Sizing Photovoltaic Systems during Early Design: A Decision Tool for Architects

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ABSTRACT

Despite all the available solar technologies and the opportunity to reduce energy demand, solar energy systems are in most cases not used in buildings today. The lack of technical knowledge among architects is one of the main barriers according to the IEA-Task 41 entitled Solar Energy and Architecture [1]. In fact, several problems face architects during the design and set-up of buildings that integrate PV systems, for example, the complexity and uncertainty of estimating the PV performance. To overcome this problem and to examine these opportunities, this study developed a decision tool to guide architects to size PV systems during early design stages. The aim of the study was to help give architects a generic idea of the potential of PV as an energy source and how to integrate PV in the building architecture. The tool is based on a transient simulation database built using TRNSYS16 and underlies research considering PV technology parameters and local climatic conditions of Egypt. Simulations of three PV systems are compared with measured data in order to form a basis for optimal design and prediction of PV system performance. For this tool we developed and presented simple graphical visualization of the verified performance indices. For example, yearly maximum output energy of PV modules, for different inclinations and orientations for Aswan, Alexandria and Cairo. The overall benefit of this simple decision tool is informing and assisting architects and designers in order to increase the use of solar energy in buildings

1. INTRODUCTION

Given the global challenges related to climate change and fossil fuel depletion, several countries seem to be settling on a goal and vision of Net Zero Energy Buildings (NZEB) and communities [2]. The first strategy to design NZEB is to reduce demand through passive architectural design. The second strategy is to utilize intensive renewable energy concepts in particular solar PVs [3]. The environmental attributes of PV systems include the reduction of fossil fuel consumption and CO2 emissions in the built environment. The later step is imposing a new responsibility on the shoulders of architects, to integrate a solar system during the early conceptual design phases. Whether we can afford to install a PV system during building construction or not we have to prepare our building stock to be receptive to PV systems at least in the near future.

Designing NZEBs in a country like Egypt, receiving an annual total irradiation above 2409 bankable kWh/m^2, implies knowing how to integrate PVs in the building design. Many studies concluded that the incoming solar energy in most Egyptian cities is sufficient to supply the energy needs of the population in the built environment and advocate its use for developing their regions [4-6]. However, the idea of integrating solar energy systems within the building architecture is considered a challenge for many architects in Egypt and elsewhere [7, 8]. There are a number of frustrating uncertainty and unknowns facing architects when designing buildings that incorporate solar active systems. A preliminary study of the existing and available software has been made, which indicates that most existing PV estimation software (e.g. PVSYST & PVGIS) are focused on electricity generation prediction and cater more for engineers and researchers [9-12]. Requested input parameters of those software are focused on module efficiency, or nominal peak power of panels while the output results focus on performance parameters (e.g. annual and monthly electric yield) [13] with no guidance on physical integration within the building envelope addressing parameters such as the panel area, mounting position, row spacing, inclination etc.

Today, there is an increasing awareness of the importance of early-design decisions and the new responsibilities assigned to architects in reaching NZEBs. Therefore, this study provides a simple architect-friendly design tool for the integration of grid-connected solar PV systems in residential buildings in Egypt. A preliminary version of the tool is available and circulating among some test-users under the provisional name EGYPV Estimator v.1.0b.

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2. METHOD

2.1 Strategy

Considering the overwhelming number of parameters requested when designing PV systems and estimating their yield (up to 40 parameters), it was decided to downsize the number of parameters and carry out a level of abstraction. The suggested decision tool is an implementation of simulation results that estimate the average performance of a PV system in different locations and positions in the built environment. The simulation-generated data was matched with real measurements obtained from literature. The simulations are dynamic ones performed for a typical Egyptian year. Instead of communicating those results in the form of textual/numerical data a graphical interactive interface is developed to convey the design guidelines in an educational and visual way. The results have been compiled into performance graphs. The interface graphs are mainly focused on:

- Relation between annual yields versus the panel area.
- Optimization of panels inclination vis-à-vis azimuth angel
- Possibilities of panels positioning and integration within building envelope

The decision tool enables architects to access results of dynamic simulations of typical cases for the design and sizing of PV systems.

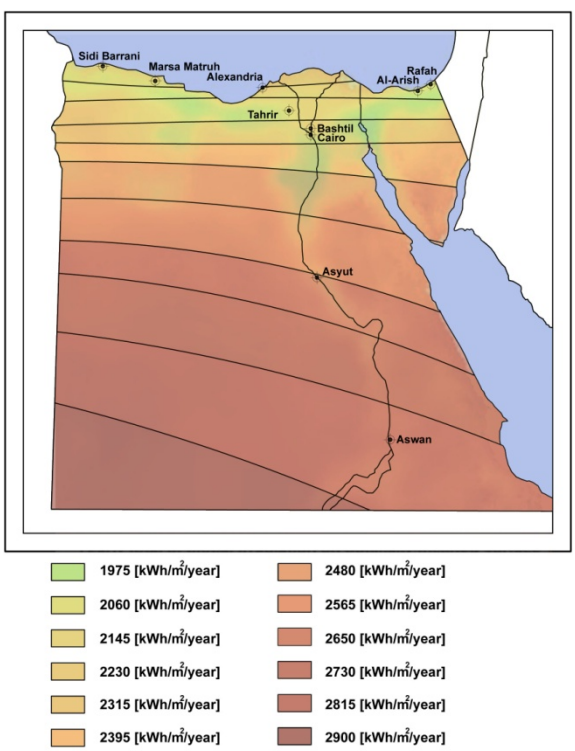

Fig. 1: The annual average of direct solar radiation over Egypt (adapted from the Solar Atlas of Egypt)

2.2 Solar Radiation Climate

Knowledge of the solar radiation climate of an area is extremely important for estimating the performance of solar-energy collecting systems. There is no specific solar-climatic classification in Egypt [14]. However, there are several studies that addressed this issue and Egypt has ten Radiation Data Centers (RDC) distributed all over the country with time-series information collected since 1967 as shown in Figure 1 [15]. In fact, the solar radiation climate can differ from urban to rural areas. Therefore, and for the purposes of design this study is concerned with highly populated urban areas where most urban development takes place. As a consequence we selected three cities, namely Aswan (South), Cairo (Middle) and Alexandria (North). These cities represent the various solar radiation climate conditions of Egypt in accordance with their urban magnitude.

2.3 Parameters

Simulations have been performed for three cities using TRNSYS16 and typical Egyptian year weather files that include average hourly diffuse, direct normal and global horizontal radiation values. TRNSYS is a transient systems simulation program with a modular structure developed by the Solar Energy Laboratory in collaboration with CSTB in France, TRANSSOLAR in Germany and TESS in the US [16-18]. However, it has a steep learning curve and a complex user interface for inputting building data. For this study, simulations are limited to residential buildings taking in consideration the following criteria:

Architectural parameters

The architectural integration of PV modules within the building envelope includes the following:

- *Location choice*: Aswan, Alexandria and Cairo
- *Collector Inclination or tilt*: the angle between collector planes and the horizontal (0,10,20,30,40,50,60,70,80,90).
- *Collector Orientation* or *Azimuth angle*: 90, 75, 60, 45, 30, 15, 0, -15,-30,-45, -60,-75,-90
- *Collector panel area*: Gross aperture area of panels.
- *Mounting position*: building integrated, free standing
- *Row Spacing:* collector length and collector inclination

PV System Installations

The performance of PV modules depends on the temperature, solar irradiance and module type. At the moment, we selected crystalline silicon cells and thin film modules due to their availability in the Egyptian market. The following parameters were considered:

- *Solar panels type:* mono-crystalline, poly-crystalline and amorphous/thin-film modules
- *Panel Efficiency*: 12%, 14% & 7% (mono-crystalline, poly-crystalline and amorphous/thin-film modules)

3. SOFTWARE DESCRIPTION

The tool is written in Visual Basic 2008 and has a wizard interface to guide users through sequential dialog boxes. The tool is organized into a two step procedure. The first step intends to identify design input parameters. The second step is concerned with analyzing the output results.

3.1 Identification of Input Parameters

To identify the input parameters 5 mandatory questions are asked on two successive screens. On the first screen users are asked to select a city, module type and mounting position (see Figure 2).

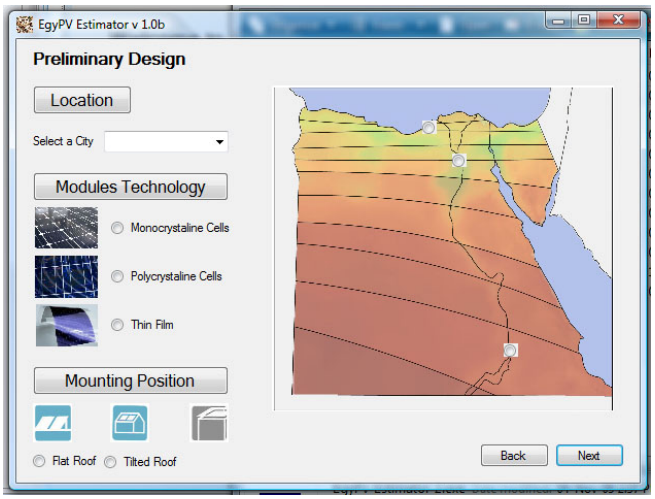

Fig. 2: First input screen

The second screen asks for input regarding panel orientation (azimuth angle) and inclination. There are two additional elective questions on screen two that allow users to input values regarding the panel efficiency and/or nominal peak power. For every question, the user has to choose between different answers, corresponding to the various simulated cases. Those questions allow identifying the architectural parameter values presented in section 2.3. But they also are the occasion to give to the user some advice. For example, there are two optimization indicators. The two graphs in Figure 3 guide and assist the user to choose the optimal orientation and inclination of the panels.

The issues of shading obstructions and the ventilation properties of the panels are also addressed. The user is advised to avoid shading the PV modules whenever possible to avoid a drop in output yield. Also the user is informed about the importance of module ventilation in a hot climate like Egypt and how the increase of PV module temperature can highly affect the panel efficiency. The aim here is to inform users about optimal choices for each of the three cities.

Additionally, by using the help cursor the user can point to any parameter to ask for an explanation and assistance. A few lines are written for every parameter-question explaining the function and meaning of the required parameter. The textual explanation is accompanied by graphical illustrations for visual communication and better understanding. The help feature inform the user and recommend a range of values highlighting the most efficient for optimal performance.

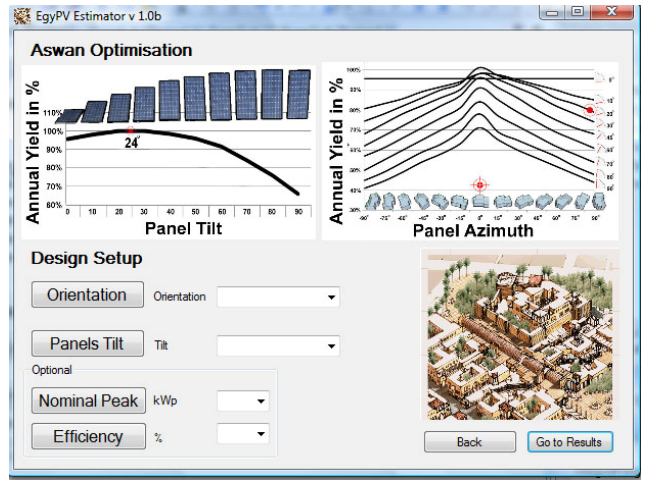

Fig. 3: Second input screen

The interface was designed in general to have a graphical look with architectural illustrations in order to facilitate the visual communication of the input and output parameters.

3.2 Output results

Once all parameters have been defined the user is guided toward the final screen. The final screen shows the expected annual yield in correspondence to the panel surface area. Based on the users choice the annual yield value can be broken down into monthly average yield. The objective of the input parameters identification process is to inform architects as early as possible about architectural physical and spatial implications of installing PV modules on the building envelope vis-à-vis the optimization of annual yield. Another feature the tool can provide is calculating the PV collector rows spacing assuming that the collector arrays are placed on a flat roof. This feature is important to ensure solar access to all arrays by spacing the rows far enough apart to eliminate shading [19]. The final message from the output results is that the architecture has to be designed understanding the relation between solar collection and solar movement.

4. RESULTS

The implementation of the decision tool described in section 3 was only a part of the research endeavor. The bedrock for this research was the simulation work. Based on the typical year of meteorological conditions of Aswan, Alexandria and Cairo the performance of the following three PV types was simulated in TRNSYS:

1- PV panels, mono-crystalline modules (type 94a)
2- PV panels, poly-crystalline modules (type 562a)
3- Amorphous/thin-film PV modules (type 94b)

The verification of the simulation results was performed through various model calibrations. The difficulty of this step is due to the large difference between simulation and monitoring outcomes. For example, in the case of Cairo the monitored PV yield was on average 18% less than the simulated PV yield. This is mainly due to the effect of urbanization and pollution [5]. The two factors highlight the importance of the knowledge of solar radiation climates in urban areas. However, by calibrating the model with several theoretical analysis and experimental verification studies found in the literature [5, 20-23], a good agreement was reached between the simulated and monitored output yield of PV modules.

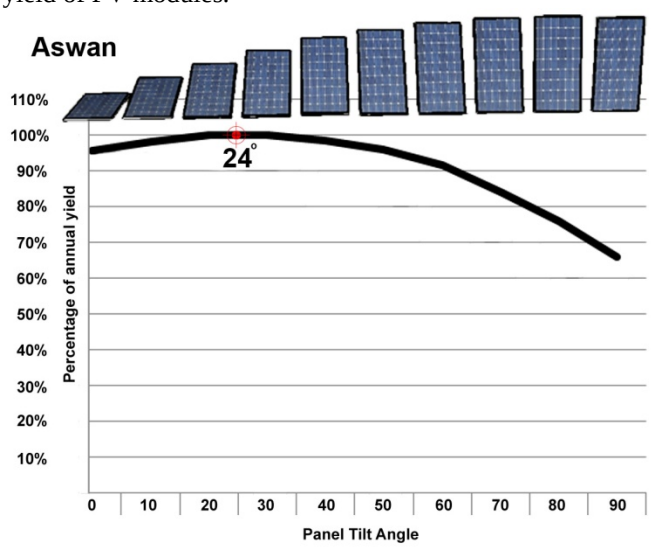

Fig. 4: Effect of tilt angle on yearly maximum output energy of south facing PV modules in Aswan

Two types of data sets were produced. The first data set was concerned with design optimization indicators. The yearly maximum output energy of PV modules, expressed in percentage, was simulated for different tilt angles and orientations in each city. The output values are used to generate design decision curves, which form the basis of the interface. For example, the effect of tilt angle on yearly maximum output energy for south facing PV modules in Aswan is illustrated in Figure 4. The figure indicates that the optimal panel tilt should be 24°. Another optimization graph is present in Figure 5. The figure illustrates the yearly maximum output energy, expressed in percentage of its value, at any tilt angle and orientation.

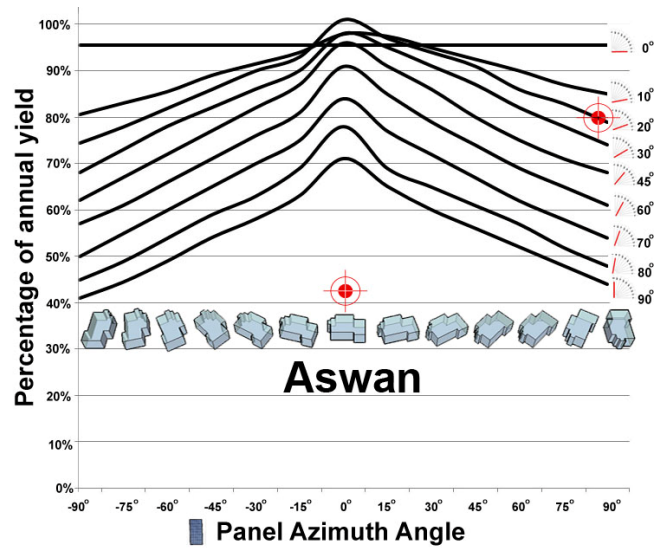

Fig. 5: Percentage of output energy of PV modules at different tilt angles and orientations in Aswan

The second data set was concerned with case specific PV yield in relation to the surface area. The yearly maximum output energy, expressed in kWh/year, was simulated for different PV tilt angles and surface areas in each city. Results for Aswan are illustrated in Figure 6. The figure illustrates the monthly maximum output energy for any surface area chosen by the user. Upon the user's choice and in the case of roof mounted panels the tool allows the calculation of collector row spacing. A simple imbedded equation in the interface defines the distance from the front of the first collector array to the front of the second incorporating the collector length, inclination angle, maximum altitude angle and azimuth angle.

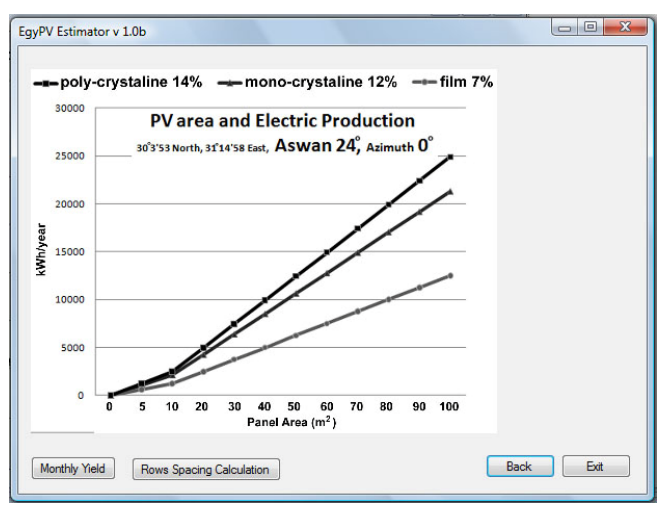

Fig. 6: Output energy of three different PV modules for optimum tilt and azimuth angle in Aswan.

5. CONCLUSIONS

This paper presents an initial decision tool that focuses on the integration of PV systems early, during the building design. A user-friendly easy and fast design decision tool has been developed to promote grid-connected PV system pre-sizing among architects and building designers. This study was based on a set of hundreds of dynamic simulations using TRNSYS as the basis of the decision tool interface. The detailed solar and PV performance results in Aswan, Alexandria and Cairo were reviewed and validated against actual measured data and it was found that there is good agreement between the two. For architects aiming to design NZEBs the tools allow the user to assess the electric power output for different PV system configurations as well as their physical impact on the building envelope. In particular, major architectural design and PV panel set-up parameters such as sizing, mounting position, inclination and orientation angles. A unique feature of this graphical and architect-friendly tool is its ability to correlate the required PV module area and physical set-up to the output yield prior to design. In contrast to the common practice, where PV integration is treated as a post-design matter, the tool allows architects to integrate PV modules into the building design during its conception. Finally, the structure and features of the new tool is presented and the major capabilities were described. The decision tool is still undergoing development and more new features are being implemented.

6. FUTURE RESEARCH

As the decision tool is in its beta version and part of an ongoing research effort, certain foreseen functions are not yet available. However, the authors will continue developing the interface dialog windows integrating a wider spectrum of choices and capabilities.

7. ACKNOWLEDGMENTS

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