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Case Study

Assesment of Effective Measures in Residential Buildings for Photovoltaic Systems Installation
(Case study: Ekbatan residential complex, Tehran, Iran)

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ABSTRACT: The solar energy has been studied in greater depth than several studies have been conducted on solar energy use systems in recent decades. Studies have identified photovoltaic (PV) systems as one of the most widely used and practical ways to use solar energy. One of the applications of such systems is their home application. Establishing photovoltaic systems on the roofs and gables of residential buildings have received a good appreciation around the world within the recent years as with the ever-increasing trend of urban life and subsequently the decrease of sufficient space for establishing such generators, now the necessity of using the dead spaces of rooftops of the residential buildings is sensed more than ever. Considering the potential of Iran due to its suitable geographic position and specially concerning Tehran metropolitan, having on average 5 hours of sunlight per day, and considering 2,214,498 residential units in Tehran, and thereby the great number of dead spaces in the rooftops of residential buildings, the necessity of conducting this research is felt even more. In this paper, while briefly introducing the network connected photovoltaic (PV) systems and the term of utilizing them on rooftops of buildings, precise and optimized design and layout of solar panels (including the number of rows, length and width of panels, distance between panels and the slope of panels to horizon) are provided using PVSOL software. Moreover, reviewing several printed articles while having a new attitude toward the field of renewable energies, we have presented the main and functional criteria and measures for installation of photovoltaic (PV) systems stationed on rooftops of residential buildings. Further, considering high diversity of the influencing indicators on the efficiency of photovoltaic (PV) systems in Tehran city, we have conducted a case study (Ekbatan residential complex) with the purpose of precisely implementing the indicators extracted from the present research.

Keywords: Solar energy, photovoltaic systems, optimal capacity, rooftops of buildings, Ekbatan Residential Complex.

RUNNING TITLE: Effective Measurment in Residiental Buildnig

INTRODUCTION

As we know our world is facing four water, energy, environment and climate change crises, which all of them are connected to each other in the form of a chain. Therefore, moving toward optimizing and appropriate productivity in terms of energy will lead to improvements

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regarding other crises.

The growing trend of energy consumption within the recent years has caused the energy crisis in the world. The global demand for energy is growing and it is anticipated that the demand for energy will have a growth rate of 35% from 2013 to 2040. Such trend is significantly higher than the global average in developing countries and especially in Iran. An accepted reality for the human communities in that the required energy in the world is increasing rapidly and the inexpensive fossil fuel resources, although slowly but definitely, will run out in within the next decades. Limitation of fossil fuels, therefore, and considering the fact that they are not renewable along with the prediction indicating increased prices, have all caused the policy makers and planners of the energy sector to put structural studies and changing the forms of energy and moving toward renewable energies on the top of them to do list. Utilizing renewable energies as the major strategy of the west, was significantly considered after the jump in oil prices in the 1970s. This strategy, paying energy subsidies to producers of the new energies, achieved considerable successes in the following years in a way that nowadays a considerable share of energy is generated from renewable sources in some European countries and there are orderly plans for continuous increase of such share until 2030.

Solar, wind and geothermal energies and the energy generated from organic materials are the most important forms of renewable energies which utilization of each depends on climatic and geographic features of the place of interest.

The trend of energy consumption is growing with a fast slope while the fossil fuel resources are increasing as well. Furthermore, Iran is facing many environmental problems which are caused due to increased consumption of energy, low quality of the consumed fossil fuels and absence of appropriate control methods. Currently, 93% of the power plants in Iran are using fossil fuels and 75% of the electricity is generated by gas power plants in Iran and about 18% of electricity is generated using oil resources. Hydroelectric power plants only generate about 7% of the electricity of this Country and the share of other resources of energy such as wind energy, biomass, solar energy and atomic energy are almost close to zero in this country. Further, over 50 billion cubic meters of natural gas were dedicated to power plants to generate electricity in 2014 which that amount indicates a growth of 14% in comparison with the previous year. In 20-Year Perspective Document, Iran intends to generate 20% of its required electricity by renewable energies until 2025, this while according to the fifth development plan (2011-2015), the Ministry of Energy was supposed to provide the grounds for producing 5000 megawatts of electricity by wind and solar energies in the country, however, only about 300 megawatts of electricity was developed via renewable energies and still only less than one percent of the total electricity required in the country is generated from these resources.

Commercially speaking, solar cells are an accessible and reliable technology for generating electricity. The countries with the most utilization of solar cells are listed in Table 1.

Tab 1: Countries with the most utilization of solar cells, Source: [16].

Item	Country	The amount of production (MW)
1	Germany	9785
2	Spain	3386
3	Japan	2633
4	USA	1650
5	Italy	1167
6	Czech Republic	465
7	Belgium	363
8	China	305
9	France	272
10	India	120

According to assessments in 2011, the rate of utilization of solar based electric energy in the world experienced a much higher growth in comparison with the previous years and was equal to 70 GW, and this is while, German having less than 200 sunny days per year and a much lower radiation intensity comparing to Iran, have utilized solar energy the most through photovoltaic system and according to Chart 1 it dominated 36.5 percent and then there are other countries such as Italy, Japan, Spain and the USA. This is while having over

300 sunny days and a radiation of 2200 watts per square meters in Iran, utilization of this free and divine gift is unfortunately less than 1% of the energy consumed in this country [7].

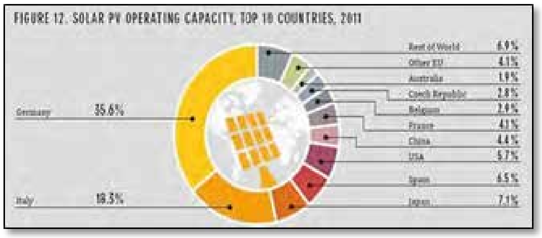

Chart 1: The Rate of utilization of solar panels in the top 10 pioneering countries in 2011, Source: [16].

The main question of this research is to conduct a potential assessment on the optimal installation of photovoltaic systems in the residential urban context of Tehran city. For this purpose, the residential context of Ekbatan residential complex was selected as a case study and the statistical population in this research.

The main reason for this choice was high diversity of the effective indicators on the efficiency of photovoltaic systems stationed on rooftops of residential buildings in an urban scale and immeasurability of some of the highly effective parameters such as shading. In the present research, therefore, all of the residential context of Ekbatan residential complex, having 33 residential blocks in three general types of A,B and C and with 15,675 residential units , were studied.

The purpose was to obtain approximate installation capacity of PV systems in Tehran through estimating the optimal installation capacity of PV systems on the rooftops of Ekbatan residential complex utilizing PVSOL solar energy simulation software and thereby obtaining the indicator of kilowatt per residential unit. Also, with extending and developing this important indicator, it is possible to identify target regions and points in Tehran city and to provide the grounds for maximum utilization of this infinite and free source of energy for all of Tehran citizens.

LITERATURE REVIEW

Research Background

Yousefi and Hafeznia 2016 [12], in an article under the title of Potential Assessment of Solar Energy for Electricity Generation in the Oceanic Shores of South East of Iran which was presented in the conference on processing the geopolitical potentials of developing southeast shores of Iran on October 18th, used fuzzy method in order to select appropriate locations for utilization of solar equipments. All of their data was prepared in GIS based software and were processed and in the end, the total amount of energy extractable from such appropriate locations in the region was calculated which indicated high potential of the South East shores of Iran for utilization of renewable energies which could be used as a driving engine for industrial, economic and social development of Morkran region.

In another study [13], the appropriate location for construction of a solar power station considering indicators and options of climate (temperature, radiation, perspiration, sunny hours and evaporation) , topography (height, slope, direction of slope, distance from fault), environment (application of lands and rivers) and human environment (residential area and roads) using GIS and hierarchical model were selected for Ilam province . In addition, the weight of each indicator was defined using the Analytic Hierarchy Process (PAA). ArcGIS software was also used and cartography of power plant construction was prepared in four different classes (i.e. low, moderate, good and very good). The results indicated that zones which were identified in the regions with very good potential covered a surface about 1510812500 sqm for which the southern and western regions of Ilam province were the best locations for construction of solar power stations. .

Hassanali faraji Sabokbar et al 2013 [8] conducted a comprehensive study in a research regarding detection of potential and highly potential regions for construction of photovoltaic power stations in Iran. For that research, in their first step after determining the zones for study, the effective indicators in potential assessment were determined using previous studies and Delphi method. In the next step, DEMATEL method was utilized for implementing the network structure and the ANP model was used for giving weight to the indicators. Then the SAW-FIS heuristic method was used to combine the results and thus the potential of all lands of Iran for establishing photovoltaic farms was obtained with the precision of about 84%.

Ebrahimi Ghavamabadi and Fooladi Dehaghi 2003 [2] studied the application of solar energy as a renewable and environment friendly energyand its role in advancement of the targets of sustainable development. In that, the researchers claimed that the ever increasing consumption of the limited fossil fuel resources and their destructive effect of the environment, have attracted the attention of the world to used renewable energies.

Djurdjevic, D. Z (2011), has conducted a study with the purpose of analysis and assessing potential, status and perspective of photovoltaic solar energy in Serbian Republic. The solar radiation maps were prepared using PVGIS software in that study. The results obtained from the aforesaid study indicated that Serbia has a high potential for utilization of both network independent and network connected photovoltaic systems.

Hofierka, J.and Kanuk, J., (2009) have presented a method for assessing photovoltaic potential in urban areas using open source solar radiation tools and three dimensional modeling of urban environment in GIS. This solar radiation tool was presented by Arsan solar radiation model and was evaluated by PVGIS software.

Izquierdo, S., Rodrigues, M., Fueyo, N., (2008) used hierarchical structures and vector layers to present a method for assessing the geographic transmittance of appropriate rooftops for installing photovoltaic equipments in urban areas in Spain. Using this method, they have assessed the average appropriate locations for installing photovoltaic equipments on rooftops in urban areas in Spain with a confidence coefficient of 95% equal to 14±4.5 m^2⁄ca.

As it was expressed, most of the previous studies have emphasized on studying different locations of a province for construction of solar power stations and usually have relied on one of the technical or economic aspects.

The attempt, in this article, is to have a new and practical look in utilization of solar energy and in particular photovoltaic (PV) systems and to conduct a potential assessment of the dead urban space (the spaces on the rooftops of residential buildings) in Tehran city, so to take an effective step forward for encouraging all investors and citizens in order to use the existing potential of such spaces in the cities. Therefore the indicators obtained from theoretical foundations in this research, in comparison with other similar works, while considering the technical issues regarding the design of PV systems, are emphasizing more on the urban indicators which have an effect of the efficiency of such systems.

The Status of Photovoltaic (PV) Systems in the World

About 30GW of the new photovoltaic capacity has became operational in the world in 2011 and having a 47% increase has reach to the amount of 70GW. The real installation and set up during the year of 2011 was almost equal to 25 GW which the operational capacity of photovoltaic systems by the end of that year was about 10 times more than the whole global installed capacity in its past 5 years which indicate an average annual growth rate of 58% in a time period from 2006 to 2011 [14].

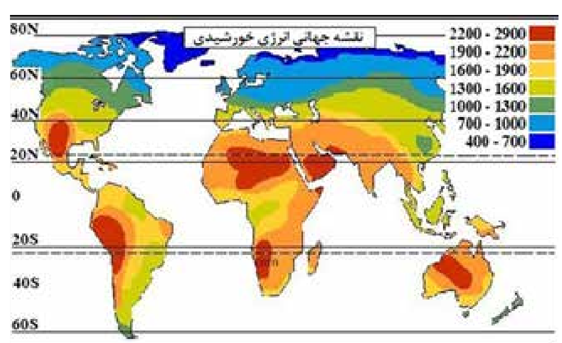

Fig 1: The Solar Energy Map of the World (label KWh/m2), Source: http://barghnews.com.

NDP solarives research institute has stated in its report that the growth rate of utilizing solar energy in Europe decreases in 2014. This institute has claimed the share of Europe for this decrease is 22% and the main reason for that is cancellation of the encouragements that used to be granted by the governments of Germany, Italy, Greece and Romania.

Electricity generation using solar energy has increased by 19.2 GW in Europe in 2011 and such a rapid growth rate led Europe to take a 70% share of electricity generation using solar energy in the world. But then in 2014 the solar energy markets grew in France, Netherlands, Austria, Portugal, Switzerland and Turkey, however the markets of Belgium, Denmark, Romania and Ukraine became smaller and on the other hand the largest growth rate was for England in terms using solar energy. By the end of March 2014, theis country reached to the capacity of generating 4.5 GW electricity using solar energy which 99% of that amount have come into operation within the past 36 months [14].

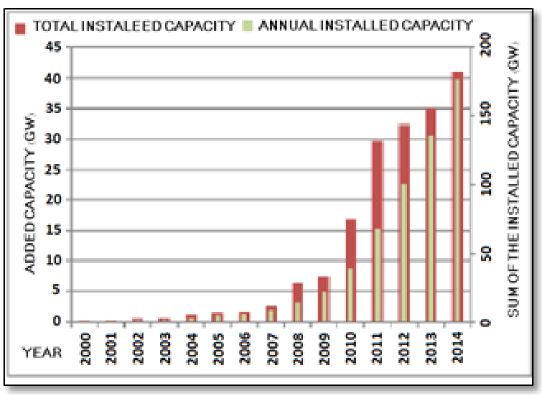

Chart 2: The increasing annual trend of photovoltaic solar stations since 2000 to 2013 and the forecast for 2014, Source:[6].

The Status of Photovoltaic (PV) Systems in Iran

According to the statement of Tasvanir Company's public relations office, up to 205.951 Million KWh of electricity was consumed in Iran in 2014, out of which only 8.6 % was generated by wind, solar and atomic resources. Electricity consumption in Iran, on average, increases by 10 % every year and this issue made the experts on electricity generation to focus less on generating it using renewable energies. Based on the very same 10 percent annual increase, Iran is forced to increase its electricity capacity rapidly and as thermal and gas power plants are constructed rapidly, therefore, most of the available resources are spent on such power plants. Another one of the reasons for lack of interest in generating electricity from resources such as wind and the sun in Iran is infeasibility of constructing such power plants. As the cost of gas and other fossil fuels to be used in gas and thermal power plants have been low in Iran until now, thus, constructing wind and solar power plants were not economically feasible. However, as the phases of the plan for targeted subsidies are implemented with more seriousness which leads the prices of fuels to be more close to the real prices, the costs for constructing and starting up power plants utilizing renewable resources are entering the range of economic feasibility. In 2013, almost 220 MW , generated from clean and renewable resources , was added to the electricity capacity of Iran > Furthermore, hundreds of villages are currently equipped with wind and solar inverters for electricity generation as it is not possible to deliver electricity to them all via cable lines. [6].

In 2013 totally 7.1 MW solar panels were installed for a thousand public subscribers (mosques, schools, executive departments and bureaus). Iran has targeted to install solar panels for 12 thousand subscribers [14]. Concerns about environmental changes along with ever increasing prices of oil and the peak of oil production and also governmental supports, have all caused ever increasing coding of laws which encourage utilization and commercialization of these rich renewable resources. In 2012, Iran rate of usage for solar energy was 0.123%, i.e. even less than 0.2 % [25]. By the late 2013, 32.4 MW electricity was generated at the water and waste water management facilities of the country using solar energy which led to saving over one million US Dollars (440,000,000,000 Rials) in this sector [6].

In 2012 about 19 % of the total consumed energy in the world was obtained from renewable energies [21]. Also in 2013 and during the conference on environment and application of renewable energies at the Isfahan University of Medical Sciences it was stated that the energy sources which we use today will face serious challenges by 2100, and thereby more attention should be paid to new energies [14]. Iran produced 46 KW electricity by network connected photovoltaic system in 2013 and and per feasibility studies in all over the country it can be stated that Iran has the capacity of producing 1140 MW electricity. There was only 130,000 sqm photovoltaic system in Iran in 2013. This is while such energy inversion in Turkey was conducted over 18 million sqm. In Total, domestic consumption comprise 30% of the country's consumption and one of the big steps in this regard is to be able to produce such huge percentage from solar energy at the buildings. In contrary to the public belief, Iran cannot transform its deserts to a big source of producing energy , as considering thermal issues, there is an optimal line which should be considered for so [6].

According to a study which was conducted by DLR research center in Germany for Iran, it is estimated that in 2000 square kilometers of the lands of Iran it is possible to obtain about 60,000 MW electricity from solar power stations. The considerable point is that as the intensity of radiation increases in the region, a significant reduction of costs will result for solar electricity [14]. According to clause 69 of the single article of budget of the country in 2013, the Ministry of Energy in addition to charging the cost of electricity, charges 0.0007 US Dollars (30 Rirals) per KWh of the sold electricity as the taxes of electricity in the bills and receives this amount from all subscribers except for the villager domestic subscribers. For the solar electricity, considering clause 69 of the budget law of the year 2013 and governmental supports, the Regional Electricity Co. proceeded with installing photovoltaic systems with a total capacity of 160 KW of which 140 KW is implemented on administrative buildings and the remaining is implemented on residential buildings as pilot plan by the Regional Electricity Co. At the present time, guaranteed purchase of electricity based on the approved prices (refer to Table 1 attached) for 20 years is the encouraging plan of the government.

The total budget for solar energy in Iran was 12 million US Dollars in the past year, and this is while the government of president Rouhani has dedicated 12 million US Dollars for this purpose in this year. Solar cells are installed in a thousand locations on buildings in Iran until now (refer to Table 2 attached). Although fossil fuels still receive subsidy in Iran, however, continuous increase in the prices of such fuels and decrease of solar equipment prices outside Iran is making utilization of new energies affordable [21]. The cost of construction and equipping with solar systems is about 1300 US Dollars (6 Million Rials) for an applicant subscriber. If every Iranian household installs only 300 W solar panel on the roof of its residential building upon government's encouragement and promotion, then, it will have 1500 Wh free electricity from the sun per day. This amount of electricity is equal to 20% of the electricity consumption of a household and thereby as easy as that, one fifth of the electricity consumption of the country can be produced by the nation themselves [14].

In 2014 the share of renewable energy in the transportation sector was 4% and in the electricity generation sector was 18%. Based on that and for the horizon of 2025 the amount of 24500 MW electricity should be generated via renewable energies in this country. As the managing director of Tavanir Co. stated, Iran has invested 75 million US Dollars (30 thousand billion Rials) for generating power from wind and solar energies in the country.

The law of Iran's membership in the International Renewable Energy Agency, after it was approved by the Islamic assembly and confirmation of the Guardian Counsel, was directed by the president on June 3rd 2012. According to this law, the government is allowed to become a member of the International Renewable Energy Agency and to pay the membership fee accordingly. Now we study the trend of some renewable energies in Iran and in the world so that we can figure the position of such renewable energies especially the solar energy with comparison of such studies.

Theoretical Foundations of the Research

Definition of Photovoltaic (PV) Systems

There are two methods for using solar energy to generate electricity, one is the direct method (photovoltaic) and the other is indirect method (solar thermal). In the photovoltaic method, the sun light hits the solar panels and is directly inverted to electricity. This method have many applications in different fields and is considered as one of the up to date sciences of the world. These photovoltaic systems were principally invented for space applications and are formed based on Einstein's theory of photovoltaic effect which states that light case the electrons to separate from each other [6].

Further importance of this system is revealed when we understand that we can invert radiant energy directly to electric energy without any need for intermediate processes. Utilization of this system reduces the consumption of fossil fuels and the attributed problems and costs for fueling various regions and provides the capability of generation at the place of consumption and thereby saving the costs of transmittance and distribution. Another one of the features of this system is prevention of producing carbon dioxide, possibility of installation and setting up at different powers, appropriate life cycle and ease of operation and also its capability of storing electric energy in batteries. The components of a photovoltaic system is as following:

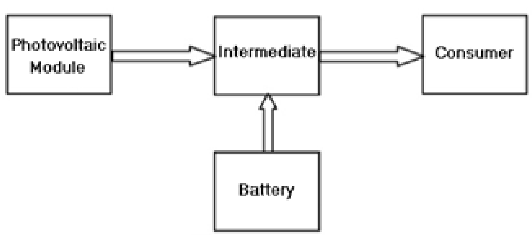

Fig 2: General model of a photovoltaic system, Source: [6].

Various Types of Utilizing Photovoltaic (PV) Systems

Generally there are three methods for utilization of a photovoltaic system:

1-Systems that are not connected to the network (Stand Alone)

Are used for supplying the needed electric energy of the locations outside the network and for preventing over – expansion of the national electricity network. In this method, the required electric energy is supplied using photovoltaic panels, storing systems and relatively simple controllers. Power range of these systems is from a few watts to several megawatts which can be installed and set up and it can be used for generating and supplying the needed electricity as a power station unit with an appropriate life cycle of about 20 years and with high reliability. However, due to the expensive price of the storing system it is usually used in small scales. As standalone systems are not in the subject matter of this research, therefore we avoid further explanations and assume the aforesaid to be sufficient only for acquaintance.

2-Systems connected to the network (Grid Connected)

For the purpose of strengthening the national electricity network and preventing electric pressure which is imposed on the power plants during the day, utilization of grid connected photovoltaic power stations , both in centralized and decentralized forms, can be among the solutions for such problems. Nowadays many countries install and utilize grid connected photovoltaic systems in small 1KW to 5KW units on the rooftops of residential buildings and also in larger units as a solar power station. The performance of this system is in a way that the electricity generated by the solar panels is directly converted to AC electricity using electronic equipments and devices and is then fed to the national electricity network.The following items are among the advantages of this method:

- Easy installation and set up.
- High efficiency and no need for complex side equipments.
- No need for battery in order to store electric energy.
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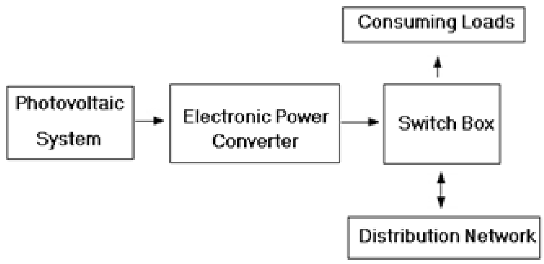


Fig 3: General model of a photovoltaic system, Source:[6].

3-Multiple Feeding Systems (Hybrid)

Should photovoltaic systems supply the required power for the unit in combination with other sources of energy supply such as turbines, diesel generators and etc, then such system is called a multiple feeding system or hybrid.

Technical Design of Photovoltaic (PV) Systems , in the network connected state and stationed on rooftop

Several strategies can be considered for designing the system. The initial phase of designing grid connected PV systems, therefore, is to determine the design criteria.

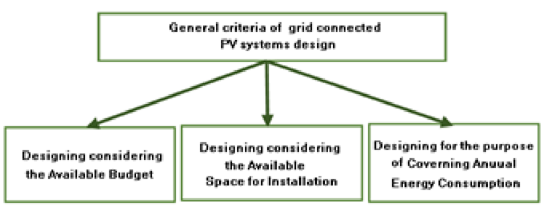


Fig 4: General criteria of grid connected PV systems design, Source: Authors

Determining the design criteria, in fact, specifies the purpose of design and considering which criterion is chosen for designing, the terms of selecting the capacity and formation of the photovoltaic array will be different.

In this research and considering the purpose which is potential assessment of installing the systems on the rooftops of the buildings of Ekbatan Residential Complex, as there is the useful space limitation factor, the criterion for design is the available space. In the following, the necessary steps for selecting the capacity and formation of the photovoltaic array for the chosen criterion is thoroughly described.

Generally, the technical design of photovoltaic systems is done considering the available space and or actually the accessible surface on the rooftops of the buildings, estimation of the bearable trust by the building and also assessing the shading on the surface on which the systems will be installed.

The weight of PV systems is calculated on average between 60-80 kg per sqm based on the type of used panel and the material of the structure. Furthermore, such structures should be built in a way to be resistance against winds with the speed of 120 km/h and thus how to fix them on the rooftops becomes of importance.

Among the other parameters effecting the calculations of the system we can address the following: radiation intensity coefficients, radiation angle, efficiency of the used PV panels in the project, layout of the panels, shading of the adjacent buildings, trees and other existing obstacles on the roof itself (shelter, facilities and equipments already stationed on the roofs, loft and etc.)

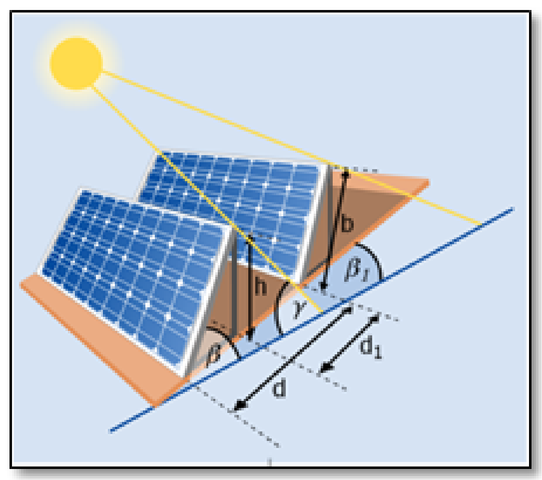


Fig 5: Displaying the factors affecting the technical design of PV systems, Source: Authors.

β: Installed angle of the solar panels

h: Structure installed height

γ: Angle of sun light radiation

d1: The distance between the end of the

structure's stand to the beginning of its next stand

d: The distance between panels

b: Panel height

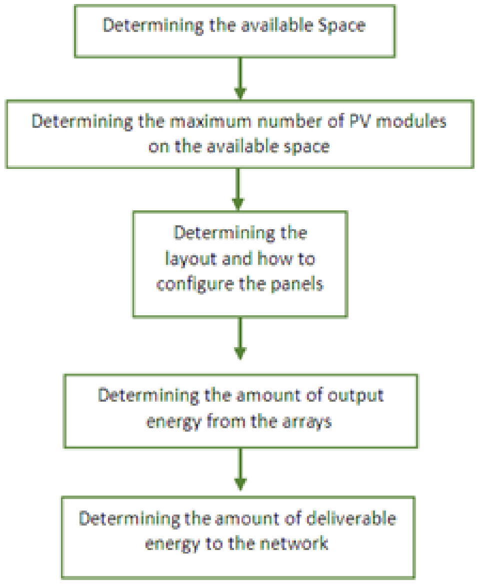


Chart 4: The steps for choosing the capacity and formation of the PV array based on the design criterion of the available space, Source: Authors.

The First Step: The first is to measure the surface area of the available space for installing PV array, therefore, the surface area of the intended location is measured in square meters. For measuring, a part of surface should be considered which has the least shading and or if possible a part that has no shading.For this purpose, the maximum rate of shading is assumed 8% and the structure and layout of the panels are assumed in one row. The distance between the panels is assumed 1 cm and the height of panel from the surface is assumed 30 cm in order to have no contact with snow and rain collected on the surface and further problems and also for ease of maintenance.

The Second Step: The second step is to determine the maximum ideal number of the panels which fit into the assumed surface for the installation. The maximum number of panels which can be ideally fitted into the surface measured in the previous step is calculated considering the specifications and dimensions of the panels, type of the used structure in the design and also the shading of the arrays themselves. The maximum number of panels that can be ideally installed equal to the available surface area (here we mean the surface of the rooftop) divided by the effective surface area of each panel. In designing the studied sample, considering that we used 270W panels, the surface area of each panel is calculated as following:

1.64 m× 0.99 m= 1.62 m2

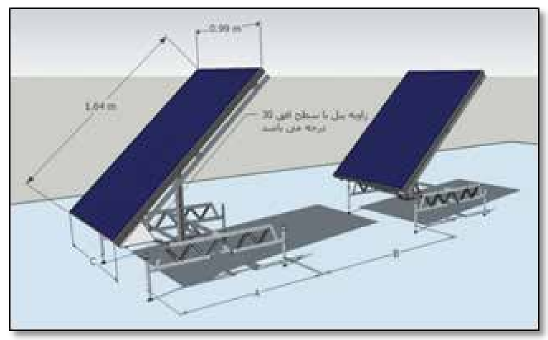


Fig 5: Simulation of the arrays for the purpose of calculating shading in SketchUp software, Source: Authors.

As it is evident is the above figure, assuming a distance of 2.5 meters between the panels in order to consider the shading, the effective surface area is calculated as following:

A= Cos 30 °× 1.64 m

B= 2.5 m

C= 0.99 m

Therefore we will have a figure like the following:

A= 1.42 m

B= 2.5 m

A+B= 3.92 m

C= 0.99 m+ 0.01 m=1 m

According to the above calculations the useful surface area of the rooftop van be carpeted with rectangular having a dimension of 1 ×3.92

meters and to estimate the number of panels approximately and then to obtain the installed capacity by multiplying the number of panels and the nominal power of each.

The Third Step: Step three is to determine the maximum number of panels which can be installed on the location. Each panel have a length and a width dimension. The panels can be installed along the length or along the width. Installation of the panels should be checked along both of the aforesaid dimensions for each space in order to be able to determine the real maximum number of them.

In the present research this work is done using PVSOL software and the results of that along with modeling the studied sample is provided. Such results are discussed in details in the findings section of the research.

The Fourth and Fifth Steps: These two steps is regarding the determination of the amount of output energy from the PV arrays and determining their deliverable energy to the network which further description on them is avoided is due to the extent of the technical discussions and since they are beyond the subject matter of this research.

METHODOLOGY OF THE RESEARCH

Research Method

In terms of purpose, the present research is among the Applied-Development researches and the method for conducting it is Descriptive-Analytical. Data collection was made both with documentary and library methods and the required data were obtained from the websites of the organizations affiliated to Tehran city, Statistics of the Statistical Center of Iran and also statistics from International Organizations and Institutes.

Variables and Indicators of the Research

In this research and for the purpose of measuring the installation capacity of PV systems on the rooftops of residential buildings, the effective indicators are categorized in four main groups as per following:

Climatic-Environmental indicators (sunny hours, number of cloudy days, number of rainy days, temperature, humidity and dust) , shading indicators (shading of the building itself, neighboring and obstacles, trees' shading and shading of the cloudy sky and pollution) , Technical Building indicators (Floor Area Ratio (FAR) , Direction of the buildings, bearable weight of the structure) and PV Systems Design indicators (direction of installation, optimal angle and repair and maintenance of the panels).

Geographic Territory of the Research

Iran is located between the latitude of 25 to 40 and have almost 300 sunny days. Under such circumstances, if only 1% of the surface area of Iran absorbs the solar energy and the efficiency of the absorbing system is 10%, then it is possible to receive 9 million MWh energy from the sun of a daily basis [14].

According to the estimations, the average annual solar energy that is absorbable in Iran is 140 to 220 Kcal per square centimeter and the average sun radiation is estimated to be between 1800 to 2200 kWh /Sqm which is above the global average and on the other hand, sunny days in Iran are over 280days per year [17].

Tehran province having a surface area of 730 square kilometers is located between the longitude of 51dgrees and 08 minutes to 51 degrees and 37 minutes East and the latitude of 35 degrees and 34 minutes to 35 degrees and 50 minutes North and thus has one of the best positions for benefiting from solar energy. On the other hand the daily solar radiation in Tehran is equal to 5.2 kWh /sqm while the maximum daily radiation is in June and equal to 7.64 kWh /sqm and the least daily radiation is in December equal to 2.25 kWh /sqm.

All of the afore mentioned, therefore, indicate that this province has a high potential in terms of benefiting from solar renewable source of energy. Considering the vastness of this province and diversity of the indicators affecting the efficiency of PV systems station on the roof of residential building which are thoroughly discussed in the following, Ekbatan Residential Complex is chosen as the case study for the present research.

Ekbatan residential Complex is one of the biggest residential complexes in the Middle East which is located in the West of Tehran, in Zone 6 of Distric 5 of Tehran Municipality. This complex has a surface of 4.59 square kilometers and a population of 44981 residents. From East, this complex is limited to Apadana complex and Kooy-e Bimeh, and from North to Tehran-Karaj Highway, from West to the Exhibition of the Aviation industry and from South to the Tehran-Karaj Specific Road.

RESEARCH FINDINGS

Climatic-Environmental Indicators

Sunny Hours: Sunny hours is the most important climatic parameter which indicate the amount of received energy in the zones from the sun. Sunny hours is the sum of monthly or annual hours of sun shine for a region. Sunny hours is obtained from dividing the annual generation of 4 kWh of a PV system by 365 days.

Number of the Cloudy Days: Clouds cause reduction of the received sun radiation and thereby decreased effective radiation. The clouds, con average, reflect 21% of the energy of short wavelength of the sun. When the sky is sunny and there is no cloud in it, the majority of sun's energy reaches the earth. Therefore, the most important factor that controls sun's radiation energy is the cloudiness of the sky.

Number of the Rainy Days: Rainy days are a negative factor for stationing panels as they are an obstacle for the solar radiation to reach earth and also as rain have destructive effects on the PV solar stations and also as it makes the surface of panels dirty.

Temperature of the Area: One of the components of the PV systems is the energy inverter, i.e. the solar panel. For this system to supply the power and required energy of the load, it should be designed properly. One of the factors that affect the size of the required panel, is its efficiency. Panel's efficiency, however, depends on its temperature and the panel's temperature is pending to the ambient temperature and intensity of solar radiation.

Relative Humidity: There is no dry air in the nature and even in the apparent dried air of the deserts there is still humidity to some extent. In regular conditions, the amount of steam in the atmosphere during the warm months of the year does not go beyond 1.3% and in the cold months beyond 0.4%. The dominant form of humidity in atmosphere is steam. The steam in atmosphere plays a significant role in the energy balance of the earth and atmosphere. For instance it reflects the short wavelength solar energy and absorbs the long wavelength earth energy radiations. The regions with relatively high humidity, therefore, are not potential for construction of PV systems as they reflect the solar short wavelength energy.

Dust: One of the important atmospheric compounds, specially close to the surface of the earth, is the non-gaseous and solid compounds that are called aerosols. Aerosols absorb about 15% of the solar short wavelength energy, and thus, zones having the least amount of dust in the air are of interest.

Shading Indicators

Shading of the building itself, neighboring and obstacles: shading between buildings should be avoided.

Shading of the tress: shading of vegetation also negatively affects the performance of PV systems.

Shading of the pollutions: Pollutions are also a kind of shading. If pollutions prevent the sun light to reach solar cells, a dusty environment may decrease the efficiency of PV panels for 4% and more. Although panels that are placed with an angle of 20 degrees and more are automatically washed and cleaned by rain, however, some kinds of pollutions such as soot particles should be cleaned with other methods.

Technical Building indicators:

Bearable Weight of the Structure: The weight of PV system is on average 60 to 80 kg per sqm. A PV system should be designed in a way to be resistant to winds with a speed of 120 km/h and thus it is important how to fit and join the structure to the roof. Generally, all buildings, whether they are with metal or concrete skeleton, can bear the weight of PV systems.

Direction of the Buildings: The best direction for the building concerning this matter is a North-South direction.

Floor Area Ratio (FAR): FAR in a zone is considerable. Where the density is high, the space between the buildings is limited and thus it is more likely to have shading and thereby increased reduction of the system's efficiency.

Building Shape: Considering previous studies [16], the more a building plan is narrow and long, the more the space increases and the receipt of sunlight radiation and thus power generation increases, and on the other hand, the more the shape is square, such amount decreases. The other point is that there is a significant difference in the amount of generated electricity when the shape of the building plan is along North-South direction to the state that it is along East-West direction.

PV Systems Design Indicators:
Direction of the installed panels: The direction of panels should be toward south with the best angle with the horizon, which such optimal angle varies in different geographical positions.

The optimal angle of installation: The optimal angle for installing a PV system is usually 3 degrees less than the latitude at which the PV system will have more annual productivity ,. This is while the seasonal optimal angle is different than this figure.

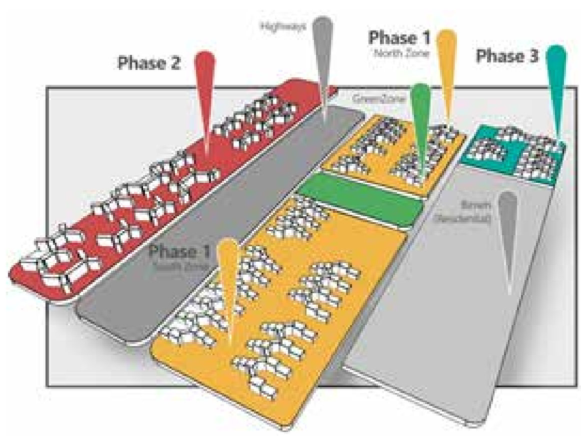
Repair and Maintenance: One of the advantages of this industry in comparison with other methods of electricity generation is that PV system require little repair and maintenance. The estimate for the repair and maintenance cost of these systems is about 1% and such systems usually have a warranty for 25 years by the manufacturer company. The only important point is regular cleaning of the surface of these panels, so they generate maximum electricity.

Data Analysis

Introducing the Studied Sample
Ekbatan Residential Complex is one of the biggest residential complexes in the Middle East which is located in the West of Tehran and in Zone 6 of District 5 of Tehran municipality and has a surface of 4.59 square kilometers and a population of 44981 residents. This complex has three phases of 1, 2 and 3 and in total is comprised of 33 blocks and 15675 residential units.

Ekbatan Complex is limited to Apadana complex and Kooy-e Bimeh, from East, and to Tehran-Karaj Highway from North, to the Exhibition of the Aviation industry from West and to the Tehran-Karaj Specific Road from South.

Fig 6: Displaying the location of Ekbatan Complex on Tehran map, Source: Authors.



- Surface Area: 4.59 Square kilometers
- Population: 45000

- Architect: Jordan Gruzen, American
- Builder: Strrett Company
- Duration of Construction: over 10 years
- Assumed Standards: Resistivity against earthquake up to 9 Richter, escape and emergency stairs, extensive landscape, independent raisers and shooting channels.
- Materials: Mostly imported (specially metals)

The American Jordan Gruzen was in charge of building this complex and Strrett Company built it. Ekbatan was the biggest construction project with foreign investment and its construction was commenced with the purpose of controlling the demographics of Tehran and transferring the population overflow as the city was entering modern era and extensive accommodation of governmental employees. Utilization of concrete technology for the first time and including the technology of slip form and providing the grounds for technology transfer to the Iranian contractor companies regarding construction and also being the first urban development experience in the city suburbs while dedicating all city spaces to it were among the advantages and considerable features that were involved in the construction of Ekbatan. For the first time, interior architecture was experienced with cement polishing instead of the common plastering. Ekbatan as built as a distinctive complex in three phases and different types, while the first phase of this complex is different with the other two.

Phase 1 of Ekbatan Complex:

Phase q is comprised of 10 blocks that is divided by Shahid Dastgerdi (Paas) Stadium and Ragh-Ahan Stadium into two 4 and 6 block parts. The four blocks to the north of the stadiums are the so called the Upper Blocks and the six blocks to the south are the so called Lower Blocks.

The Lower Blocks:

Block 1A or 1 of Ekbatan Complex
Block C or 2 of Ekbatan Complex
Block 1B or 3 of Ekbatan Complex
Block 2A or 4 of Ekbatan Complex
Block 3A or 5 of Ekbatan Complex
Block 2B or 6 of Ekbatan Complex,

Upper Blocks:

Block 3B or 1 of Ekbatan Complex
Block 4A or 1 of Ekbatan Complex
Block 5A or 1 of Ekbatan Complex
Block 4B or 1 of Ekbatan Complex

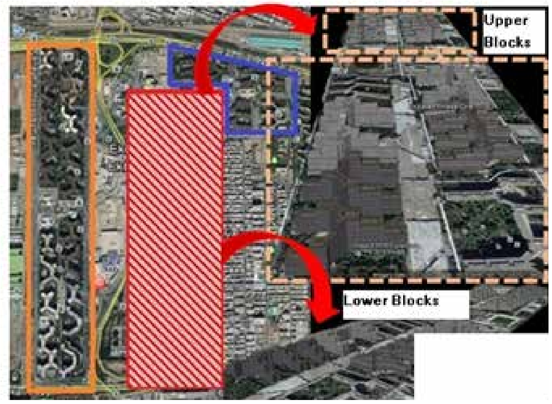


Fig 8: Displaying Phase 1 of Ekbatan Complex.

Solar Design for Phase 1:

The blocks located in this phase of Ekbatan Complex are comprised of three general building types , namely A,B and C. The following Figures demonstrate the 3D display of the blocks and their exposure to sunlight and shading are provided separately.

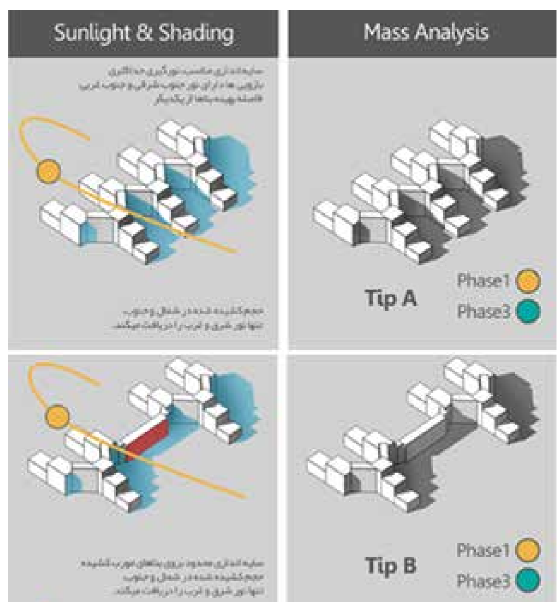
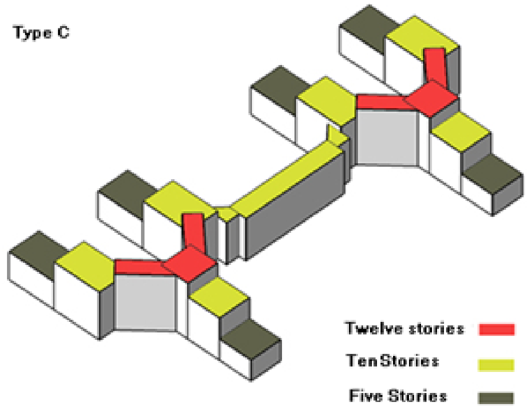


Fig 9: 3D display of the A,B and C types located in Phase 1, Source: Authors.



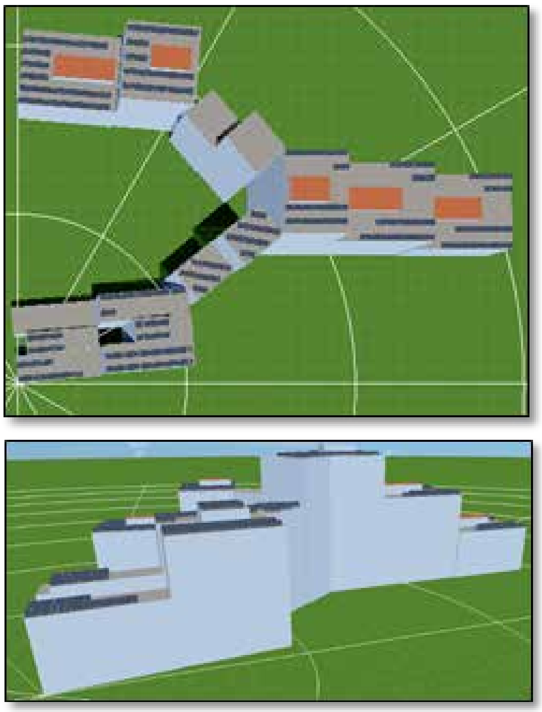


Fig 10,11: 3D simulation of Phase 1 of Ekbatan Complex in PVSOL software, Source: Authors.

Item	Building Type	Number of Blocks	Roof Surface (sqm)	Useful Surface for Installation (sqm)	Installation Capacity (kW)
1	A	5	43990	34136	1650
2	B	4	42850	35452	1700
3	C	1	8720	6518	300
The Sum of the Capacity that can be installed while accounting for a maximum 8% shading					3650

Tab 2: calculations for Capacity Assessment of Installing PV System in Phase 1 of Ekbatan Complex using PVSOL software, Source: Authors..

Solar Design for Phase 2:
The blocks comprising this phase are also in three genral types, namely A, B, and C which are extended in the North-South direction.

Fig 12: Displaying Phase 2 of Ekbatan Complex (Source: Authors)

Tab 3: calculations for Capacity Assessment of Installing PV System in Phase 2 of Ekbatan Complex using PVSOL software (Source: Authors)

Item	Building Type	Number of Blocks	Roof Surface (sqm)	Useful Surface for Installation (sqm)	Installation Capacity (kW)
1	A	9	48250	41009	2180
2	B	9	38290	32546	1700
3	C	4	22000	18695	1000
The Sum of the Capacity that can be installed while accounting for a maximum 8% shading					4880

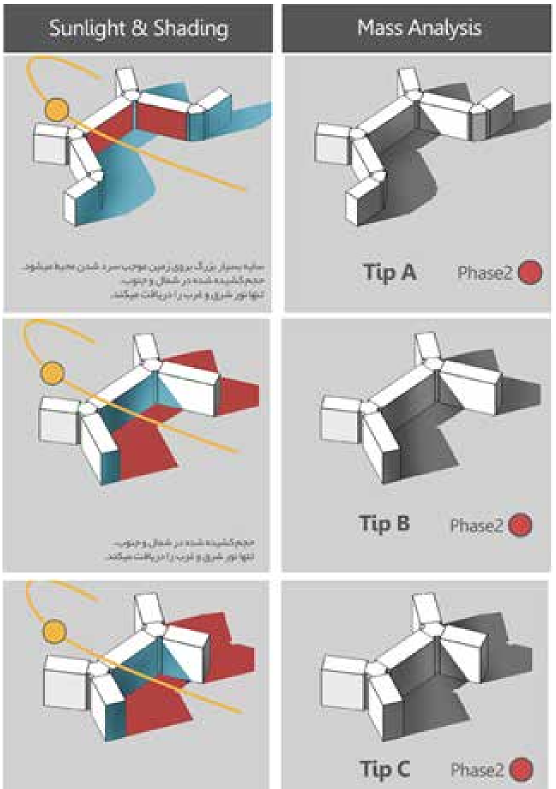


Fig 13: 3D display of the A, B and C types located in Phase 2 (Source: Authors)

Solar Design for Phase 3:

This phase of Ekbatan Complex is comprised of 4 blocks namely 1E ,2E, 1D and 2D . This phase came to operation in 1991 and thus is newer than phases 1 and 2.

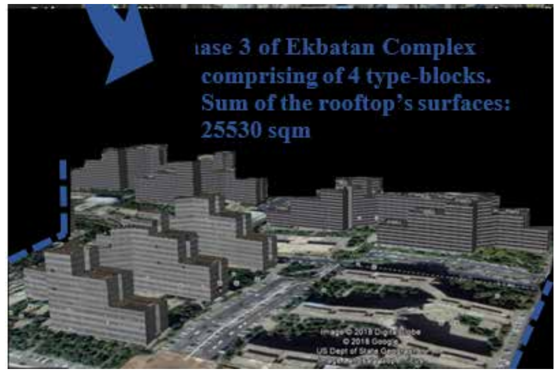


Fig 14: Displaying Phase 3 of Ekbatan Complex (Source: Authors)

Tab 4: calculations for Capacity Assessment of Installing PV System in Phase 3 of Ekbatan Complex using PVSOL software (Source: Authors)

Item	Building Type	Number of Blocks	Roof Surface (sqm)	Useful Surface for Installation (sqm)	Installation Capacity (kW)
1	E1	1	9500	7085	350
2	E2	1	7590	5670	270
3	D1	1	9000	6539	310
4	D2	1	8285	6235	300
The Sum of the Capacity that can be installed while accounting for a maximum 8% shading					1230

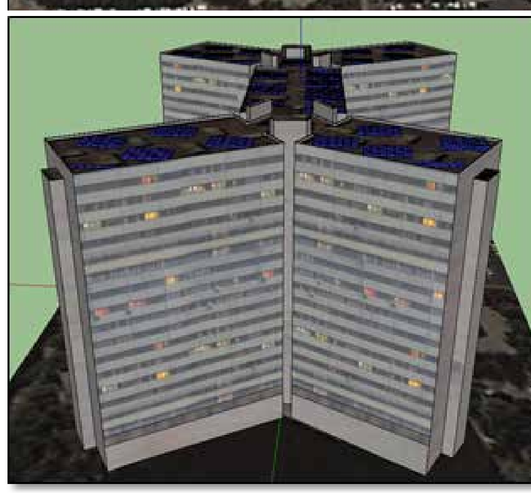


Fig 15,16: 3D display of Phase 3 of Ekbatan Complex in PVSOL software (Source: Authors)

CONCLUSION

Considering the results of this research, the sum of optimal capacity that can be installed on the rooftops of Ekbatan Residential Complex in all three phases is precisely calculated with PVSOL software and the obtained figure is equal to 9760 kW. This figure, on average, indicates an electricity generation of 4880kWh per day, which according to the global standard (stating the consumption of each household equal to 5 kWh) it is equal to the electricity consumption of 9760 households. It is worthy to mention that the statistics of electricity consumption of each household in Iran is 10kWh per day, which even considering this rate, the studied power station still is capable of supplying the electricity needed for 4880 households.

Tab 5: Calculations for Capacity Assessment of Installing PV System throughout Ekbatan Complex using PVSOL software (Source: Authors)

Phase	Building Type	Number of Blocks	Roof Surface (sqm)	Useful Surface for Installation (sqm)	Installation Capacity (kW)
1	A	5	43990	34136	1650
	B	4	42850	35452	1700
	C	1	8720	6518	300
2	A	6	48250	41009	2180
	B	9	38290	32546	1700
	C	4	22000	18695	1000
3	E1	1	9500	7085	350
	E2	1	7590	5670	270
	D1	1	9000	6539	310
	D2	1	8285	6235	300
Total		**33**	**238475**	**193885**	**9760**

If we divide the production capacity of this power station by the number of residential units in this complex (i.e. 15675), we obtain the important indicator of Kilowatts per residential unit which is an indicator for measuring the extent of installation of these systems considering the population density of each texture. Upon further expansion of this indicator for other zones of Tehran city it will be possible to obtain important results such as target zones and districts, prioritizing urban zones and etc for the city of Tehran.

Furthermore, with such obtained results it is possible to identify and study how the urban structure affects the optimal capacity of photovoltaic systems and thereby to identify which negative factors affect the reduction of this indicator and then to provide maximum utilization of the solar energy for the citizens of Tehran upon elimination or modification of such factors in the new urban pattern.

Considering the existing rules and laws in this country concerning non-cumulative grid connected PV systems, it is also recommended to proceed with the price of 0. 20US Dollars (8000 Rials) per kW for the sale of such generated electricity. According to the Table 2 attached to this research, at the present time and considering the encouragement package proposed by the government for a guaranteed purchase of electricity for 20years, all of the dead spaces such as rooftops of the residential buildings can become a source of income, in addition to its positive environmental effects. For instance, considering the results of this research , in case of equipping the surface areas of all 33 blocks of Ekbatan Residential Complex , an annual income of approximately 3,625,000 US Dollars (145/000/000/000 Rials) will be achievable.

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