeometryFactory
    'Set ArcObjects com library variables
    pDoc = ThisDocument
    pMap = pDoc.ActiveView.FocusMap
    pEnumLayer = pMap.Layers
    pLayer = pEnumLayer.Next

    'Check if building layer is existed or not
    'In thesis' project building layer should called buildings
    'Do loop for layers
    Do Until pLayer Is Nothing
        'Check if buildings layer is found or not
        If pLayer.Name = "buildings" Then
            pFeatureSelection = pLayer
        End If
        pLayer = pEnumLayer.Next
    Loop

    'If buildings layer is not found
    If pFeatureSelection Is Nothing Then
        '**Alarm message box**
        MsgBox("Please check if buildings layer was added and try" _
            & "again")
        'Reset form
        clearFunc()

    'If buildings layer is found
    Else
        'form a single geometry from the selected features in a layer
        pEnumGeom = New EnumFeatureGeometry
        pEnumGeomBind = pEnumGeom
        pEnumGeomBind.BindGeometrySource(Nothing, _
            pFeatureSelection.SelectionSet)
        pGeomFactory = New GeometryEnvironment
        pGeom = pGeomFactory.CreateGeometryFromEnumerator(pEnumGeom)
        pFeatureSelection.SelectionSet.Search(Nothing, False, pFCursor)
        pFeature = pFCursor.NextFeature
        'Check if user selected feature (building) or not
        If pFeature Is Nothing Then
            '**Alarm message box*
            MsgBox("Please select building first")
            'Call reset function
            clearFunc()
        End If

        'Check if selected plot has building or not
        If Cint(pFeature.Value(pFeature.Fields.FindField("Avg_shadow"))) _
            = 100 Then
            '**Alarm message box*
            MsgBox("Plase note selected building demolished, space land" _
                & "or missing data")
            'Call reset function
            clearFunc()
        End If
    End If

```

```

'Check if cell technology and/or module dimensions are set or not
If pvEfficiencyRate = 0 Or mArea = 0 Then
    '**Alarm message box*
    MsgBox("Please set PV cell technology and/or module" _
    & "dimensions")
    'Call reset function
    clearFunc()
End If
End If
End Sub

```

Code 4.3.code for checking function

Checking function starts with declaring ArcObjects variables. The ArcObjects variables are used here will be detailed in the following lines.

The *pEnumLayer* returns a set of layers and used to extract buildings layer. *pLayer* is used to set the selected feature layer. *pFeatureSelection* is basically used here to retrieve selected object/s from feature class, in the thesis project selected object is building. The required fields of the selected feature can be retrieved using *pFeature*. *pFCursor* returns an object from feature class and is used here to check if user select building or not. *pGeom* gives access to common geometric objects' proprieties and methods. *pGeomFactory* is used to create geometry bag containing references to geometries returned by the input geometry enumerator that sets *pGeom*. *pEnumGeom* is a collection source of geometry that is used in *pGeomFactory.CreateGeometryFromEnumerator*. *pEnumGeomBind* binds selected feature or building to *pEnumGeom*.

The function continues with setting the declared ArcObjects' variables thereafter, checks if the buildings layer was added to mxd file, if the user selected plot, if the selected plot has a building and if the user set PV module dimensions and cell technology. In case of any of previous conditions does not exist, alarm message-box will be appeared (see Appendix B) thereafter the function calls reset function which resets the form and stops the execution of the code. See code 4.4.

Reset function resets all form's combo-boxes and captions and sets *stopeExcution* variable in true in order to stop the execution of the code.

```

'Reset function
Private Function clearFunc()
    cmbCellTech.ListIndex = 0
    cmbModuleDims.ListIndex = 0
    lblSurfaceSuitability.Caption = ""
    lblPwrOutput.Caption = ""
    lblCo2Red.Caption = ""
    lblPwrReq.Caption = ""
    lblAddress.Caption = ""
    instModuleArea.Caption = ""
    chBoxStandAloneSys.Value = False
    stopeExcution = True
End Function

```

Code 4.4.code for reset function

4.2.4.1 Show Address

Show address function just zooms in the selected building and shows building address in Arabic language.

Address is composed of first building number and first street name. The function works by clicking on calculate button, see code 4.5. The code extracts the selected buildings' number and street name.

```

Private Sub zoomAndShowAdressFunction()
    If Not pFeature Is Nothing Then
        'Set address text
        address = pFeature.Value(pFeature.Fields.FindField("BUILDNO")) + _
            & " " + pFeature.Value(pFeature.Fields.FindField("FIRST_STR"))
        lblAddress.Caption = address

        'zoom to selection
        pDoc.ActiveView.Extent = pGeom.Envelope
        pDoc.ActiveView.Refresh()
    End If
End Sub

```

Code 4.5.code for zoom and show address function

4.2.4.2 Installable Module Area

In order to find modules area of a PV rooftop integration system we should firstly find suitable roof area for using PV modules. This process is extremely intricate and need more studies about each building's rooftop; here we work at urban planning scale. Code 4.6 is of course just a good approximation that can be used to compute total modules area.

```

Private Sub findInstallableAreaFunction()
    'Find installable module area
    stblRoofArea = pFeature.Value(pFeature.Fields.FindField("Area")) -
        (pFeature.Value(pFeature.Fields.FindField("Area")) * _
        (pFeature.Value(pFeature.Fields.FindField("Avg_shadow")) / 100))'in SqM
    'Find number of modules
    If mArea > 0 Then 'check module area
        mdlNum = Fix(stblRoofArea / mArea)
        'Set Installable modules area caption
        instModuleArea.Caption = Str(Fix(mdlNum * mArea)) + " M2"
    End If
End Sub

```

Code 4.6.code for find installable modules area

The main functions those used for finding modules area are detailed in the following lines.

Calculating available area that can be used as an installation area for PV modules by subtracting annual average shaded area from the total rooftop area

$$A_s = A_r - (A_r \times (S_a / 100)) \quad (4.1)$$

Where A_s is available installation area, A_r building rooftop area and S_a total annual expected shadow in per cent.

In order to execute this function user should set the module dimensions by selecting appropriate dimensions from module dimensions combo-box, see code 4.7.

```

Private Sub cmbModuleDims_Change() 'Module dimensions combo-box
    Select Case cmbModuleDims.ListIndex
        Case 0 'Default
            mArea = 0
        Case 1
            mArea = 1 * 0.5
        Case 2
            mArea = 1.33 * 0.33
        Case 3
            mArea = 1.2 * 0.7
    End Select
End Sub

```

Code 4.7.code for setting module dimensions

Not all available area can be used for PV modules installation that's mainly based on the roof dimensions and PV module dimensions.

Many producers design modules in many different dimensions. However the main standard module dimensions we can use in this brief study are 1.0×0.5 m, 1.33×0.33 m or 1.2×0.7 m. [11]. Next equations can be used to find total modules area

$$M_n = \text{Fix}(A_s / M_a) \quad (4.2)$$

$$M_{ia} = M_n \times M_a \quad (4.3)$$

Where M_n is modules number, M_a module area and M_{ia} is installable modules area.

Fix function used in equation 4.2 returns the integer portion of a number, say if the calculation returned number is 24.3 or 24.8 the returned number using fix function will be 24, this function used because we cannot install just a part of module also cannot exceed available area for installation.

4.2.4.3 Estimating System Output

Electricity production from a PV roof integration system is a function of several factors, which are detailed in the following lines.

Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially; reaching inner temperatures of $50-75^\circ\text{C}$. A Temperature Correction Factor (TCF) relies on cell technology. However, assume that the average inner temperature is 60°C then TCF is about 80% or 0.8 [8, 33].

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. A typical recommended annual dust reduction factor to use is about 93% or 0.93 [12].

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to preserve these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95 [12].

The DC power generated by the solar module must be converted into common household AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Actual field conditions usually result in overall DC-to-AC conversion efficiencies of about 88-92%, with 90% or 0.90 a reasonable compromise [12].

If decision of using stand alone system was taken then about 85% or 0.85 of power is lost as a result of battery efficiency [8].

The output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25°C ; solar irradiance = 1000 W/m^2 ; and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum) [12]. A manufacturer may rate a particular solar module output at 100 Watts of power under STC. However, the standard PV cell technology efficiency will be used in this

study. According to studies we will assume that PV module efficiency based on PV cell technology “with standard module dimensions” as follows [11]

Table 4.2 PV cell technology efficiency

Cell Technology	η_{pv} “PV efficiency”
Single-Crystalline Silicon	15% or 0.15
Polycrystalline Silicon	14% or 0.14
Thin-film Silicon	9% or 0.09
Thin-film Cadmium	10% or 0.1

A good approximation of output power from PV system can be computed by the following formula

$$PV_{output} = S_{input} \times TCF \times \eta_{pv} \times \eta_b \times \eta_{inv} \times M_{ms} \times M_{dd} \times M_{ia} (\text{KWh/year}) \quad (4.4)$$

Where

PV_{output} is PV system output

S_{input} is region, Cairo, annual average of solar energy input (about 2445 KWh/m²)

TCF is temperature correction factor

η_{pv} is PV efficiency

η_{inv} is inverter efficiency

η_b is battery efficiency (stand-alone systems only)

M_{ms} is modules mismatch

M_{dd} is dirt and dust

In order to get PV module efficiency rate, user has to select PV cell technology from PV cell technology combo-box, please see code 4.8.

```
Private Sub cmbCellTech_Change() `Cell tech. combo-box
    Select Case cmbCellTech.ListIndex
        Case 0 `Default
            pvEfficiencyRate = 0
            pvLCEm = 0 `PV life cycle emissions (grams)
        Case 1 `Single-Crystalline
            pvEfficiencyRate = 0.15 `(15%)
            pvLCEm = 45
        Case 2 `Polycrystalline
            pvEfficiencyRate = 0.14
            pvLCEm = 45
        Case 3 `Thin-film silicon
            pvEfficiencyRate = 0.09
            pvLCEm = 45
        Case 4 `Thin-film Cadmium
            pvEfficiencyRate = 0.1
            pvLCEm = 23
    End Select
End Sub
```

Code 4.8.code for setting module dimensions

The code illustrates this function is shown in code 4.9. Code begins with checking system type, whether stand-alone system or grid connected system.

```

Private Sub findMaxOutputFunction()
    'check type of system "stand alone or not"
    If chBoxStandAloneSys.Value = True Then 'Stand alone system
        sysOutput = 2445 * 0.8 * pvEfficiencyRate * 0.85 * 0.9 * 0.95 * _
        0.93 * (mdlNum * mArea)
        lblPwrOutput.Caption = Str(CInt(sysOutput)) + " kWh/year"
    Else 'Grid connected system
        sysOutput = 2445 * 0.8 * pvEfficiencyRate * 0.9 * 0.95 * 0.93 * _
        (mdlNum * mArea)
        lblPwrOutput.Caption = Str(CInt(sysOutput)) + " kWh/year"
    End If
End Sub

```

Code 4.9.code for finding system output

4.2.4.4 Building Rooftop Suitability

In order to find the suitability of a building rooftop for PV modules installation, several factors have to be considered. Some of them are global such as annual average of direct solar radiation; some depend on the roof itself such as its size and effects by surrounding vertical objects.

The following function has been developed with the purpose of finding building suitability class. In order to perform its functionalities two functions are necessary, the installable module area as part 4.2.4.2 and system output as part 4.2.4.3.

Generally, there are no limits on the area that available for PV modules installation. However, because the system installation is too expensive, the system should be cost-effective. We assume that the efficient system should produce sufficient amount of electricity for at least one family per year, recommended by Dr. Moamen Afify, Department of Architecture, Cairo University.

The most important feature that should be taken into account is the location of the roof. The solar installation must receive as much direct sun light as possible. Shadows cast by neighboring buildings must be kept in mind during the design process.

The average shadows percentage cannot be considered as an only aspect to find suitability scale for specific rooftop. As a proof of concept, if there are two buildings "building A and building B" with an area of building rooftops 100 m² "for A" and 400 m² "for B" with shadow 20% "for A" and 90% "for B" so the suitable area for PV system is 80% "80 m²" for building A and 10% "40 m²" for building "B" therefore, we should consider the annual productivity of the system.

Here in Egypt the average number of family members is 4.18 (2006 statistics, Egypt's State Information Service "SIS") in general. In fact this average number varies between rural and urban collections, some studies indicate that the average number of family members in urban is 3.94 and in rural is 4.37.

However if we assume that the average number of family members is about 4 then can find how much the annual electricity consumption per family

$$C_f = N_f \times A_c \quad (5.1)$$

Where C_f is an average family consumption per year, N_f family members' number and A_c is annual Egypt's electricity consumption per capita.

Annual Egypt's electricity consumption is about 1295.8 kWh per capita (CIA FactBook).

$$C_f = 4 \times 1295.8 = 5183.2 \text{ kWh/year} \quad (4.5)$$

If expected system output is found then rooftop suitability can be computed as follows

$$R_s = PV_{\text{output}} / C_f \quad (4.6)$$

Where R_s is rooftop suitability, PV_{output} is the maximum annual PV system output (see equation 4.4).

According to R_s number that has been found from equation 4.6 the building rooftop suitability can be categorized into six classes, see code 4.10; appropriate number of classes should be less than seven to make recognition by users' eyes more easier, recommended by Eng. M. Ghareeb, ITI, Egypt.

Table 4.3. Building rooftop suitability classes “A is the highest class, F not suitable”.

If system technology is thin film, stand alone system, based on these parameters the maximum numbers of families are about 140.

Category	Rooftop suitability
A	>16
B	8 – 16
C	4- 8
D	2- 4
E	1- 2
F	0- 1 (family)

```
Private Sub setSuitabilityClassFunction()
    'Set surface suitability text
    'Classify suitability into six sets
    Dim roofSuit As Double
    roofSuit = sysOutput / 5183.2
    'Set roof suitability class caption
    If roofSuit >= 0 And roofSuit < 1 Then
        lblSurfaceSuitability.Caption = "F"
    ElseIf roofSuit >= 1 And roofSuit < 2 Then
        lblSurfaceSuitability.Caption = "E"
    ElseIf roofSuit >= 2 And roofSuit < 4 Then
        lblSurfaceSuitability.Caption = "D"
    ElseIf roofSuit >= 4 And roofSuit < 8 Then
        lblSurfaceSuitability.Caption = "C"
    ElseIf roofSuit >= 8 And roofSuit < 16 Then
        lblSurfaceSuitability.Caption = "B"
    ElseIf roofSuit > 16 Then
        lblSurfaceSuitability.Caption = "A"
    End If
End Sub
```

Code 4.10.code for finding suitability class

4.2.4.5 Reduction of CO₂ Emissions

Solar energy is a sound financial investment, producing solid energy, but the emissions of greenhouse gases (GHGs) mainly CO₂ are needed to be considered. See code 4.11.

```
Private Sub co2RedFunction()
    Dim pvER As Double
    Dim pvToaLlCe As Double
    'Find How much carbon dioxide is produced when fossil fuels used
    pvER = sysOutput * 460 'grams
    'Find CO2 emissions during PV module life cycle
    pvToaLlCe = sysOutput * pvLCEm 'grams
    'Set CO2 reduction caption
    lblCo2Red = Str(CInt((pvER - pvToaLlCe) / 1000)) + " Kg"
End Sub
```

Code 4.11.code for finding reduction of CO₂ emissions 34

The main functions are used for finding reduction of CO₂ emissions are detailed in the following lines.

In order to find the annual CO₂ reduction several factors have been taken into account including the energy source the solar production is replacing (coal, gas, hydro-electric, nuclear...), the quantity of energy produced by the solar roof (depending on the roof's location, orientation, inclination and shading), the average emission of CO₂ per kWh electricity produced by fuels and the average emission of CO₂ from PV life cycles includes quantity of electricity needed to manufacture the photovoltaic system (modules, inverter, cables, etc.) [18].

According to the International Energy Agency (IEA), CO₂ emissions per kWh for electricity produced by fuels for Egypt are about 460 g/kWh [13].

Expected reduction of CO₂ emissions (PV_{er}) by using PV system, can be calculated by the following equation

$$PV_{er} = PV_{output} \times 460 \text{ g/year} \quad (4.7)$$

Equation 4.7 cannot give a fair result; PV produces CO₂ emissions since its life cycle. Expected CO₂ emissions during lifetime for single-crystalline silicon, polycrystalline silicon and thin-film silicon cell technology are about 45 g CO₂-eq./KWh and for thin-film Cadmium about 23 g CO₂-eq./KWh with expected lifetime of 30 years [14], this piece of code was illustrated in code 4.8.

$$PV_{totalce} = PV_{output} \times PV_{lce} \text{ g/year} \quad (4.8)$$

Where PV_{lce} is PV life cycle emissions and PV_{totalce} is PV total life cycle emissions per year.

Total annual CO₂ emissions reduction can be computed using equations 4.7 and 4.8

$$PV_{ter} = PV_{er} - PV_{totalce} \text{ g/year} \quad (4.9)$$

Where PV_{ter} is total CO₂ emissions reduction.

4.2.4.6 System Output Is Sufficient for How Many Persons

In order to provide a clear image for planner or researcher whom may concern PV tool, we can supply more information, for instance, how many people can utilize PV building rooftop integration system output as mentioned in 4.2.4.3. See code 4.12.

Annual Egypt's electricity consumption is 1295.8 kWh per capita. By dividing expected system power output into electricity consumption per capita we can find how many people can use the PV system output.

$$PV_{os} = PV_{output} / A_c \quad (4.10)$$

Where PV_{os} is PV output sufficient for numbers of people and A_c is annual Egypt's electricity consumption per capita.

```
Private Sub consumptionSufficient()  
    'Find consumption sufficient for how many person  
    lblPwrReq = Str(CInt(sysOutput / 1295.823)) + " Person/year"  
End Sub
```

Code 4.12.code for finding how many people can utilize system output

4.2.4.7 Help Button

Help button opens CHM, Microsoft Compiled HTML, help file.

Help file contents are introduction, a brief description about tool; tool instructions, a detailed instructions for using tool and tool's buttons and outputs. See code 4.13.

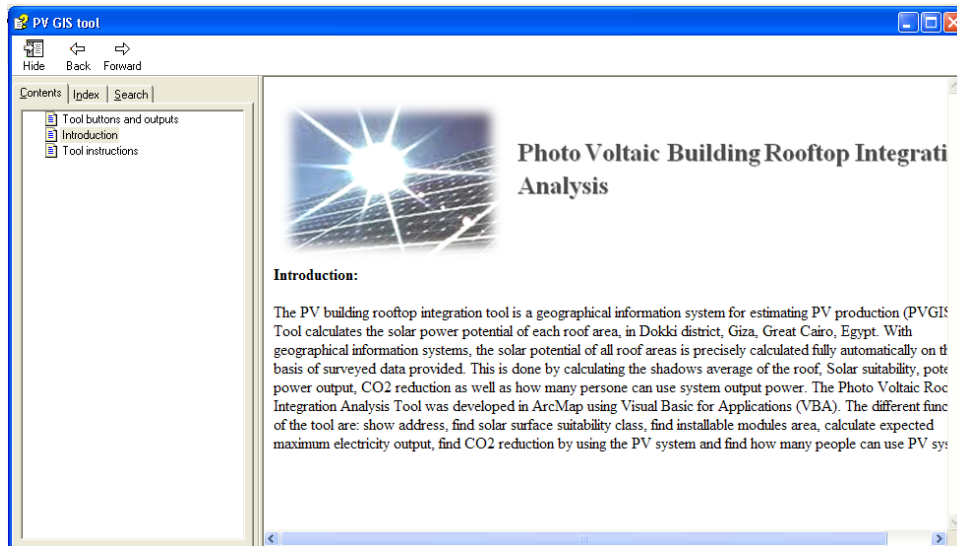


Fig. 4.13 CHM help file opened by clicking on help button

```
Private Sub helpBtn_Click()  
    Dim hplFile As String  
    hplFile = CurDir & "\help.chm"  
    HTMLHelp(0, hplFile, 0, 0)  
End Sub
```

Code 4.13.code for help function

Help function commences with defining chm relative file path. *HtmlHelp* function is publicly defined in a module called *HTMLHelpAPI*. See code 4.14.

```
Public Const HH_DISPLAY_TOPIC = &H0  
Public Const HH_HELP_CONTEXT = &HF  
  
Declare Function HTMLHelp Lib "hhctrl.ocx" Alias "HtmlHelpA" _  
    (ByVal hwndCaller As Long, ByVal pszFile As String, _  
    ByVal uCommand As Long, ByVal dwData As Long) As Long
```

Code 4.14.code for HTMLHelpAPI module

This declaration uses the ANSI version of the *HtmlHelp* function exported by *HHCtrl.ocx*, an ActiveX file created by Microsoft in order to describe Microsoft HTML Help Control. The arguments of the function are *hwndCaller*, a handle to an application window or *Null*; *pszFile*, which specifies which window type to display it in; *uCommand*, the action to be performed, and *dwData*, which specifies additional data depending on the value of *uCommand*. In order to make the function working we should declare two constants, *HH_DISPLAY_TOPIC* and *HH_DISPLAY_CONTEXT*, to pass as the *uCommand* argument [32].

5 Results

Study results tries to answer a number of questions, how much electricity could be produced per year if each suitable roof in the district was equipped with PV modules?, how much CO₂ emissions can be reduced per year?, and how many people can utilize system outputs?.

District contains 5191 buildings and 592 open area or missing data.

Detailed results for one of crystalline and one of thin film technologies will be shown following.

Table 5.1 illustrates detailed results, assuming that the cell technology is polycrystalline and module dimensions are 1×0.5 M.

Table 5.1: estimated building rooftops suitability where cell technology is polycrystalline

Suitability class	Number of buildings		%		Max. output KW/year	
	Stand alone	Grid connected	Stand alone	Grid connected	Stand alone	Grid connected
A	832	1092	16.03	21.04	129973124	176308757
B	1423	1549	27.41	29.84	83077637	91792392
C	1156	940	22.27	18.11	36432039	29228327
D	787	823	15.16	15.85	11680955	12245506
E	635	523	12.23	10.08	4999739	4086415
F	358	264	6.90	5.09	1189115	871084
Total	5191	5191			267352609	314532481

Total expected output from suitable classes, classes A to E, are about 260000 MW/year (stand alone system) and about 310000 MW/year (grid connected system).

Total reduction in CO₂ emissions are about 107000 tons/year (stand alone system) and about 128000 tons/year (grid connected system).

Total people could utilize system's output, cover all energy needs if we assumed that the annual Egypt's electricity consumption per capita is 1295.8 kWh (CIA FactBook), are about 200000 (stand alone system) and about 240000 (grid connected system).

Table 5.2 presents results, assuming that the cell technology is thin-film Cadmium and module dimensions are 1×0.5 M.

Table 5.2: estimated building rooftops suitability where cell technology is thin-film Cadmium

Suitability class	Number of buildings		%		Max. output KW/year	
	Stand alone	Grid connected	Stand alone	Grid connected	Stand alone	Grid connected
A	409	598	7.88	11.52	63460507	91642337
B	1078	1262	20.77	24.31	61616712	72317402
C	1492	1353	28.74	26.06	45405812	41917201
D	826	792	15.91	15.26	12582177	11754727
E	785	735	15.12	14.16	5951554	5590071
F	601	451	11.58	8.69	1949387	1444320

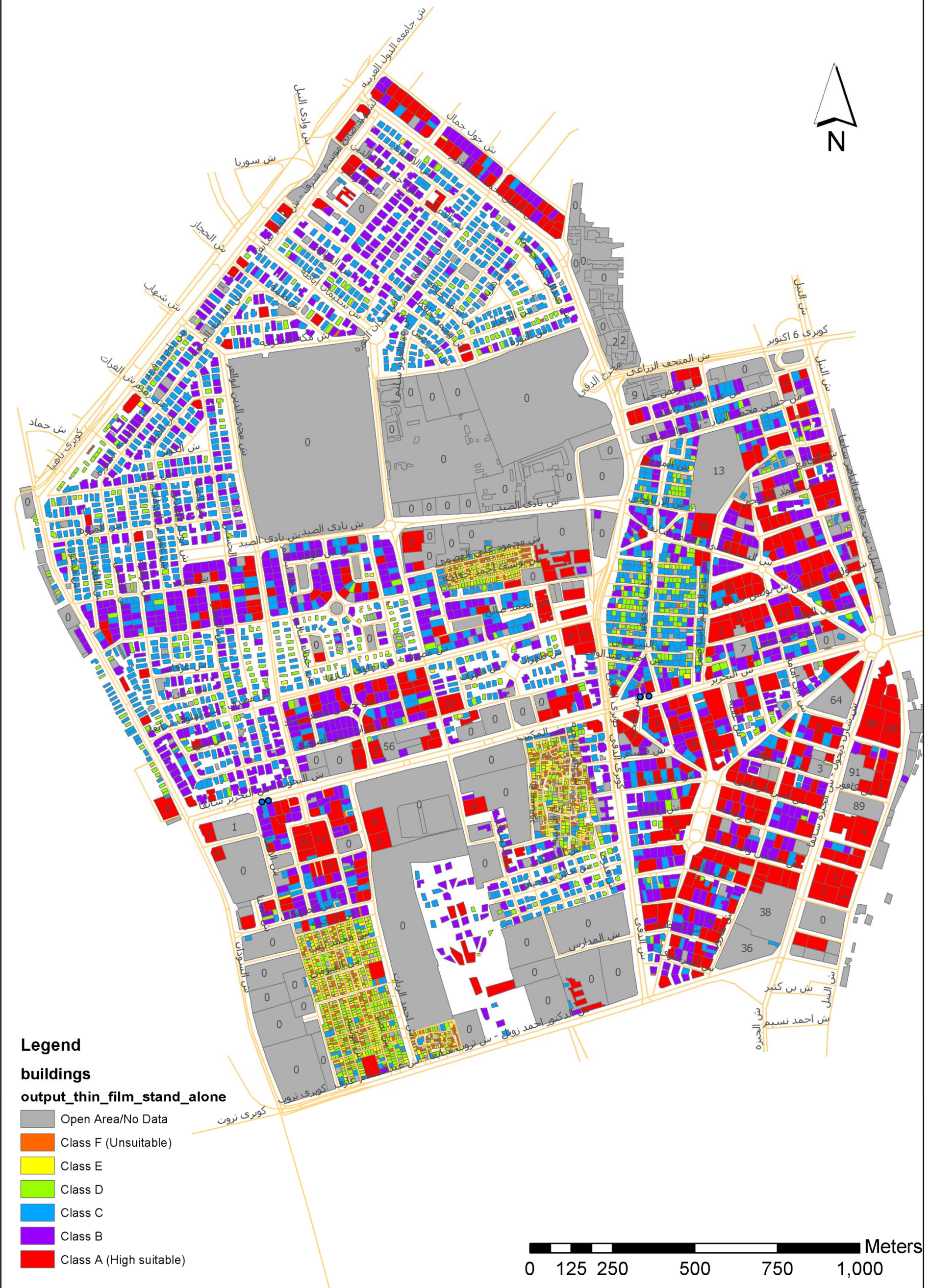
Total 5191 5191 100 100 190966149 224666058

Total expected output from suitable classes, classes A to E, are about 190000 MW/year (stand alone system) and about 220000 MW/year (grid connected system).

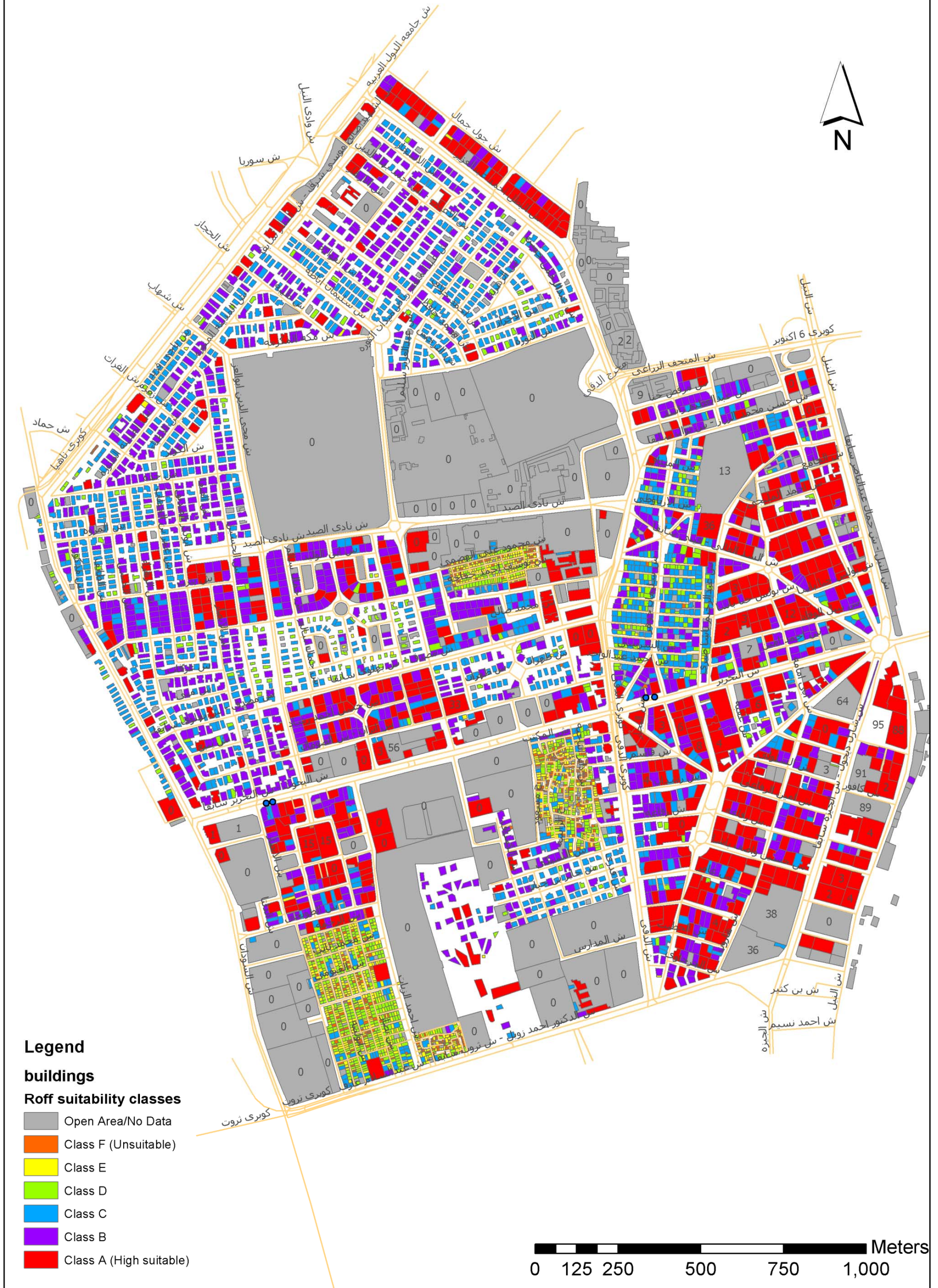
Total reduction in CO₂ emissions are about 83000 tons/year (stand alone system) and about 96000 tons/year (grid connected system).

Total people could utilize system's output are about 140000 (stand alone system) and about 170000 (grid connected system).

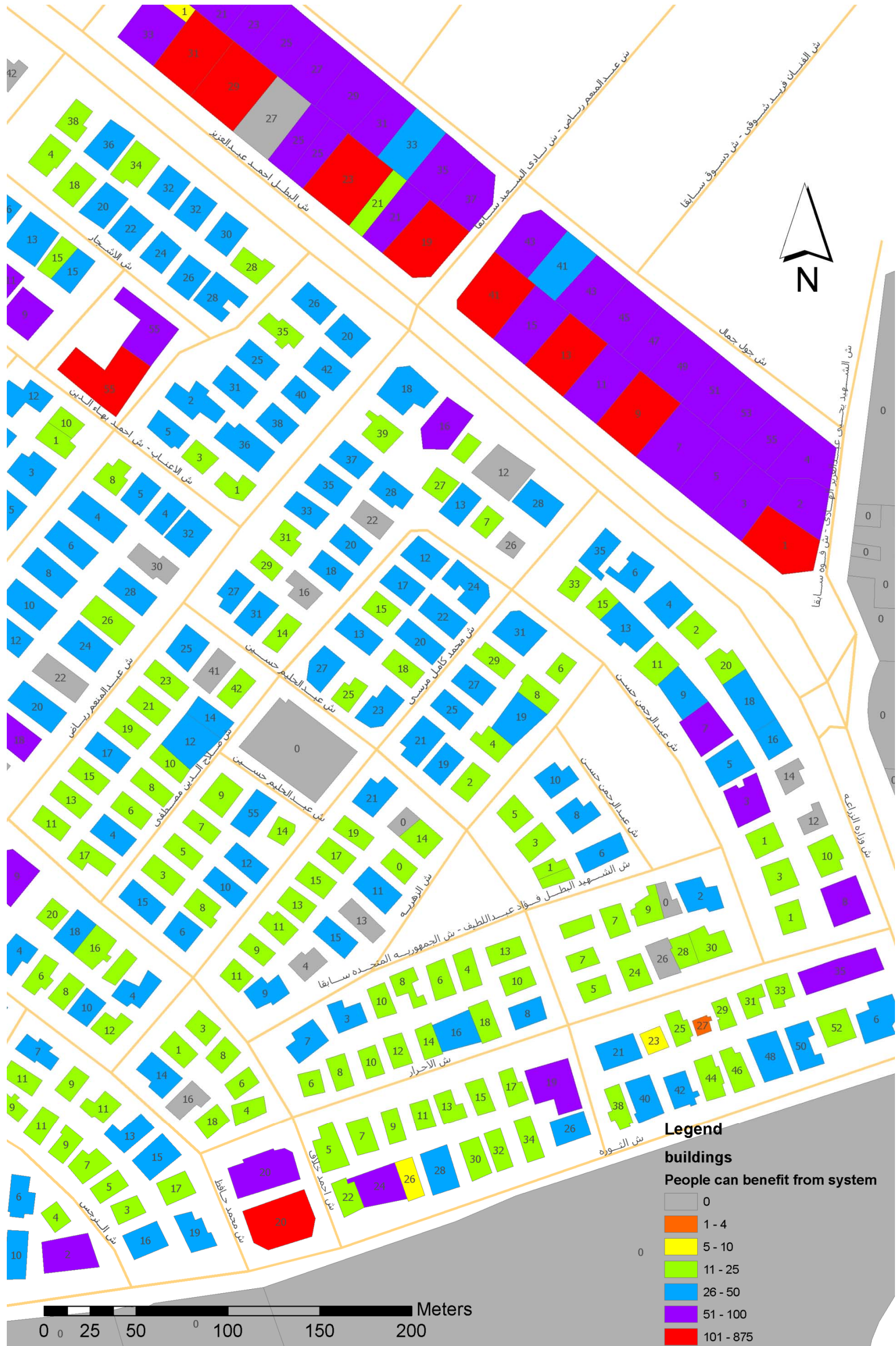
Building rooftop suitability (Thin Film, Stand alone system)



Building rooftop suitability (Thin Film, grid connected system)



Selected sample shows numbers of people can benefit system output (Thin film, grid connected system)



6 Discussions

Study area is well suitable for generating electricity using photovoltaic systems. The results show that about 90% of the district's rooftops are suitable for using photovoltaic cells in case of standalone systems and about 93% in case of public grid connected systems. The expected results relies on cell technology and system type, stand alone or grid connected system. Output could cover the complete power requirements of about 35000 families throughout the district while the total number of families in Dokki is about 30500 families which mean the surplus system's outputs can be exported to the public electricity grid and thus the district population can benefit from exported electricity.

The CO₂ emissions could be reduced by about 83000 tons/year. According to U.S. Environmental Protection Agency (EPA), the annual CO₂ emissions of a typical passenger vehicle is 5.1 tons [33]. That means the annual reduction in CO₂ emissions by using PV systems equals the CO₂ emissions of about 16200 cars per year.

When comparing the output of the grid connected systems with stand alone systems one can obviously notice that the grid connected system output is more than stand alone system, see chart 6.1. The consensus on this comparison is that the grid connected system is evidently advantageous since more output will be produced, moreover grid connected system is less expensive than the stand alone system. That's because the batteries cost will be deducted. Battery is one of the highest expensive items in the system.

Governments should endeavor to support people to install PV systems by allowing them to connect their PV systems to public electricity grid; in this case one meter run two ways should be used. Some utilities offer for customers with PV systems the option to use this type of meters to meter the excess of power generated by the PV system. As an example, Gainesville Regional Utilities (GRU), Gainesville, USA offer customers who invest PV systems on their homes can interconnect with the GRU electric system and receive reimbursement from the solar energy they do not use. GRU program offers customer who will be reimbursed for the excess electricity generated by their PV system, measured in kilowatt hours (kWh). The reimbursement is calculated as (Energy Rate + Fuel Adjustment)/kWh. For example, as of October 1, 2011, the net metering reimbursement rates were \$0.064+ \$0.051= \$0.115/kWh [30].

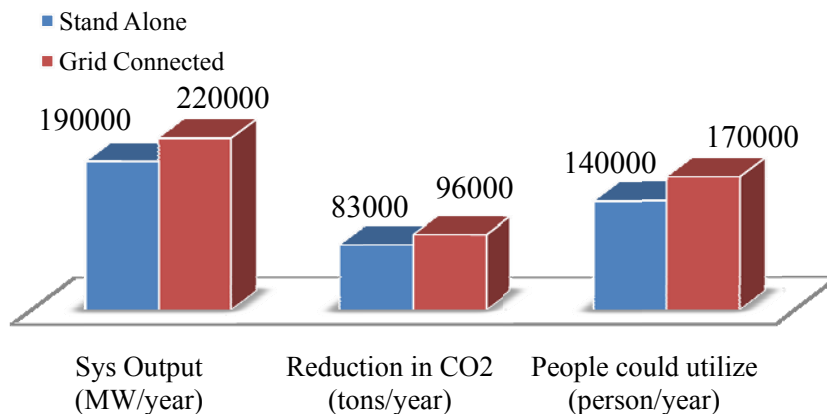


Chart 6.1. Comparison between stand alone and grid connected systems, thin-film Cadmium technology

Needing to ensure an adequate accuracy level of results and how it close to the reality plays an important role here. Significant impediment to test system on site is the installation cost, estimated cost for one hundred square meters exceeds 35000 US\$, instead of that, because of limits, the system results can be compared with similar project results. System outputs will be compared with SUN-AREA project results. SUN-AREA project calculates the sun power potential of each roof area for Germany and available on internet [<http://www.sun-area.net/index.php>]. Figure 6.1 below shows sample of system output for building in Osnabrück city.

If we assume that the annual average of solar energy input in Germany is 1220 KWh/m² [29] then make required changes in the background code by changing Egypt annual solar average 2445 to match Germany annual solar average input 1220 then the PV tool outputs from similar suitable area 129m² will be as next figures 6.1 and 6.2.

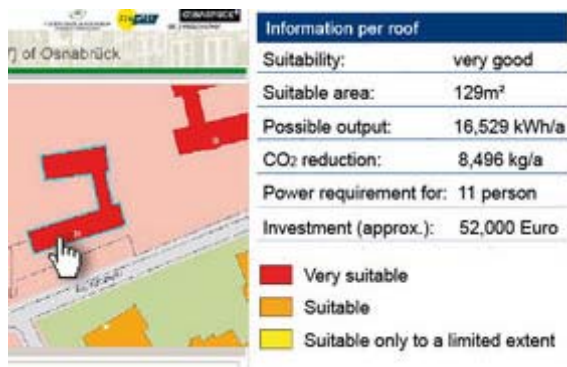


Fig. 6.1 SUN-AREA project, sample of system output

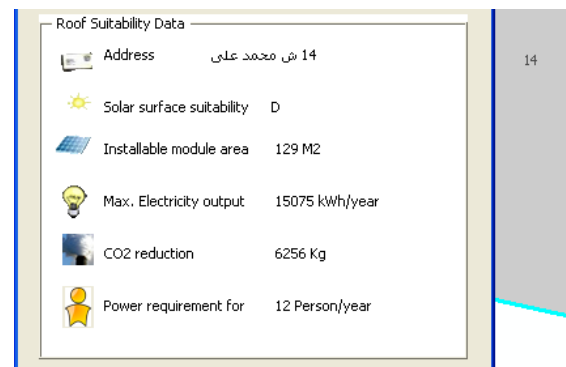


Fig. 6.2 PV tool, sample of system outputs. Annual average of solar energy input is 1220 KWh/m²

Total possible annual output from SUN-AREA project is about 16500 kWh/y and from PV tool with the identical installable module area is about 15000 kWh/y. The differences here are a result of the input parameters. Parameters are used in SUN-AREA project cannot be defined exactly and the PV tool parameters take into account many factors including temperature correction factor, dirt and dust reduction factor, module mismatch reduction factor, inverter efficiency, and cell technology efficiency.

In addition, SUN-AREA project used all suitable area, after subtracted shaded area, on the other hand in PV tool not all suitable area will be used but just the matching area with selected module's dimensions as shown in part 4.2.4.2.

A power requirement for a number of people is very similar in two projects in spite of the difference in two systems' outputs, that's because the annual electricity consumption per capita is different from one country to another.

The reduction of CO₂ emissions in SUN-AREA project is 8490 Kg/year and in PV tool is about 6250 Kg/year. In the PV tool The PV module CO₂ emissions during its lifetime is taken into consideration as described in part 4.2.4.5.

In order to assure that the functions in the PV roof integration analysis tool gives a correct result; the computed calculations by the tool will be compared with calculations that are done by hand. The test case and the test results are presented below.

The output results from the tool for building number 11 Abualsoud Street are: surface suitability class is D, installable modules area is 87 M², maximum output is 17252 KWh/year, CO₂ reduction is 7160 Kg and power requirement for 13 persons/year, in case of the input parameters are: roof area is 307.877m², average shadow is 71.58%, system type is stand alone, cell technology is single-crystalline and module dimension is 1 × 0.5 m, figure 6.3.

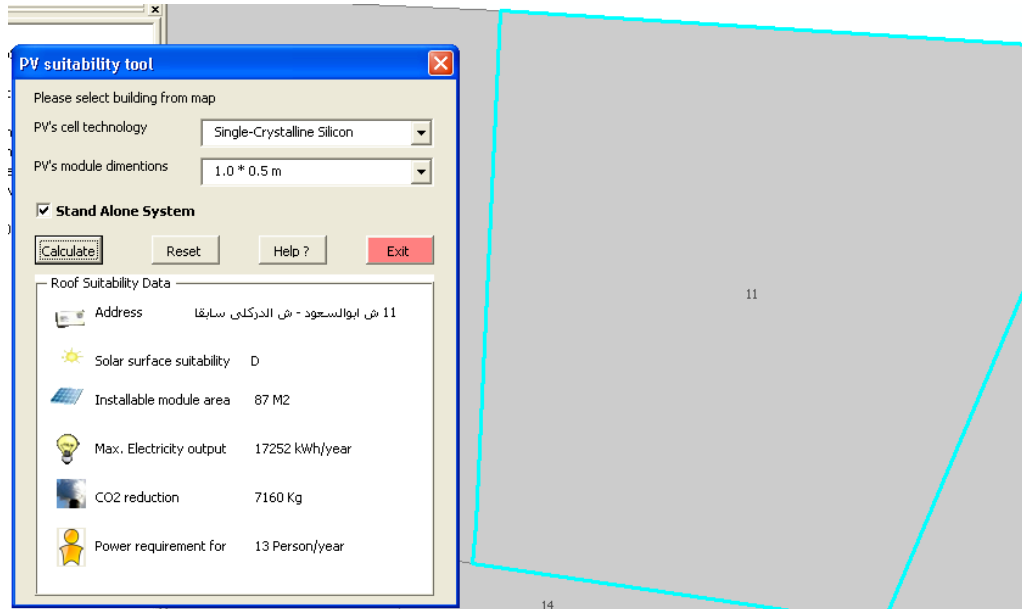


Fig. 6.3 tool outputs for building number 11 Abualsoud

The same inputs will be used to manually calculate output data for the same roof as detailed in next lines.

Installable modules area can be found using equations 4.1, 4.2 and 4.3. As per equation 4.1 available area for installation equals roof area – (roof area × (shaded area / 100)) = 87.50. Using function 4.2 in order to find modules number where equals fix(available area for installation/module area) = 174. Finally, the installable modules area equals modules number × module area = 87 m².

Maximum electricity output can be found using equation 4.4 and it will equal $2445 \times 0.8 \times 0.15 \times 0.85 \times 0.9 \times 0.95 \times 0.93 \times 87 = 17252.31$ Kwh/year.

According to equations 4.5 and 4.6 the suitability class is D.

The reduction of CO₂ emissions, based on equations 4.7, 4.8 and 4.9 equals $7936064 - 776354.1 = 7159710/1000 = 7159.71$ KG/year.

According to equation 4.10 the system output can cover the complete electricity consumption for 13persons/year.

The consensus on this comparison between the PV roof integration analysis tool outputs and the results that were found manually is that the results are identical.

In order to assure the shadow percentage that has been produced by Ecotect solar exposure tool, we measure the shadow produced on the roof of building #7 Dobgy Street. There is a fence with height of 0.5m and the shadow for this fence extended to about

0.7m in reality. Temporary fence was created for building #7 using ArcMap (temporary polygon) and the 3D model exported once again using ArcSiense to test the shadow produced by this temporary fence. The shadow extended to about 0.68m as shown in Figures 6.4 and 6.5. The difference here is slight and often goes back to the solar data, which deals with Cairo Airport Meteorological Station which is away from the Dokki district of about twenty kilometers.

The measurements were done on 01 February 2012 at 10.30 am.



Fig. 6.4 Building #7 Dobgy Street at 10.30 am on 1 Feb 12.

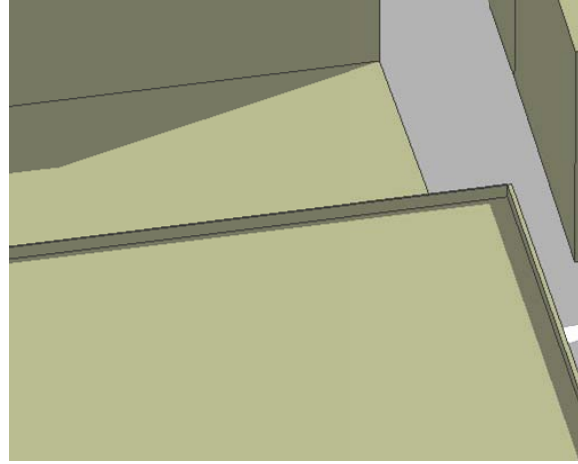


Fig. 6.5 Building #7 Dobgy Street at 10.30 am on 1 Feb 12 produced by Ecotect tool.

This study deals with urban scale therefore it must be difficult to take into account all stuff those might be found on each roof. Generally, there are some stuff we can find on a number of rooftops (Figures 6.5, 6.6, 6.7, 6.8 and 6.9), for instance, small fence with height varies between 0.5 and 1 meter and sometimes without fence, temporary buildings, satellite dishes and others.



Fig. 6.5 Buildings' rooftops Dobgy Street



Fig. 6.6 Building #5 Dobgy Street
-Fence and dished



Fig. 6.7 Building # 7 Dobgy Street
-Fence, dished and temp buildings



Fig. 6.8 Building # 6 Hussin Kamal Street
-Fence, dished and temp buildings



Fig. 6.9 Dobgy and Hussein Kamal Streets

Alternative energy field can achieve more interest from society in general, and planners in particular, by increase awareness of the advantages of using alternative energies, especially solar and wind. On the other hand, governments must encourage people to use these types of energy, e.g. make discount on initial components cost of the system and provide required support.

The major PV systems disadvantages are that the outputs are a variable energy source and PV makes it more expensive to produce power than conventional sources of energy. There are no negative impacts that can be mentioned for PV systems except for the environmental impacts throughout the manufacturing processes.

7 Conclusions and Future Work

Nowadays we cannot afford more to get our electricity from fuels and I just won't accept that we have high potential on our roofs, and we don't use it.

The aim of the thesis project was to create a toolbox of functions in order to facilitate the user to perform a quick and accurate analysis of the suitability of photovoltaic modules for a specific roof area. This objective has been achieved by the implementation of several analysis functions.

The PV building integration rooftop tool tries to find how much electricity could be produced if every suitable rooftop is equipped with photovoltaic modules and find roof suitability for using PV modules. In addition, takes green demission into account by finding how much CO₂ emissions can be reduced by using PV systems.

According to the results, study area is very suitable for generating electricity using photovoltaic systems.

The use of GIS as a planning tool has many advantages. For example, it is possible to analyze energy usage in urban district and to prepare Energy Atlases for renewable resources. This can be advantageous to realize where and what efforts are needed for a positive development of the country.

Using the output of programs based on GIS concepts, simply programs that deal with any physical object in four dimensions x, y, z and attributes, for instance, ArcGIS and Autodisk Ecotect analysis we succeeded to great extent to produce dynamic and reliable tool but still we need more scientific support in the PV field and more accurate data. A problem connected to data collection is that detailed buildings data might not always exist.

The PV building rooftop integration tool can be further developed. Examples of how it could be expanded are detailed in next lines.

Add more module models and attributes, the PV modules' specifications can be provided by manufacturers.

Add more calculation parameters. Especially tilted roof parameters e.g. tilted angle and orientation. These parameters are not considered in thesis project because of the study area is Cairo, Egypt and almost 99.9% of buildings' rooftop in Egypt are flat.

Make tool more dynamic. In PV building rooftop integration tool user should add layer with the name "buildings" and this layer should contain attributes e.g. Avg_shadow and F_Address; in order to apply the tool for more districts, cities or countries we should follow instructions such as name of layers and attributes therefore, by using of means e.g. XML file, we can change the variables and VB code can access this file and read required information.

Trying to represent data in a Web. The resulting online solar mapping gives everyone the opportunity to check the suitability of its own roof for solar installations. Just one click and the information can be retrieved in detail for every building. Each visitor to the website can know if a roof is suitable for a PV, how much electricity power could be produced, and how much CO₂ can be saved per year.

Using more detailed and accurate data to get more accurate results. Data used here were collected based on a ground survey and there are many missing data especially governmental buildings. There are many other technologies can be used to produce more accurate 3D data mainly depend on aerial and satellite images to produce Digital Orthophoto then DTM, also LIDAR instruments are used widely for surveying and 3D mapping.

Shadows cast by vertical objects on the PV modules can cause significantly greater power reductions. We can produce more accurate shadows per cent by create digital model surface with small dimensions such as 1×1 m. The input parameters are the digital surface model grid, the geographical site, and the daily & seasonal changes in sun angle.

An expansion of the tool would make it possible for the planners and researchers within planning and green architectural sciences to perform more advanced planning analyses. This would further motivate the planners and researchers to perform their energy analyses using PV building rooftop integration tool in a GIS.

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Appendix A: Installation Options and Configurations

The installation options and required configuration are presented below.

A.1 Compile Options

For VBA developments, there are several ways to distribute the code and UI customizations. The code and UI customizations may be packaged in either the document file for example, a .mxd file for ArcMap or a template file.

The first method to deploy this information is to simply copy the document and/or template to the appropriate directory on the target machine.

This method has some disadvantages for example if your document contains an enabled extension and the target machine does not have that extension installed, the document will not open on the target machine, and the user cannot extract any code from that document. Another disadvantage is that if you are distributing a Normal template, it will overwrite any customizations that already exist on the target machine.

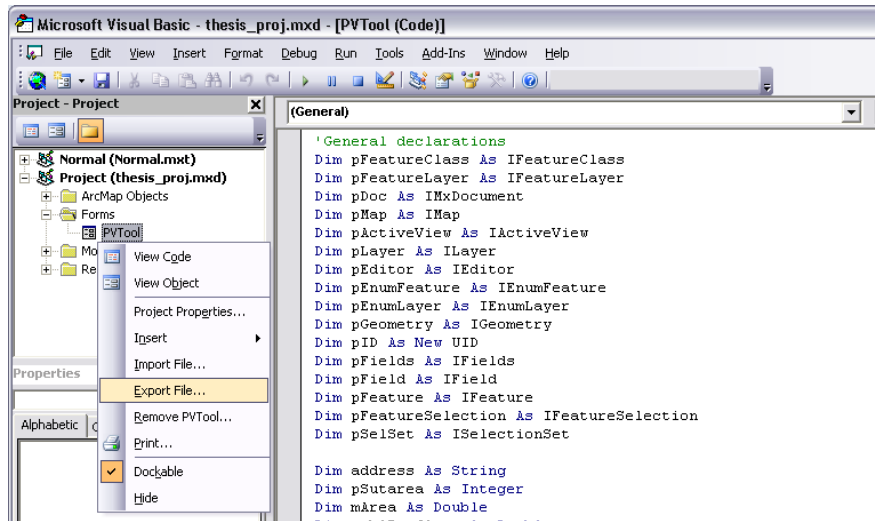


Also, keep in mind that when you save a document, you have a choice of storing absolute or relative pathnames. If you intend to distribute a mxd file and data to other users, try to use relative pathnames such that when they open the document it will look for the data in a pathname relative to the mxd file rather than a hardcoded path that may not exist on the target machine. Next piece of code shown how relative pathname can be used

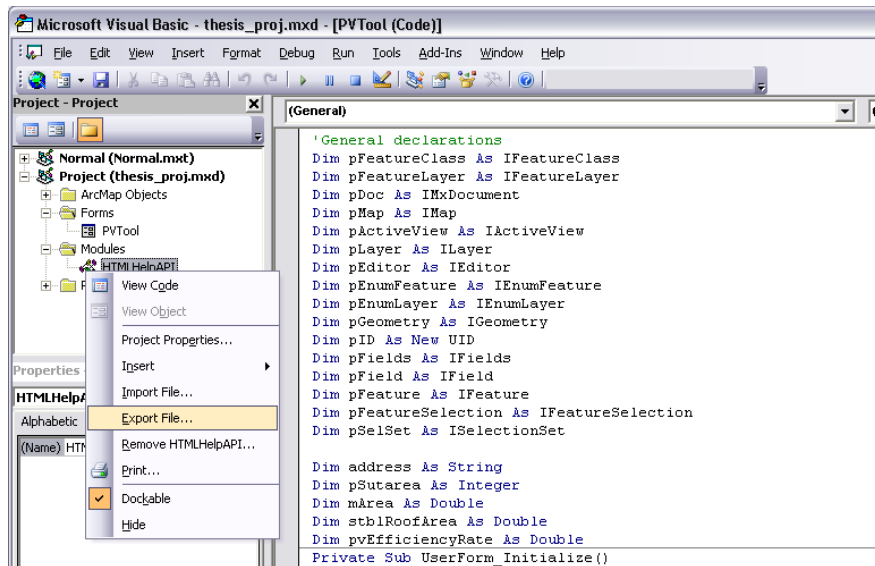
```
Private Sub helpBtn_Click()  
    Dim hlpFile As String  
    hlpFile = CurDir & "\help.chm"  
    HTMLHelp 0, hlpFile, 0, 0  
End Sub
```

The second method is to export the VBA code modules to text files, copy those files to the target machine, and then import the files into an application's VBA session.

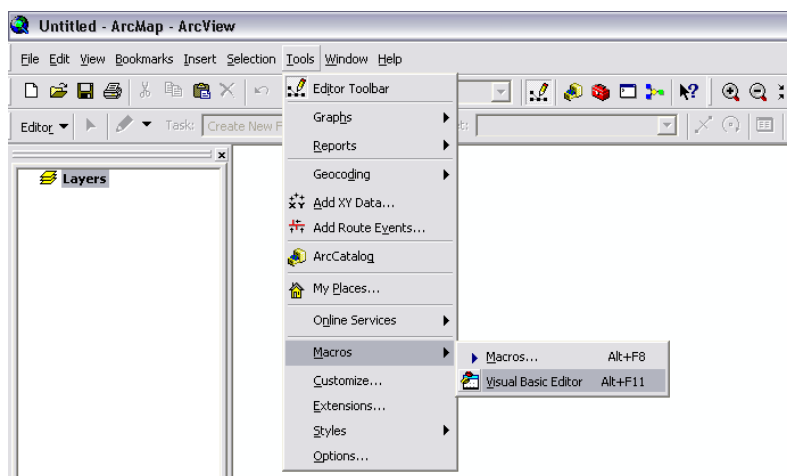
Next screenshots illustrate how VBA code modules can be exported to files and imported in target machine



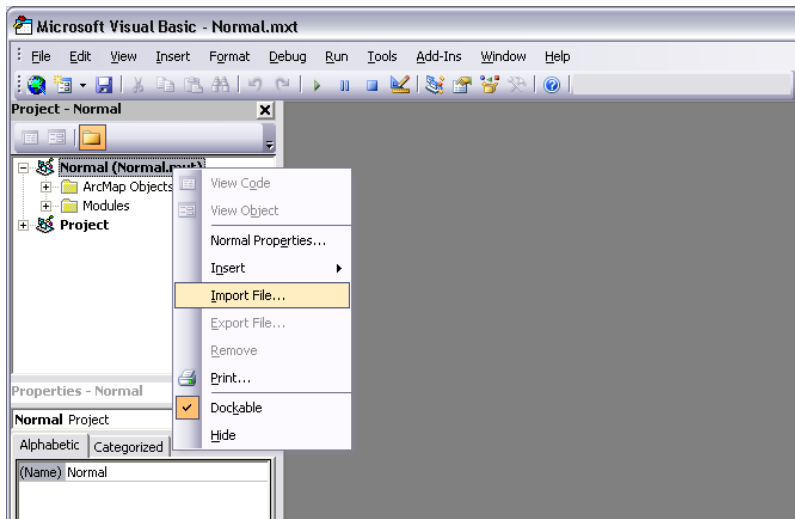
Export tool form code file



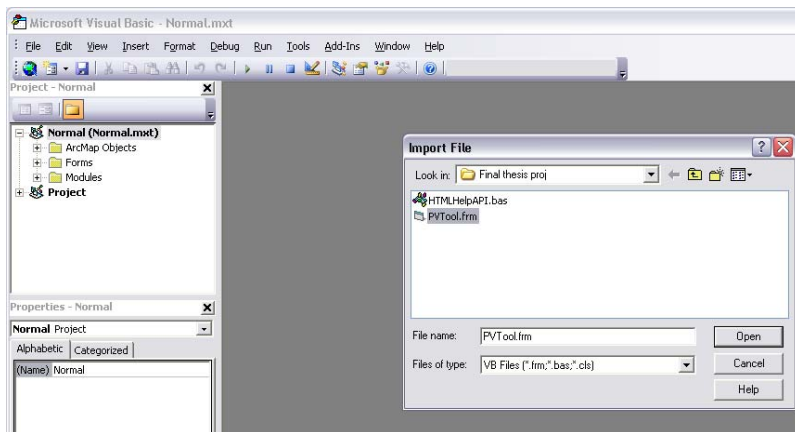
Export tool help module code file



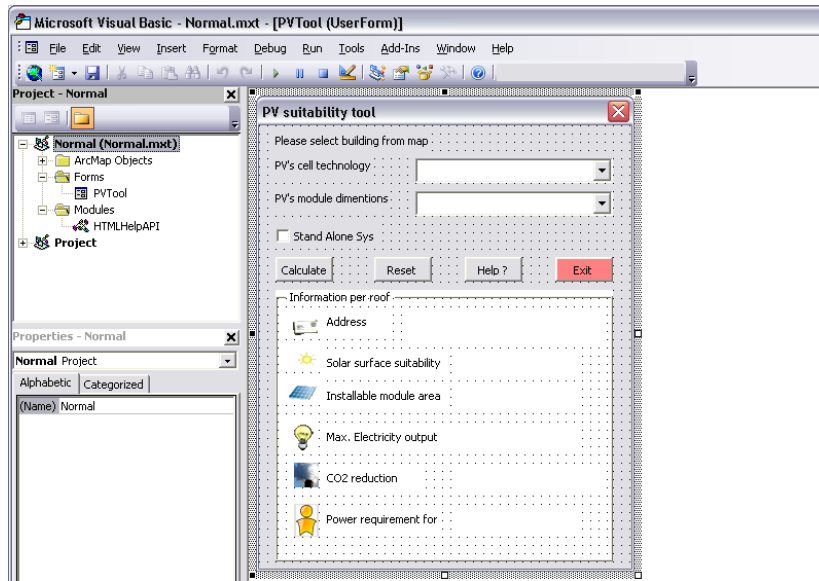
Open ArcMap> Visual Basic Editor on target machine



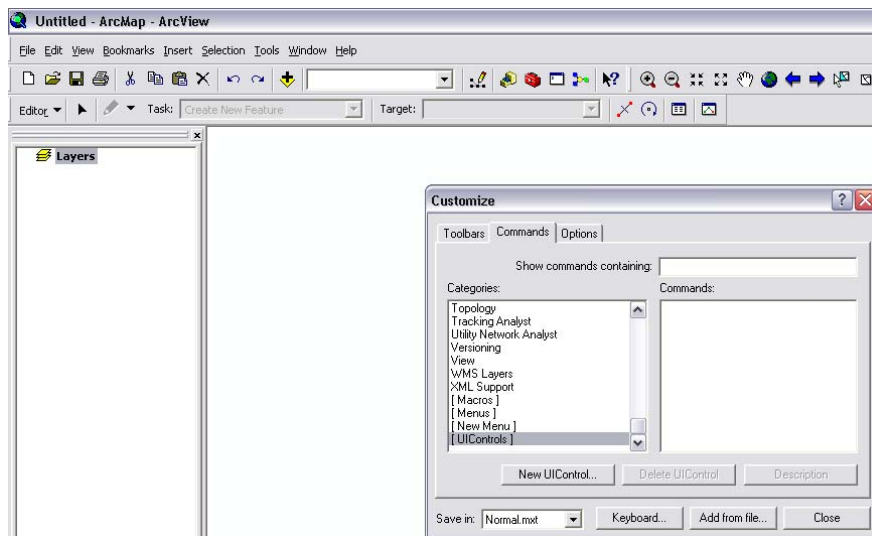
Import files “form and help module”



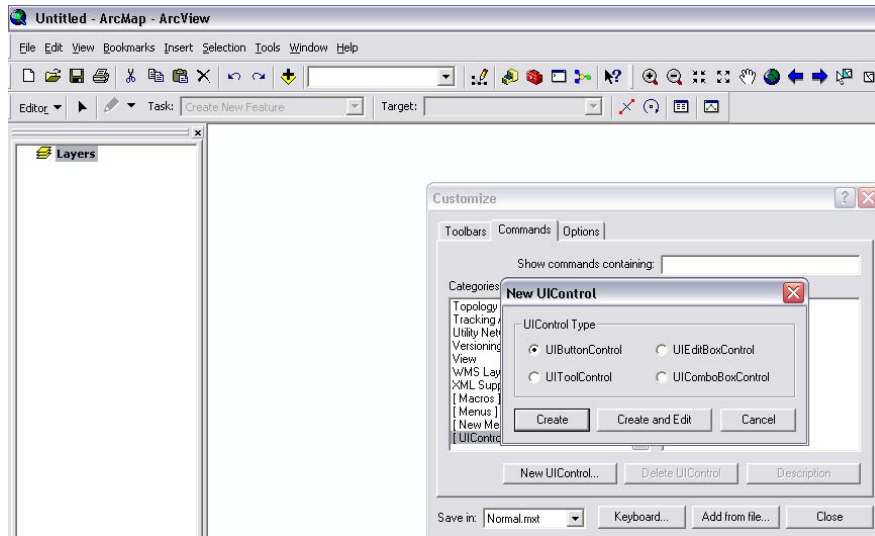
Import files “form and help module”



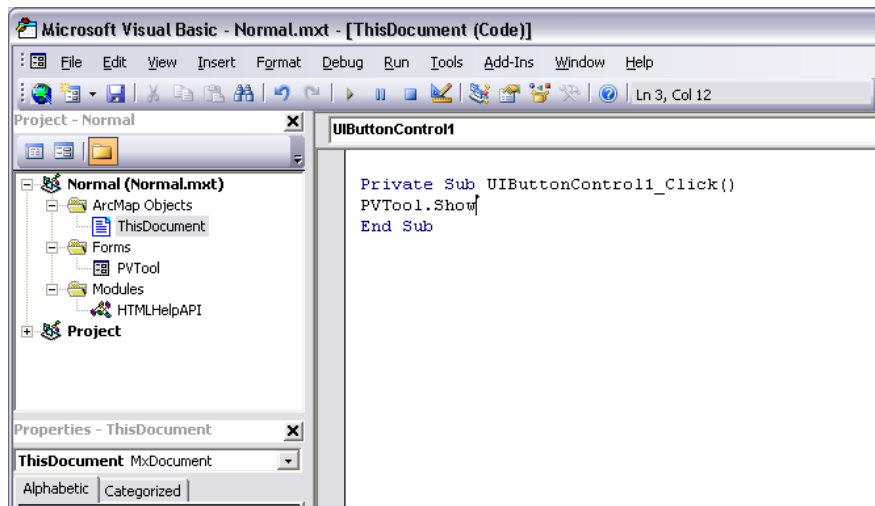
Project code files will
opened



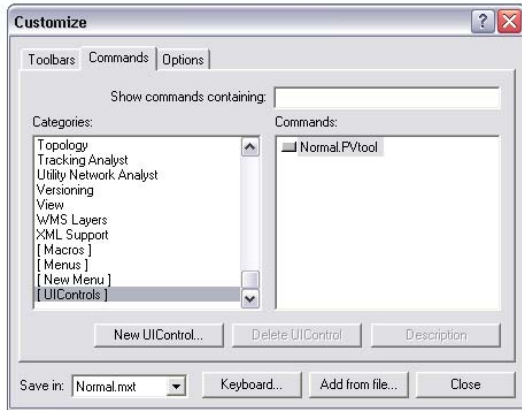
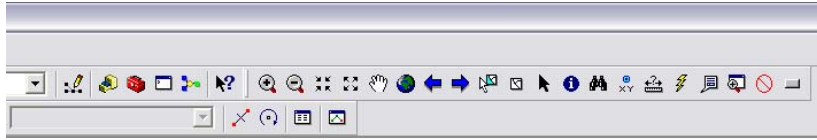
Tools > customize >
commands > new
UIControl



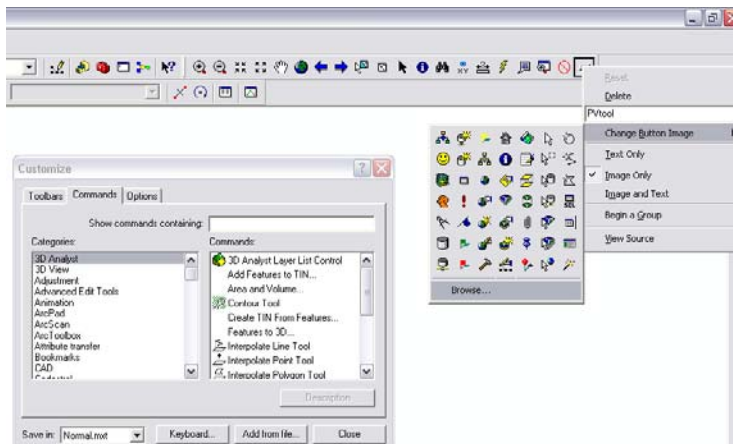
Select
UIButtonControl



Set UIButton click
event code to call
PVTTool form



Drag and drop UIbutton

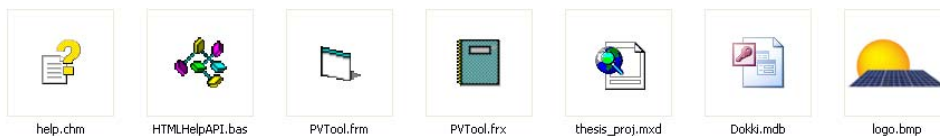


Right click > change button image "if required"

The disadvantages with this second method include the manual process of exporting and importing potentially large numbers of files and the fact that UI customizations cannot be transferred this way.

A.2 File Formats

The data is delivered in the folder "Thesis project". This parent folder includes the following:



-help.chm: Help file, Microsoft Compiled HTML Help (chm)

-HTMLHelpAPI.bas: Module contains initialization code, Basic file (bas)

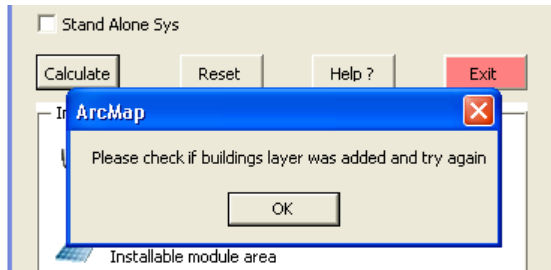
-PVTool.frm: Main form that contains project code, Form file (frm)

- PVTool.frx: Main form binary data file, used to store binary information for the form (.frm)
- thesis_proj.mxd: A file contains a map, its layers, display information and VBA form, ArcMap document file (.mxd)
- Dokki.mdb: Geo-database includes the basemap layers and all information regarding the buildings.
- logo.bmp: Logo image “if required”.

Appendix B: Tool Alarmed Messages

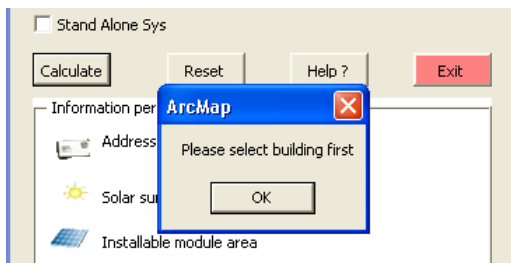
Tool contains four alarm message boxes

-If buildings layer not found in mxd file.



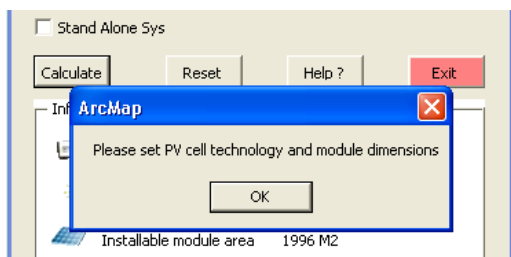
Alarm message box: if user not add buildings layer to mxd file

-If user didn't select building



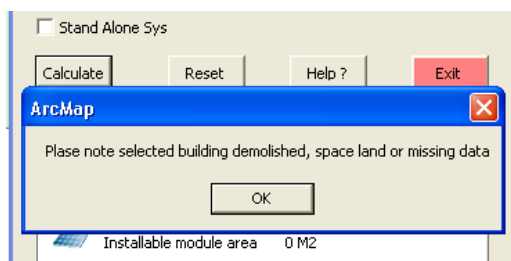
Alarm message box: if user does not select target buildings

-If user didn't set PV's cell technology or PV's module dimensions



Alarm message box: if user does not set required PV cell technology or module dimensions

-If selected building is demolished, space/open area or missing data in a sense if the floor sum is 0



Alarm message box: if selected building is demolished, space area or missing data

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