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Energy Consumption Management of Commercial Buildings by Optimizing the Angle of Solar Panels

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ABSTRACT

One of the main reasons of environmental pollution is energy consumption in buildings. Today, the use of renewable energy sources is increasing dramatically. Among these sources, solar energy has favorable costs for various applications. This study examined a commercial building in a hot and humid climate. The findings showed that choosing the optimal angle of solar panels with the goal of optimized energy consumption would yield reduced costs and less environmental pollutants with the least cost and maximum energy absorption. In this study, to calculate the energy requirements of the building, DesignBuilder software was used. To study the solar angles and estimate the energy produced by the solar panels, Polysun software was used after simulating the building energy. Energy simulation results showed that the whole building energy consumption was 26604 kWh/year. Finally, the evaluation results of solar panels showed that the energy produced by photovoltaic modules at an optimal angle of 31° would be equal to 26978 kWh/year, which is more than the energy required by the building. This system can prevent 14471 kg of carbon dioxide emissions annually. Sustainable energy criteria showed that for the studied building, photovoltaic modules could be used in energy production to reach a zero-energy system connected to the grid with an annual energy balance.

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1. INTRODUCTION

Today, environmental threats have created a negative impact on construction fields due to urbanization and lack of energy in the public sector and professional organizations. Commercial buildings play an important role in saving energy. According to the Iran Department of Energy (2015), residential, commercial, and office buildings consume about 40 % of the total energy in the country [1, 2]. Due to the large share of final energy consumption in this sector, accurate analysis of the thermal and cooling loads of a building and the efforts to reduce energy losses in it are effective ways to reduce energy consumption [2]. Important decisions must be made by architects and engineers in the early stages of building design, regarding the final effects of building physics on the overall performance of the building [3]. As mentioned, one of the main reasons of environmental pollution is fuel consumption in commercial and residential buildings. This issue has captured the attention of many researchers and experts in recent years due to the need to optimize energy consumption in cities, especially the construction sector [4]. Amani and Reza Soroush (2020) examined effective parameters of energy consumption in the building. Their findings showed that each of the building components had a significant role in evaluating the energy performance of the building [2]. Today, the use of solar panels is increasing worldwide due to the importance of solar energy production [5]. Solar panels are one of the best renewable technologies for energizing buildings. For this purpose, knowledge of the optimum tilt angle is necessary for obtaining the highest possible annual or seasonal energy yield. The optimum tilt angle is dependent on many factors such as the latitude, weather conditions, and surroundings [6, 7]. To increase the efficiency of solar systems, it is suggested that necessary measures be considered from the initial phases of design to combine solar panels with the building facade [8]. For active solar systems such as solar collectors and PV panels, it is important to estimate the possible thermal or electrical energy production [9]. The availability of global irradiation data measurements is one of the most important factors in the assessment of the solar potential for the installation of photovoltaic panels [10]. For this purpose, the use of daily data for modeling is very important. Also, input data for the models and the data for validation should be assessed at the same station [9]. In some countries where it is not possible the use of numerical models has been proposed to estimate the monthly, seasonal, and annual solar radiation (global diffuse and direct solar radiation), especially on tilted surfaces [10]. Many solar panels are connected serially. As a result, the panels are often exposed to relatively high potential relative to the ground, resulting in High Voltage Pressure (HVS). The effect of this pressure was considered on the long-term stability of solar panels by NREL in 2005 [5]. One of the effective measures in the field of optimizing fuel consumption in commercial and residential buildings is the use of natural

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energy in the climatic design of buildings based on the principles of architecture compatible with the climate of each region. Therefore, one of the main tasks of planning and design in Iran can be the revision of the construction laws due to the energy crisis and the necessity to save on energy consumption [11]. Ifaei et al. (2017) conducted a study on sustainable development in Iran using Technical-Economic-Socio-Environmental Multivariate Analysis (TESEMA) using renewable energy. The results showed that the current centralistic policies in Iran should be revised to achieve sustainable development [12]. Also, Karbasi et al. (2007) showed that increasing energy efficiency, including combined cycle power generation, was the most economical option for reducing greenhouse gas emissions in Iran. Therefore, price reform is the key policy in promoting energy savings and replacing fuel with renewable energy [13]. The most important factors that have challenged human beings in the past are climatic elements. Therefore, one of the issues that leads to the incompatibility of architecture with the regional climate is the lack of sufficient knowledge on recognizing the climatic conditions and their impact on architecture [11]. Since a large part of the country is located in a hot climate, the implementation of appropriate methods to reduce the cost of cooling the building is very important. Due to the climate of Ahvaz city, characterized by long and hot summers, it is necessary to apply the principles of energy optimization in the building [14]. On combined wind and solar systems, Ifaei et al. (2017) stated that Iran was mainly a solar country and had approximately 74 % solar energy fraction under optimum conditions [15]. Also, Karbassi et al. (2008) showed that solar water heating systems as a means of conventional energy substitution could reduce the use of electricity or fossil fuels by up to 80 % [16]. Due to the importance of reducing energy consumption to achieve sustainable development and reduce operating costs [17], the ways should be sought to reduce fossil fuel consumption. One of the building's energy management solutions is the use of new technologies to optimize and sustain energy. In other words, the use of new technologies in energy management is felt based on the cooling-heating needs of buildings in Iran. A comprehensive review of previous research has been done on the energy consumption of buildings using solar panels. These studies were adopted from such famous databases as Science Direct, Wiley, and Taylor & Francis. The issues relating to the building energy conservation and efficiency with solar panels through modeling and simulation have been discussed [18-29]. To perform energy analysis, DesignBuilder software was used. This software is one of the best building energy simulation and analysis software packages. The main reasons for choosing this software are its high accuracy in calculations as well as forecasting air temperature at any time of the year. Also, the application of advanced EnergyPlus engine may yield the results of energy analysis graphically and numerically. In this study, a 5-story commercial building in Ahvaz was simulated and it was finally showed that the use of solar panels to optimize energy consumption could reduce costs and environmental pollutants. It should be noted that the optimal angle of panels plays an important role in achieving this goal. It is a conceptual framework for implementing the principles of energy management and its application strategies in buildings with the perspective of the construction life cycle to contribute to sustainable development. This study intends to minimize the costs of using a solar panel system to optimally convert solar energy into electrical energy by selecting the suitable angle of solar panels using Polysun software.

2. METHODOLOGY

2.1. Software selection

In this study, DesignBuilder software was used to create the energy model. This software can be used to calculate cooling and heating loads based on such parameters as material structure, occupants, mechanical and electrical systems, and annual or hourly climate data to keep the temperature in the comfort range. Another feature of this software is predicting air temperature at different spaces of the building based on the mentioned parameters at any time of the year. After creating the energy model in DesignBuilder software, the annual energy requirement of the building was calculated. Then, to supply the required energy of the building using solar panels, Polysun software was used. According to the geographical location of the project, the angles of solar radiation were examined by Polysun software to select the most optimal annual angle. Fig. 1 shows the details of the composite roof layers in the DesignBuilder software.

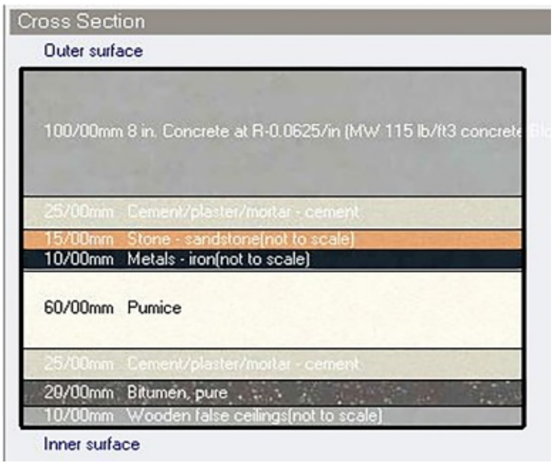

Figure 1. Details of the composite roof layers in DesignBuilder software

2.2. Case study

The case study building is a 5-story commercial building in Ahvaz with an area of 2200 m^2, which is located on an integrated concrete surface with a height of 30 cm. To calculate the amount of energy required to reach the comfort level, which is the supply of temperature and humidity in the standard range, the conditions of the spaces must be transient. For this purpose, the studied building was simulated using DesignBuilder software. This software provides the ability to energy simulation on an hourly basis throughout the year. Fig. 2 shows a three-dimensional view of the building in DesignBuilder software. The height of each floor is 3.5 m and the total height up to the rooftop is 17.5 m above the ground. The thickness of the exterior walls of the building was 20 cm and the roof material was the type of composite. All windows are double glazed with a 6 mm thickness middle air layer and have no shades. The window-to-wall ratio on the southern side of the building was 8 % and the eastern side of the building was 9 % on the floors. Also, the doors were made of unbreakable glass. The building lighting was supplied by fluorescent lamps with a light intensity of 600 Lux and a brightness coefficient of 0.74. The average number of customers was considered 60 people per day.

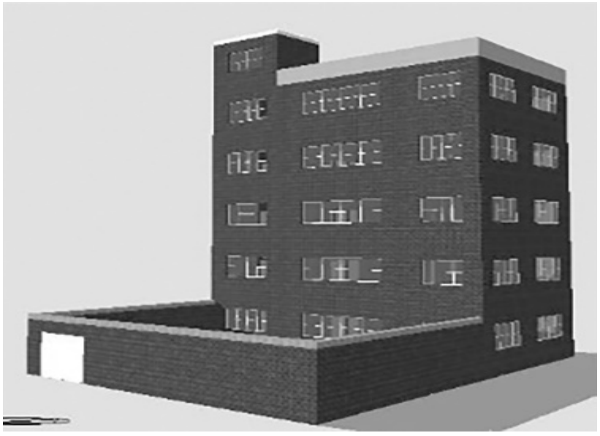

Figure 2. Three-dimensional view of the building in DesignBuilder software

2.3. Climate conditions

Ahvaz is characterized by particular climatic conditions due to its location in a special geographical location (topographic and climatic conditions of the region). One of the features of this climate is the high intensity of sunlight, which according to Article 19 of the National Building Regulations of Iran [30], is in the group of buildings with high energy consumption. Extreme heat causes many problems for people. Hence, the study of climatic conditions is an attempt to reduce relevant problems. For this purpose, synoptic meteorological data were employed to examine the climatic situation of Ahvaz. As shown in Table 1 [31], Ahvaz has hot and long summers and short and mild winters. The maximum temperature in July and August is higher than 50 °C and the maximum relative humidity in January is 60 %. The maximum rainfall in April is 40.8 mm. Also, the highest hours of sunshine in June are equal to 353 hours and the lowest hours of sunshine in January are equal to 167.5 hours.

2.4. Solar radiation analysis

Solar radiation modeling is a complex process that examines factors such as latitude, solar radiation interval, model height, surface orientation, surface reflectivity, and atmospheric phenomena. The results show that the lowest average monthly sunshine is in December, and its value varies from 2.83 to 3.46 kWh. Then, January and November have the least amount of sunshine. The maximum value of sunshine is in June with an average daily of 8.29 kWh/m^2. The average daily sunshine from April to September is higher than 5.78 kWh/m^2 (more than the average annual radiation). The average annual intensity of solar radiation is equal to 5.18 kWh/m^2/day, which is in a very suitable category according to the division of solar radiation by the US National Renewable Energy Laboratory. The highest amount of solar energy is in the hot months of the year, which coincides with the highest electricity consumption in Ahvaz. The high energy received during these months makes it possible to use it to supply part of the region's electricity and reduce the pressure on power transmission lines and, consequently, reduce the power outage. However, despite this massive potential, there is no photovoltaic power plant in Khuzestan province and solar energy production is negligible in the experimental and research stages. Fig. 3 shows the intensity of solar radiation based on the annual average [32].

Table 1. Meteorological information of Ahwaz station per month

Month	Temperature (°C)				
	Maximum average	Minimum average	Average	Highest maximum	lowest minimum
January	20.5	9.2	14.9	25.9	9.2
February	19.2	7.1	13.2	25.2	7.1
March	25.4	11.3	18.3	30.5	11.3
April	29.5	16.0	22.7	35.6	16.0
May	39.7	23.8	31.8	45.8	23.8
June	42.3	26.4	34.4	47.8	26.4
July	47.3	30.7	39.0	50.4	30.7
August	47.4	29.9	38.6	50.4	29.9
September	45.0	27.4	36.2	49.1	27.4
October	38.2	20.0	29.1	43.5	20.0
November	31.6	15.5	23.6	36.6	15.5
December	20.8	9.0	14.9	25.6	9.0

Month	Rainfall (mm)	Maximum rainfall in one day (mm)	Relative humidity (%)	Frosty day (s)	Dusty day (s)	Sunshine duration (h)	Wind speed (m/s)
January	16.5	16.5	60.0	0.0	3.0	167.5	15.0
February	6.0	2.8	54.0	1.0	8.0	179.1	18.0
March	24.9	15.2	47.0	0.0	3.0	215.8	19.0
April	40.8	23.0	48.0	0.0	3.0	269.4	20.0
May	0.3	0.2	36.0	0.0	5.0	308.9	17.0
June	0.0	0.0	23.0	0.0	8.0	353.0	16.0
July	0.0	0.0	25.0	0.0	6.0	348.0	13.0
August	0.0	0.0	30.0	0.0	1.0	351.7	12.0
September	0.0	0.0	27.0	0.0	3.0	319.3	16.0
October	0.0	0.0	29.0	0.0	5.0	275.5	14.0
November	0.0	0.0	44.0	0.0	3.0	236.4	15.0
December	21.3	11.0	49.0	0.0	2.0	193.3	17.0

Solar radiation depends on the climate of the region and the different seasons of the year. The building orientation should be such that it receives the most solar radiation in cold months for maximum use of solar energy. Conversely, during hot months, the intensity of sunlight should be reduced on the surface of the building. However, according to the criteria of the region, the building location was considered to the south. The amount of solar energy received in different places varies based on latitude, altitude, atmospheric phenomena, and so on. Therefore, to receive information about solar radiation, the latitude and altitude of the region must be determined. In this case, the monthly and annual averages of solar radiation can be calculated for the desired location at all levels with different directions and slopes. In this study, the latitude is 31.3° and the altitude is 16 m. Fig. 4 shows the values of solar radiation in the building on an annual basis. These values have been extracted up to an acceptable level of 400 Lux, depending on the amount of energy received from the translucent walls. Also, all the spaces had enough light.

2.5. Surface coverage and location for solar panels

The use of solar panels reduces the cost of electricity in the building. These panels must be installed in the right place and at the right angle to achieve greater efficiency. The building roof has a high potential for using solar energy. Also, it is very important to determine the sunray angle to the desired surface. To install solar panels, much research has been done on the amount of usable roof area of buildings. One study in the United States shows that 32 % of the total roof area of houses can be used to install solar panels. This value will be 18 % for houses with sloping roofs and 65 % for flat roofs [33]. Another study shows that 60 % of flat roofs can be used in the tropical regions of the United States to install solar panels [34]. Another study showed that in places where there is no accurate information about its characteristics for the installation of solar panels, 50 % of the roof area can be considered [35]. Moreover, one study in Taiwan showed that 25 % of buildings' roofs for the installation of solar panels were considered [36]. In this study, the panel surfaces were determined by about 25 %. In order to increase the efficiency of solar panels, the angle of the panels should change according to the position of the sun in the sky. For this purpose, the angle of the sun must always be perpendicular to the surface of the panels. The angular altitude of the sun is indicated by SA and the latitude by L. Thus, the maximum and minimum values of the angle of radiation on the first days of summer and winter are calculated through Eqs. 1 and 2, respectively. On the first days of spring and autumn, the earth is in the middle of its orbital path between the two maximum and minimum values and the angle of deviation remains unaffected. Therefore, the average of the solar altitude angles is calculated through Eq. 3.

$$SA_{(Max)}=90-L+23.5=90-31.3+23.5=82.2 \quad (1)$$

$$SA_{(Min)}=90-L-23.5=90-31.3-23.5=35.2 \quad (2)$$

$$SA_{(Mid)}=90-L=90-31.3=58.7 \quad (3)$$

According to the above Equations, different approaches can be used to adjust the angle of the panels. Based on Rule no. 667 of the Ministry of Energy, the energy absorption efficiency rates in different modes of panels installation as the fixed panel, two-season constant, four-season constant, and two-axis tracker relative to the optimal annual angle of 23.7° for Ahvaz are equal to 71.1 %, 75.2 %, 75.7 %, and 100 %, respectively [37]. Energy simulation results show that the whole building energy consumption is 26604 kWh/year. Accordingly, the value of building energy consumption is 69.10 kWh/m^2/year. Due to the investment cost and the need for minimum energy in the building, which is the result of its architectural energy, it can be converted into a zero-energy building that is also economical. For this purpose, new energy production systems should be used. To achieve zero-energy standard, different ideas and methods are used. The use of active solar systems such as photovoltaic modules and solar water heater system is one of the most important solutions to produce the energy required by the building.

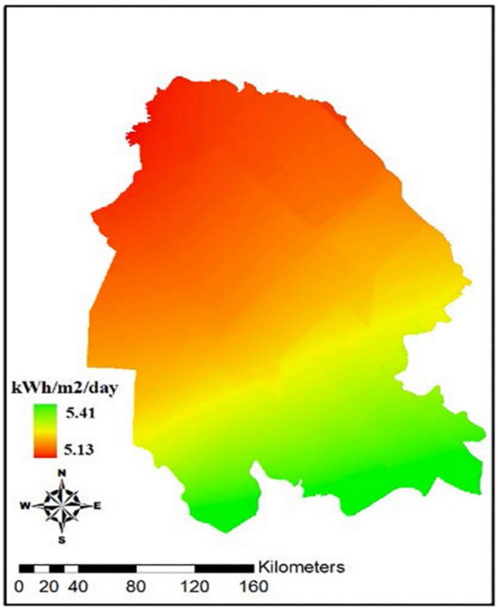

Figure 3. Average annual of daily solar radiation in Khuzestan province

Temperatures, Heat Gains and Energy Consumption - test, Building 1

EnergyPlus Output — 1 Jan - 31 Dec, Daily — Evaluation

Day										
Air Temperature	26/00	30/81	34/73	37/70	46/04	47/44	47/07	41/87	39/17	31/93
Radiant Temperature	27/61	31/82	35/47	39/00	46/87	48/10	47/73	43/24	40/48	33/67
Operative Temperature	26/81	31/31	35/10	38/35	46/46	47/77	47/40	42/55	39/82	32/80
Outside Dry-Bulb Temperature	14/46	20/51	26/55	29/42	36/48	39/23	38/79	31/28	26/53	16/31
External Infiltration	-94/33	-81/64	-63/36	-63/55	-71/50	-60/97	-61/28	-81/06	-98/31	-125/57
General Lighting	48/51	64/68	64/68	0/00	64/68	64/68	64/68	48/51	64/68	64/68
Miscellaneous	5/78	27/86	27/86	1/73	27/86	27/86	27/86	5/78	27/86	27/86
Occupancy	2/24	4/14	0/56	0/00	0/00	0/00	0/00	0/00	0/00	3/05
Solar Gains Exterior Windows	67/21	122/57	111/77	97/56	71/52	90/67	77/37	100/13	123/79	136/71
Mech Vent + Nat Vent + Infiltration	0/73	0/72	0/72	0/72	0/72	0/72	0/72	0/72	0/73	0/74

Figure 4. The values of solar radiation in the building using DesignBuilder software

2.6. Evaluation of photovoltaic modules in polysun software

In Polysun software, it is possible to simulate solar systems as well as facilities including heat pumps, geothermal energy, etc. to cover all or part of the building's energy needs. In this research, by specifying the project location in Polysun software, the required data were collected by the software. Table 2 shows the value of the energy generated by photovoltaic modules on an annual average. Also, for example, the value of energy production was calculated in August and February. The results showed that the average annual value of energy generated by 61 photovoltaic modules with a power of 350 watts and an angle of 31° was equal to 26978 kWh/year. This value will be higher than the whole building energy consumption. Also, the value of energy generated in August by 41 photovoltaic modules with a power of 350 watts and an angle of 5.3° is equal to 27572 kWh/year. This value of energy for February by 80 photovoltaic modules with a power of 350 watts and an angle of 42.3° will be equal to 26463 kWh/year. The surface coverage of panels in all cases was 99.5 m^2. Energy storage can be used based on the review in August and February to balance energy throughout the year. The angles provided based on the software analysis follow the minimum costs for installing solar panels to convert solar energy into electrical energy. Fig. 5 shows the value of energy generated by photovoltaic modules in general mode (annual average) in Polysun software. The results show that this system can prevent the emission of 14471 kg of carbon dioxide annually. Also, by using the solar water heater system, the release of environmental pollutants can be prevented as much as possible. At the national level, this amount can help preserve and sustain the environment and lead the country towards sustainable development.

Table 2. Energy generated by photovoltaic modules in Polysun software

Component overview (annual values)				
Photovoltaics roof plan	PV-Modul-350W			
	Unit	Annually	August	February
Number of modules		61	41	80
Total nominal power generator field	kW	21.35	21.35	21.35
Total gross area	M^2	99.47	99.47	99.47
Tilt angle (hor.=0°, vert.=90°)	°	31	5.3	42.3
Orientation (E=+90°, S=0°, W=-90°)	°	0	0	0
Inverter 1: Name		Inverter 10500T		
Manufacturer		Anonymous		
Inverter 2: Name		Inverter 4000		
Manufacturer		Anonymous		
Manufacturer		Anonymous		
Energy production AC [Qinv]	kWh	26978	27572	26463

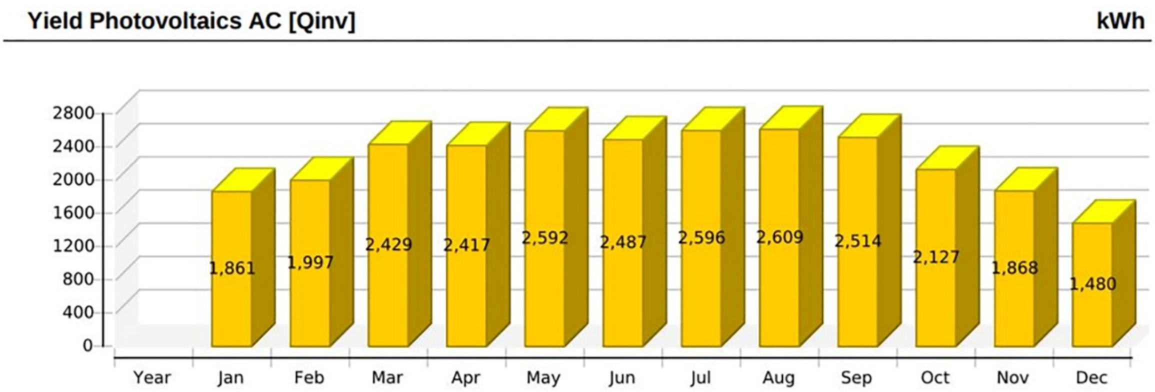

Figure 5. The energy produced by photovoltaic modules monthly

3. DISCUSSION

Increasing global warming and environmental pollutants has been on the minds of researchers for years to make a useful contribution to the future with the development of new energies. Solar energy is one of the clean and available energies. The solar panels are of great importance in this field due to the direct conversion of solar energy into electrical energy. The tilt angle of a solar energy system is one of the important parameters for achieving maximum solar radiation falling on the solar panels. This angle is site-specific which is dependent on the daily, monthly, and yearly path of the sun. The accurate determination of the optimum tilt angle is essential for maximum energy production by the system. Yadav and Chandel (2013) conducted a study on the relevance of the optimum tilt angle in energy production and reducing the cost of solar energy systems. Their findings showed that for maximum energy gain, the optimum tilt angle for solar systems must be determined accurately for each location. For this purpose, different anisotropic models and optimization techniques could be used. Also, for urban areas, the obstacles affecting solar radiation should be considered for computing optimum tilt angles [38]. In addition, Yadav and Chandel (2014) studied different isotropic and anisotropic diffused solar radiation models for determining optimum tilt angle in India. They found that the Liu and Jordan models showed the lowest error among other models. Accordingly, the annual optimum tilt angle was determined to equal to 27.1° [39]. The thermal performance of a passive solar commercial building was evaluating by Chandel and Aggarwal (2008) in the Indian state of Himachal Pradesh. The results showed that the solar passive system features saved on the electricity required for space heating and the heat losses in the building are reduced by about 35 % [40]. Ben Othman et al. (2018) evaluated global solar radiation on tilted surfaces in Tunisia and found that the optimal annual angle in the north was equal to 37.5°and the northeast and south were equal to 36.6° [10]. This research simulated a commercial building in Ahvaz. Due to the high intensity of sunlight, Ahvaz is in a group of buildings with high energy consumption. This climate has a high potential for the optimal use of sunlight to produce energy. Solar radiation studies showed that the lowest average monthly solar radiation was in December and its value varied from 2.83 to 3.46 kWh. Also, the maximum value of sunshine was in June with an average daily rate of 8.29 kWh/m^2. The average daily sunshine from April to September is more than 5.78 kWh/m^2, which will be more than the average annual radiation. The optimum tilt angle of solar photovoltaic panels plays an important role in the optimum sizing of solar photovoltaic systems for a location. Hence, the capability of a solar module to maximize the incident radiation depends on monthly, seasonal, and yearly optimum tilt angles, which should be determined for the considered site to enhance the power generation of solar photovoltaic systems. In this study, the optimal tilt angle of the photovoltaic panels was determined to be 31°. Evaluation of photovoltaic modules showed that the angle of placement of panels affected the amount of energy produced and the number of modules. As a result, choosing the optimal angle of placement of panels will have a significant impact on cost optimization in the building life cycle. Sustainable energy criteria showed that the studied building could use photovoltaic modules in energy production to reach a zero-energy system connected to the grid with an annual energy balance. In designing zero-energy buildings, in addition to environmental aspects such as reducing energy consumption, economic and socio-cultural aspects should also be considered. The high potential of solar energy in Iran to diversify the energy basket and create a platform for the development and promotion of renewable energy provides the possibility of exploiting this endless resource.

4. CONCLUSIONS

The optimal annual angle for Ahvaz at 23.7° was set by Rule no. 667 of the Ministry of Energy. However, this study showed that determining the optimal angle of solar panels, based on the energy required by the building, would be the most important factor in reducing costs for optimal energy management. These results would minimize the cost of using solar panels to convert solar energy into electrical energy. Energy simulation results showed that the whole building energy consumption was 26604 kWh/year. Accordingly, the value of building energy consumption was equal to 69.10 kWh/m^2/year and to bring it to zero, the solar panels were used. Also, the results of photovoltaic modules evaluation in Polysun software showed that the energy generated by 61 photovoltaic modules with a power of 350 watts and surface coverage of 99.5 m^2 was 26978 kWh/year. This value was higher than the whole building energy consumption. By using this system, the emission of 14471 kg of carbon dioxide can be prevented annually. Finally, the comparison of different modes of energy consumption showed that the best method to achieve zero energy system was 61 photovoltaic modules with a power of 350 watts and an angle of 31° with a surface coverage of 99.5 m^2.

5. ACKNOWLEDGEMENT

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