Greening the Kuwaiti Houses: Studying the Potential of Photovoltaics for Reducing the Electricity Consumption

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Abstract

This paper investigates the potential of the photovoltaics (PVs) in reducing the electricity consumption of the residential buildings in Kuwait. A sample of 25 houses are selected and analyzed according to their surface areas and orientation. The computer simulation software, PVSYST, is used to calculate the electrical generation from these PVs when installed on the available building surfaces. A comparison between the PV electricity generation and the electricity consumption of the residences is also discussed.

Introduction

After evidences of global warming and thinning of the ozone layer and after the nuclear disaster at Chernobyl and the resources depletion, architects are facing increasing pressure to design buildings that are friendlier to the environment. Low-energy design concepts once encouraged in the mid 70's and 80's may not be enough anymore. A shift to a higher level of energy conservation measures have been encouraged in the 90's to design zero-energy architecture and at the dawn of the new millennium to design green and energy-exporting architecture. The American Institute of Architects' (AIA's web site: http://www.aia.org/release_121905_fossifuel) Board of Directors has set a goal of slashing the fossil fuel consumption of buildings by a minimum of 50% by the year 2010 and expressed strong support for consensus based standard for sustainable design (AIA, 2005).

One method for achieving this goal is the application of the Photovoltaics (PV). PV is a versatile electricity technology that can be used for many applications, from the very small to the very large. It is a modular technology that enables electric generating systems to be built incrementally to match growing demands. PV is easy to install, maintain and use. It is a convenient technology that can be used anywhere there is sunshine and that can be mounted on almost any surface. It can also be integrated with building structures to maximize aesthetics and multifunctional value (www.nrel.gov/ncpv/value.html). When it becomes part of the building envelope (displacing windows, walls, roofs, and eaves) it is called Building Integrated Photovoltaics (BIPV).

PV technology in Kuwait

The primary source of energy from which Kuwait obtains all of its electrical power is gas and liquid oil products (MEW, 2000). This electricity is highly subsidized and sold to the customers for 0.00067 $/kWh; one-tenth the fraction of the actual cost. As a result, no serious studies were conducted to investigate the feasibility of other sources of energy such as renewable energies. The few solar energy studies on building systems in Kuwait have been conducted between late 70's to late 80s by the Kuwait Institute of Scientific Research.

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During that period three projects were initiated and operated successfully: a kindergarten, an office, and a high school. Monitoring their results showed that these systems are not economically feasible and no serious attempts to follow up have been made since then.

However, with the current development in the efficiency of the PV modules and its advanced integration with the building envelope in what has been called BIPV there is a need to reinvestigate its potential in Kuwait especially that the residential sector consumption of electricity is continuously rising and approaching 50% of the total electricity generation (MEW, 2000). The annual per capita electrical consumption in Kuwait currently is 12,538 kWh, the 6th highest in the world (NationMaster.com, 2006).

Objectives and Methodology

The objective of this study is to investigate the potential of the PV technology in Kuwait. The “potential” may be categorized into three: area potential, technical potential, and market potential. The area potential includes the architectural areas suitable for installing the PV modules. The technical potential includes the system performance of these modules. The market potential includes both the financial aspect and the value added (image, publicity, education, etc). This study will focus on the first two categories only. It intended to be the first of a series of studies towards a comprehensive investigation which include further analysis on the area and technical potential as well as the market potential of implementing the PV technology. Similar studies have already been carried out addressing the potential of PV in 14 countries worldwide (IEA, 2002).

A sample of 25 houses is first selected from a larger sample collected by a group of students at the department of Architecture at Kuwait University four of which are shown in Figure 1. These houses do not necessarily represent the typical Kuwaiti house, per say; they are somewhat inclined toward educated, middle-class families in their 40s and 50s , however, they are located all over Kuwait and can represent a good portion of the Kuwaiti residences. More details on how this sample was prepared can be taken from a previous study conducted by the author (Almumin, A. et al, 2003). Next, the computer simulation software PVSYST is used to calculate the electricity generated from the PV modules (which are assumed to be located on the entire surface area of the building). Then, finally, the level of solar power produced by the PV is compared to the current electricity consumption rates and analysis is made.

The study pursued two approaches to achieve this objective: First by analyzing the dimensions of a one house that represents the average of the entire sample houses, and second by analyzing the dimensions of each of the 25 sample houses.

Figure 1: A sample of the Kuwaiti residential buildings.

Availability of Surface Areas for BIPV

The surface area of each sample house is classified based on its orientation and shown in Figure 2. These areas vary widely from one house to the other, for example, the roof area varies from 170m^2 to 570m^2 and the south facing area ranges from 133m^2 to 422 m^2. The average area of each surface ranges between 180m^2 at the northeast and southwest direction, to 221m^2 at the east and west direction, to 232m^2 at the north and south direction, with an average roof area of 308m^2 (See Figure 3) These results suggest that the houses in Kuwait are compact in shape and their surfaces have similar dimensions. The floor plan of an average house is found to be 19m x 16m with a height of 12 m (3 floors). These dimensions will be used in this study as representatives for the "average" residential house in Kuwait with an assumption that they are perfectly fit for the PV installation which is an ideal and best case scenario.

Figure 2: Surface areas of each house.

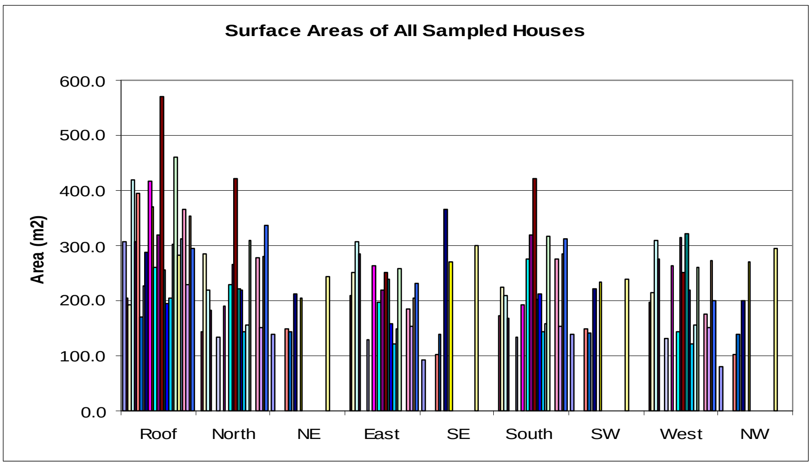
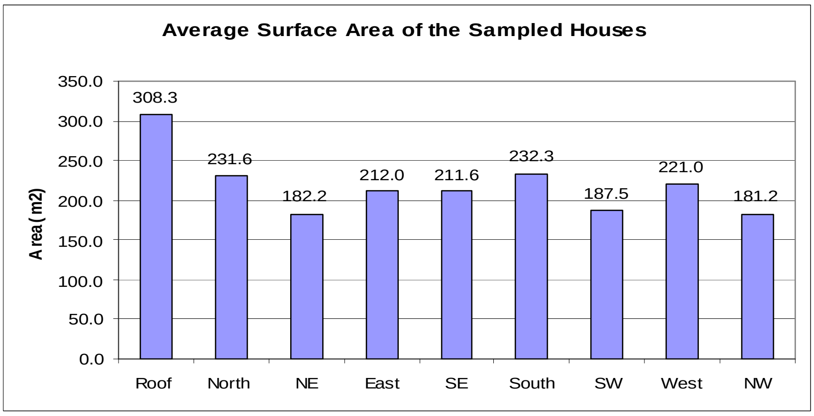


Figure 3: Average surface areas of the sampled houses.



Solar availability on the building surfaces (tilt and orientation effect)

PVSYST software was used for the simulation of the electricity generated by the PV modules which, in this study, would be the mono-crystalline BP 585L Saturn. The nominal power of the PV is 85 W_p per module and its efficiency is 13.54% (PVSYST 2003). The weather data of Kuwait is taken from the Kuwait Institute for Scientific Research (KISR) and adapted for the PVSYST weather format. Kuwait is located at 29°30' N Latitude and 45°45'E Longitude in a dry desert region described as one of the hottest places on earth with more than 80% of annual sunshine. Figure 4 shows the monthly electricity generation from a 1 m^2 of that particular PV product when located on the roof (and tilted 20 degrees toward the south for an optimum orientation) and on the eight main wall directions (with 90 degree tilt). The roof is clearly the most suitable surface for an effective PV generation of electricity and the North wall is the least productive surface orientation.

Figure 4: Monthly electricity generated from 1m² of BP585L Saturn module in Kuwait.

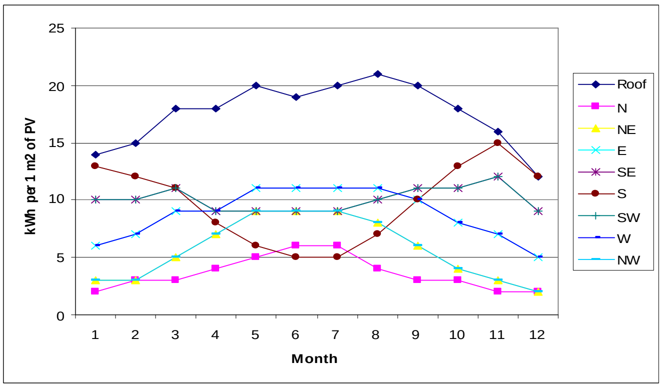
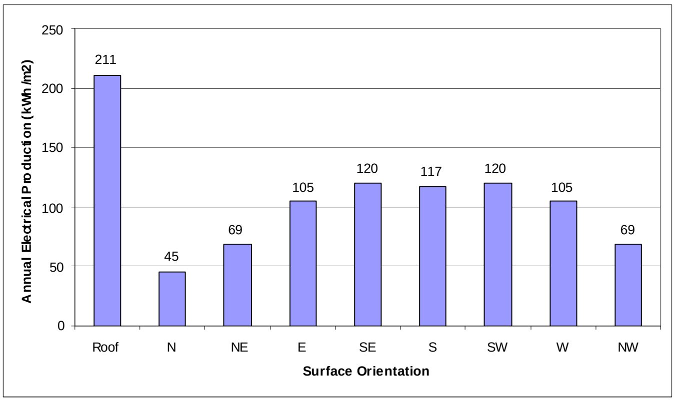


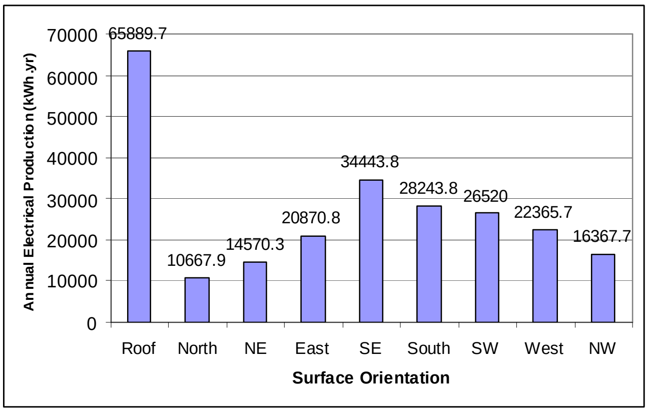
Figure 5 shows the annual amount of electricity generated by 1 m^2 of PV module at each of the building nine surfaces. Note that a 1 m^2 of PV module located on the roof will produce a maximum of 211 kWh per year (when tilted at an optimum tilt angle of 20 degrees), however, when it is located on the south wall (a tilt of 90 degrees) it will only produce 140 kWh per year; 0.55 of the maximum possible. The effectiveness of the PV will be 0.21 of the maximum when facing north. In general, electricity production from the PV modules will suffer tremendously if they are installed on any vertical surfaces regardless of their orientation.

Figure 5: Annual electricity generated from 1m^2 of mono crystalline PV module in Kuwait.



When PV modules completely cover the entire surfaces of an "average" residential house in Kuwait they will produce an annual amount of electricity of 148,039 kWhr.yr (65,890 kWhr.yr from the roof, 10,668 kWhr.yr from the North, 20,871 kWhr.yr from the East, 28,244 kWhr.yr from the South, 22,365 kWhr.yr from the West). The "average" house surface areas are shown previously in Figure 3. If the building is oriented toward SE-NW axis the total electricity generated would increase a bit to 157,792 kWhr.yr. The average electricity production of the two orientations is 153,000 kWhr.yr.

Figure 6: Annual electricity generated from the PV modules covering the entire surfaces.



Supply versus Demand

Figure 7 shows the annual electricity demand of the entire 25 sampled houses (labeled as Electrical Consumption). The consumption ranges from as low as 22,663 kWh per year to 473,867 kWh per year, with an average of about 128000 kWh per year per house. The very high consumption in house number 9 is attributed to the four families living in four apartments inside that house which is a case that often happens in Kuwait.

Comparing the average yearly consumption of 128,000 kWh to the electricity generated from PV modules installed on an "average" house (which is calculated to be 153,000 kWh) there is an expected surplus of about 25,000 kWh of solar energy per year. In another words, the PV modules are expected to cover 120% of the electricity demand.

Figure 7 also shows the electricity generated from the PV modules for two scenarios: If installed at all the building surfaces, and at only the roof with an optimum tilt angle of 20 degrees for each sampled house. The same results are shown in a different format in Figure 8.

Figure 7: The yearly electricity demand by the 25 sampled houses compared to the electricity supply by the PV modules.

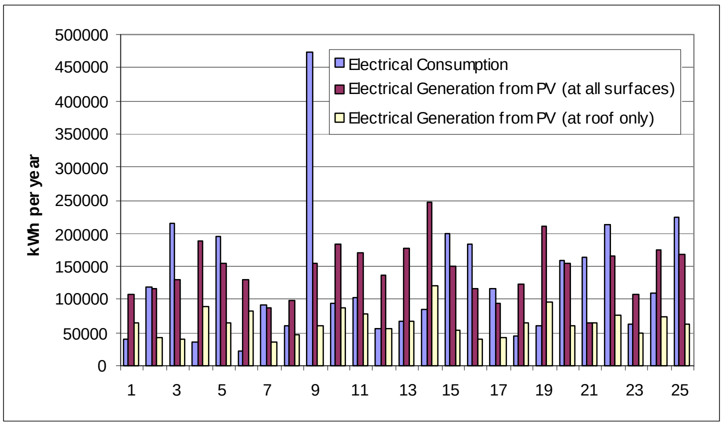
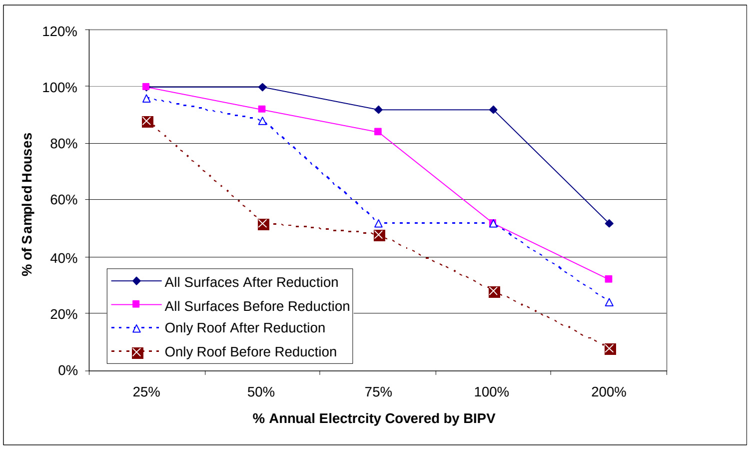


Figure 8 shows the relationship between the percentages of the sampled houses (y-axis) and the percentages of the annual electricity consumption that can be covered by the PV modules (x-axis). The results are displayed for two cases: when the PV modules installed on the entire envelope (roof and the four walls) and when the PV installed on the roof only (dotted line). For each scenario two additional cases are presented: one with the current consumption rates and one after the consumption is reduced by 39%. It was shown in an earlier study by the author that 39% of the current annual electricity consumption can be reduced if the occupants better manage their lighting switches and thermostat, such as switching the lights off when they leave the rooms, and setting the AC thermostat to 24^{o}C instead of the current 22^{o}C mark (Almumin, A. et al, 2003). Additional reductions are then expected if the current residential designs are better optimized to the climate. Optimization of building designs and sensible adaptations to the lifestyle are necessary steps before committing to BIPV technology. After all it does not make sense to generate electricity and waste it at the same time.

Figure 8: Percentage of electricity consumption covered by BIPV in the sampled houses.



The results in all cases are encouraging. Even with the worst case scenario, i.e., the PV at the roof only with the current high electrical consumptions, results show that the PV can cover 50% of the current consumption for 52% of the sampled houses. When the necessary measures are taken to reduce the consumption by 39% then the same PVs, installed on the roof only, can cover 50% of the electrical consumption for 88% of the sampled houses. It is also interesting to see that when the PV modules are installed on the entire envelope 100% of the houses will have 50% of their electricity needs covered; 92% of the houses will have 100% of their electricity needs covered; and 52% of the houses will have 200% of the their electricity covered.

Conclusions

The study is the first of a series of studies for the investigation of the PV potential in Kuwait. It investigates the area and technical potential of the PV technology leaving the market potential for future studies. It pursued two approaches to investigate the technical potential of the PV modules: First, using the dimensions of the calculated "average" house, and second, using the dimensions of each of the 25 sampled houses. In both scenarios the high levels of solar radiation combined with the high percentages of sunshine hours have proved to be good conditions for the generation of solar electricity in Kuwait.

In the first approach it was found that the "average" Kuwaiti house has dimensions of 19m x 16m x 12m (high), or in terms of surfaces areas, 180 to 230 m^2 for the wall areas and 300 m^2 for the roof area. It was also found that the average house in Kuwait consumes 128,000 kWhr.yr and when the PV modules cover its entire surfaces (on the roof and the four walls) the electricity generated can reach 153,000 kWh.yr, i.e., a surplus of 25,000 kWh.yr over the annual electricity needs. In the second approach, analyzing each of the 25 sampled houses, the results showed that under the ideal conditions PV can cover 100% of the electricity needs for more than 90% of the houses if installed on the entire building surfaces. However, since the study also showed that vertical surfaces will seriously impede the effectiveness of the PV generation of electricity to half of its full potential when installed on the south wall or even to a quarter of its full potential in case it is installed on the north wall it is highly recommended that the PV modules be located on the roof only, for example, as shading devices with appropriate tilt angles. When doing so the electricity generated from the roof PVs can provide 50% of the electricity needed for 52% of the sampled houses. These percentages are based on the current rates of electricity consumption and they can improve even further if some energy conservation measures are implemented before committing to the PV technology.

It should be noted these results were simulated under the following two ideal situations:

1. All surfaces were assumed to be perfectly ready for PV installation.
2. All surfaces were not exposed to any shading sources (trees, shading devices, neighboring buildings, and others).

Thorough analysis in the PV area potential is needed to address the first assumption. A closer up investigation of the actual physical obstacles that work against installing the PV modules on the building structure is needed. For example, out of the total wall or roof areas available in a house, how much area will it be suitable structurally and architecturally to install the PV modules?

In addition, detailed analysis in the PV technical potential is also needed to address the second assumption. For example, out of the net area that is structurally and architecturally suitable, how much area will it be suitable for an effective electrical generation (for example, an area from which a production of no less than 70% of its maximum potential can be obtained)? The effect of shading should also be fully investigated in this regard.

While this study managed to reveal some new findings regarding the PV potentials in Kuwait a follow up study is needed. It can adopt the same methodology followed in this study but with a bigger sample and should address the assumptions discussed above to come up with more reliable findings.

Acknowledgement

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