Çukurova Üniversitesi Mühendislik Fakültesi Dergisi, 37(3), ss. 685-697, Eylül 2022
Cukurova University Journal of the Faculty of Engineering, 37(3), pp. 685-697, September 2022

Energy Analysis in a Solar House with Building-Integrated Photovoltaic (BIPV) System

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Geliş tarihi: 23.05.2022 Kabul tarihi: 23.09.2022

Atıf şekli/ How to cite: TANTEKİN, A., TÜMEN ÖZDİL, N.F., (2022). Energy Analysis in a Solar House with Building-Integrated Photovoltaic (BIPV) System. Çukurova Üniversitesi, Mühendislik Fakültesi Dergisi, 37(3), 685-697.

Abstract

Increased energy demand and fossil fuel usage of the world has led to the search for new and clean energy production methods. Renewable energy sources are developing and emerging options for energy production methods. Sun is the most accessible and stable renewable energy source. There are several methods to produce energy from the sun. The building-integrated photovoltaic (BIPV) system is a well-known method for generating electricity by using solar cells to transform the energy from the sun into electricity. BIPVs are a new technique to reduce energy consumption from fossil fuels. Passive solar houses mean that the energy demand of the living space is met with the usage of solar energy for the heating and cooling demand of the living space. In this study, an existing house, located in Istanbul, is modeled and covered with photovoltaics with the help of a computer program and the amount of energy produced with the aid of these photovoltaics is presented. The analysis demonstrates that the yearly average amount of daily electricity production is varied between 1.05 kWh as the minimum value and 19.7 kWh as the maximum value for all facades. The yearly average amount of monthly electricity production is varied between 31.8 kWh as the minimum value and 599 kWh as the maximum value for all facades.

Keywords: Passive solar house, Building integrated photovoltaic system, Energy analysis, SketchUp

Binaya Entegre Fotovoltaik Sistemli Bir Güneş Evinde Enerji Analizi

Öz

Dünyanın artan enerji talebi ve fosil yakıt kullanımı, yeni ve temiz enerji üretim yöntemlerinin aranmasına neden olmuştur. Yenilenebilir enerji kaynakları, enerji üretim yöntemleri için gelişen ve ortaya çıkan seçeneklerdir. Güneş, en erişilebilir ve istikrarlı yenilenebilir enerji kaynağıdır. Güneşten enerji elde etmek için çeşitli enerji üretim yöntemleri vardır. Binaya entegre fotovoltaik sistemi, güneşten

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gelen enerjiyi elektriğe dönüştürmek için güneş pillerini kullanarak elektrik üretmek için iyi bilinen bir yöntemdir. Binaya entegre fotovoltaik sistemler, fosil yakıtlardan enerji tüketimini azaltmak için yeni bir tekniktir. Pasif güneş evleri, yaşam alanının enerji ihtiyacının karşılanması, yaşam alanının ısıtma ve soğutma ihtiyacı için güneş enerjisi kullanımı anlamına gelmektedir. Bu çalışmada, İstanbul'da bulunan mevcut bir ev, bir bilgisayar programı yardımıyla modellenerek fotovoltaiklerle kaplanmış ve bu fotovoltaikler yardımıyla üretilen enerji miktarı sunulmuştur. Analiz, tüm cepheler için yıllık ortalama günlük elektrik üretim miktarının minimum değer olarak 1,05 kWh ve maksimum değer olarak 19,7 kWh arasında değiştiğini göstermektedir. Tüm cepheler için aylık ortalama elektrik üretim miktarı minimum değer olarak 31,8 kWh, maksimum değer olarak 599 kWh bulunmuştur.

Anahtar Kelimeler: Pasif güneş evi, Binaya entegre fotovoltaik sistem, Enerji analizi, SketchUp

1. INTRODUCTION

Energy is a substantial term to maintain the living standards of humanity. In the last decades, energy consumption with the usage of fossil fuel increases at a fast pace. The usage of fossil fuels causes a significant amount of environmental pollution, global warming and harmful effect of human health. Based on the statistical data of the International Energy Agency (IEA), fossil fuels have the highest percentage between world total primary energy supplies from 1971 to 2013 [1].

In order to decrease the fossil fuel depletion, some new ideas and methods show up with the help of emerging technology. Energy production from renewable energy sources becomes more popular and preferable instead of energy production from fossil fuels [1].

There are several renewable energy sources which are used for energy production in recent years. The well-known renewable energy types are hydroelectric, geothermal, solar, wind, biomass and ocean energy. Recently, a lot of investigations have been reported about these renewable energy sources such as hydroelectric [2], geothermal [3], solar [4], wind [5-8] and biomass [9]. Although the investment cost of solar energy is high, the sun is the most accessible and preferable option for energy production between all the other renewable energy sources. Photovoltaic panels have a major advantage between all other solar energy systems in terms of direct conversion from solar energy to electricity. Moreover, photovoltaic panels are simple, easy to construct and they can be integrated into the buildings without any extra effort. A photovoltaic panel solar system contains three main parts, i) photovoltaic modules or solar arrays, ii) balance of system, iii) electrical load. The solar cells are the primary unit of a photovoltaic system.

Although there is a lot of information about photovoltaics in literature, the information about the application of photovoltaics and its energy production analysis is not sufficient. Based on the study of Aronova et al. [10], a passive house was transformed as an energy plus house. The amount of electricity production based on solar energy was predicted. They concluded that the amount of insolation and solar radiation receipt from the sun were affected the electricity generation efficiency using photovoltaic modules in Macedonia weather conditions.

Tian et al. [11] implemented a feasibility study of a building achieving zero energy. Software TRNbuild was used to set up a 12-story residential building as a reference building. Therefore, the passive building design was applied in order to decrease heating and cooling load with the help of high-performance envelope, airtightness and fresh air heat recovery efficiency. The annual energy consumption of reference buildings was found as 30.33 kWh/m^{2}a. It was observed that photovoltaic array production on the roof could have met its energy demand. It was proved that it was feasible for residential buildings in Beijing to reach nearly zero energy.

According to the studies of Kwan and Guan [12], the evaluation of the energy performance, financial feasibility and potential energy savings of zero-energy houses were presented. A 5 stars energy rated home was modeled with the help of a computer simulation technique and confirmed by comparing the energy performance of a basic standard house in Brisbane. It was found that almost 66% of energy savings can have achieved with the annual energy usage of households by increasing the thermal performance of building envelope and decreasing the energy requirements with the help of solar energy technologies.

Berry and Whaley [13] demonstrated a case study about the performance of the photovoltaics for zero-energy houses, in their study. The average size for all photovoltaic systems was 2.47 kW_p with the smallest capacity of 1.5 kW_p and the largest 4.2 kW_p. The results showed that there were some problems to obtain optimal performance of the photovoltaics because of installation faults such as orientation, tilt angles and overshadowing from trees and buildings.

Adam and Apaydin [14] analyzed the effect of the photovoltaics on the greenhouse gas emission reduction and CO_2 emission reduction using RETScreen software in Gaziantep city of Turkey. They concluded that the emission reduction capacity of the photovoltaic system was reasonable but increasing the share of the solar photovoltaic system can be achieved if only adequate financial incentives are provided by the government.

Kapsalis and Karamanis [15] investigated the effect of a building added photovoltaic array on the energy demand of buildings during different seasons. Two roofs with a 9.6 kW polycrystalline photovoltaic array system were explored as part of a detailed building energy system considering the microclimate external flow patterns, the geometry of the canopy architecture and the electricity production. The results showed that the decreased incoming solar fraction on the surface reduced the heat gain and increased the heating loads.

Peng et al. [16] discussed building-integrated photovoltaics in architectural design in China. They considered building-integrated photovoltaics in terms of cost, technology, functionality and aesthetics. They concluded that there are limits in the use of the current form of building-integrated photovoltaics owing to economical and technical constraints. Moreover, it was understood that tighter integrations of building-integrated photovoltaics were not preferable in terms of energy efficiency. Furthermore, easy maintenance and replacement were found as an important parameter in terms of increasing energy efficiency with developing technology for building-integrated photovoltaics.

Norton et al. [17] implemented a review about enhancing the performance of building integrated photovoltaics. They concluded that the cost of a building integrated photovoltaic system can be diminished with the help of decreasing manufacturing, installation, operation and maintenance costs and enhancing the efficiencies of photovoltaic modules. They suggested that government subsidies and tax reductions on building integrated photovoltaic systems should be necessary for the improvement of market development.

Shukla et al. [18] prepared an extensive review about the design of building integrated photovoltaic systems. They revealed the classification of solar photovoltaic cells and building integrated photovoltaic systems in terms of design purposes. They explained that building integrated photovoltaics are an exchange of conventional construction material by photovoltaic materials like two-function material. They proposed that the conventional building roof, façade and window shading systems can be exchanged with building integrated photovoltaic products.

Yang and Zou [19] investigated the costs, benefits and risks of building integrated photovoltaics and proposed suggestions for better and efficient applications. They concluded that, although building integrated photovoltaics have high initial investment costs, there are important long-term benefits for clients, end-users and the entire society. Moreover, they said that, in order to support building integrated photovoltaics, costs should be decreased and also government policy support and incentives are required.

Cucchiella et al. [20] purposed to identify the number of photovoltaic systems required to reach the target of renewable energy production. They observed that the economic results were strongly affected by the annual average insolation value however, the consumption of consumers was not found critically important. Furthermore, they found that the design principle of photovoltaic systems had an important effect on energy efficiency.

Biyik et al. [21] reviewed the building integrated photovoltaic systems according to energy generation amount, efficiency, nominal power, type and performance assessments in detail. They observed that the shadowing effect, the direction of the building, ambient temperature, the slope of the photovoltaic panel can be listed as significant parameters to obtain high energy efficiency in experimental applications.

Perez et al. [22] presented the life cycle and performance assessment of a building integrated photovoltaic system in New York City. They found that the major drawback of the façade building integrated photovoltaic system was its vertical orientation and receiving lower radiation than roof and ground installations. Moreover, they also mentioned two major advantages as no requirement any virgin land for its operation and interchangeability of structural units.

Photovoltaic panel technology has developed a lot in recent years and its use has become widespread. Especially, as the damage caused by the use of fossil fuels to the world increased, solar energy, which is a clean energy source, started to be preferred more.There are few studies concern with the BIPV applications on the residential areas and there are some details that need to be discussed and discovered to improve the efficiency of the BIPVs. In this study, a BIPV house which is located in Istanbul - Turkey was modeled and the energy analysis was applied with the help of the computer program. The annual energy consumption and the number of average energy requirements were observed.

2. MATERIALS AND METHODS

Istanbul city of Turkey is chosen as the case study due to the high energy requirements and high environmental pollution of this city. The house, which is located in the Uskudar district of Istanbul, is modeled with the help of a computer program. The total building area of this house is approximately 150 m^2. The model is drawn based on the original architectural project. The SketchUp program is used for modeling the house in the 3D version. The Skelion plugin program is performed to add photovoltaic panels to the 3D house model. Moreover, this program is used to calculate the amount of annual energy production. The period of this analysis is considered as one year. In order to obtain the exact results of the energy production, the angles of the solar rays are investigated according to months. The optimum solar ray angle is chosen to obtain the optimum value of energy production. The appliance and equipment audits are also implemented to compare the amount of energy consumption and energy production. The most energy-efficient appliances are identified to decrease energy consumption. According to these appliances and other equipment, the average annual energy consumption of a typical house is calculated as approximately 6480 kW. Moreover, all insulation materials in the market are evaluated according to their superior properties. The properties of the most superior insulation material are chosen to be used for this study. Two types of photovoltaic panels have been chosen according to the dimensions of the surface to be applied, the dimension of the small panel is 0.84 x 0.95 m and the dimension of the large panel is 1.53 x 0.73 m. In this study, 107 small panels and 30 large panels are used to generate electricity for this house. According to the given dimensions and number of panels used in the house, the total photovoltaic panel area is calculated as 188.88 m^2. The schematic representation of the modeled house can be seen in Figure 1-5. The general electricity generation formula of a photovoltaic panel can be seen below.

$$E = A \times r \times H \times PR \quad (1)$$

where E is energy amount, A is total solar panel area, r is solar panel efficiency, H is annual average solar radiation on photovoltaic panels and PR is performance ratio. For this study, A, r and PR values of the photovoltaic panels are defined in the program according to selected panel types. Furthermore, the H value of the given region can be found in the Turkish State Meteorological Service [23].

Figure 1. Front view of the house

Figure 2. Side view of the house

Figure 3. Rare view of the house

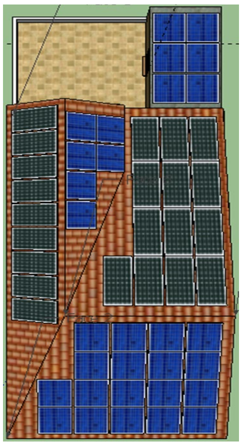

Figure 4. Top view of the house

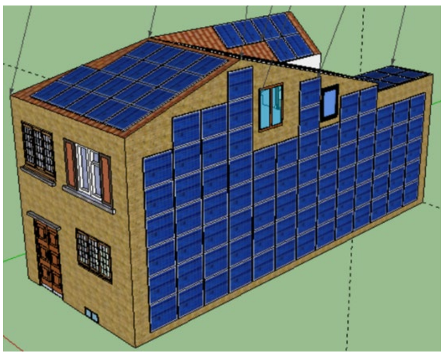

Figure 5. Isometric view of the house

3. RESULTS AND DISCUSSIONS

This study reveals the real-life application of energy assessments. The energy performance of a BIPV house is introduced in order to observe whether the photovoltaic panels satisfy the energy requirements or not. Firstly, a real house is selected in order to model in a 3D program. Then, with the help of a plug-in program, photovoltaic panels are added to the house. The location of the house on the globe is used as an input value in order to determine the amount of incident solar radiation depending on the position of the house. Besides, energy-consuming appliances are selected to calculate how much energy consumed in a day.

The average daily electricity generation, the average monthly electricity generation, the average daily sum of global irradiation per square meter received by the modules and the average sum of global irradiation per square meter received by the modules are observed with the help of Skelion plug-in program. Before the calculations, the inclination angle of the panels is chosen as 16^o in order to obtain optimum electricity production from the panels. For each face, the results can be seen from the Tables 1-11 based on the months of a year.

As can be seen from Tables 1 to 8, daily and monthly electricity production rates are altered based on the angle of the sun for all facades of the house. This means that the amount of electricity produced during the summer season increase due to the angle of incidence of the sun. Turkey receives sun rays at a steeper angle in June and July compared to other months. The yearly average amount of daily electricity production (E_d) is varied between 1.05 kWh as the minimum value and 19.7 kWh as the maximum value for all facades. The yearly average amount of monthly electricity production (E_m) is varied between 31.8 kWh as the minimum value and 599 kWh as the maximum value for all facades. When considering the amount of global irradiation per square meter received by the modules, it is observed that the average value of the daily sum of global irradiation per square meter is close to another for all faces. The value of the daily sum of global irradiation per square meter (H_d) is varied from 3.66 to 4.66 kWh/m^2. The value of the sum of global irradiation per square meter (H_m) is varied from 111 to 142 kWh/m^2. The difference in the amount of electricity production between all faces, while the amount of global radiation per square meter close to each other, is revealed that the direction of the panel surface affects the efficient electricity production process.

The site to source conversion factors of the system can be seen in Table 10. For photovoltaic panels as an electricity generation system, the aim of the site to source conversion factors is taken into account of conversion, transmission, and distribution losses on the electricity generation [24]. For this study, there is not an analogous conversion loss because electricity is derived from the sun, which is not considered as fossil fuels. Therefore, the site to source conversion factors for the photovoltaic panel system are almost 1 except for electricity. The fact that the site to source conversion factor of electricity is greater than 1 indicates that there are distribution and transmission losses in the system. With the reduction of the distribution and transmission losses in the system, the site to source conversion factor for the electricity will decrease and approach to almost 1.

The amount of total site energy, net site energy, total source energy and net source energy can be seen from Table 11. Source energy means the total amount of raw fuel that is required to exploit the house. Site energy means the amount of heat and electricity consumed by a house. As can be seen in Table 11, the total site energy of the house is calculated as 89.04 GJ while the net site energy is 88.27 GJ and the total source energy and the net source energy is calculated as 281.14 GJ. Source energy is the fairer unit of assessment of the energy analysis. For this reason, in order to obtain source energy value from the site energy value, the site to source conversion factors can be used at the international level of the energy assessments. The total end usage of the electricity for different applications of the house can be seen in Table 11. The total end usage of the electricity for heating application is calculated 30.92 GJ as the maximum value and it is followed by interior equipment as 201.3 GJ. The total end usage of electricity in the whole house is calculated as 89.04 GJ and also it can be seen from Tables 9 and 11.

Table 1. The results for the face 1

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	0.27	8.48	1.05	32.6
Feb	0.49	13.7	1.66	46.5
Mar	0.85	26.5	2.80	86.8
Apr	1.29	38.8	4.30	129
May	1.77	54.8	6.06	188
Jun	1.95	58.6	6.88	206
Jul	1.95	60.4	6.91	214
Aug	1.60	49.6	5.68	176
Sep	1.09	32.7	3.82	114
Oct	0.62	19.1	2.18	67.4
Nov	0.34	10.1	1.28	38.3
Dec	0.30	9.36	1.16	36.1
Yearly average	1.05	31.8	3.66	111

Table 2. The results for the face 2

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	1.25	38.8	1.53	47.5
Feb	1.82	51	2.19	61.2
Mar	2.81	87.2	3.40	106
Apr	3.83	115	4.80	144
May	4.97	154	6.44	200
Jun	5.34	160	7.11	213
Jul	5.43	168	7.27	225
Aug	4.70	146	6.30	195
Sep	3.52	106	4.60	138
Oct	2.30	71.4	2.91	90.1
Nov	1.56	46.7	1.93	57.9
Dec	1.30	40.3	1.60	49.6
Yearly average	3.24	98.7	4.18	127

Table 3. The results for the face 3

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	2.35	72.9	1.98	61.3
Feb	3.16	88.6	2.67	74.8
Mar	4.60	143	3.96	123
Apr	5.88	176	5.26	158
May	7.34	227	6.76	210
Jun	7.69	231	7.29	219
Jul	7.96	247	7.57	235
Aug	7.15	222	6.83	212
Sep	5.68	170	5.29	159
Oct	4.01	124	3.58	111
Nov	2.95	88.6	2.54	76.2
Dec	2.39	74.2	2.01	62.5
Yearly average	5.11	155	4.66	142

Table 4. The results for the face 4

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	0.78	24.3	1.98	61.3
Feb	1.05	29.5	2.67	74.8
Mar	1.53	47.6	3.96	123
Apr	1.96	58.8	5.26	158
May	2.45	75.8	6.76	210
Jun	2.56	76.9	7.29	219
Jul	2.65	82.3	7.57	235
Aug	2.38	73.8	6.83	212
Sep	1.89	56.8	5.29	159
Oct	1.34	41.4	3.58	111
Nov	0.98	29.5	2.54	76.2
Dec	0.80	24.7	2.01	62.5
Yearly average	1.70	51.8	4.66	142

Table 5. The results for the face 5

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	7.52	233	1.52	47.1
Feb	11	308	2.18	61
Mar	17.10	530	3.40	106
Apr	23.30	698	4.80	144
May	30.20	937	6.44	200
Jun	32.40	973	7.11	213
Jul	33	1020	7.27	225
Aug	28.60	886	6.30	195
Sep	21.40	642	4.60	138
Oct	14	433	2.90	90
Nov	9.35	281	1.92	57.5
Dec	7.81	242	1.59	49.3
Yearly average	19.7	599	4.18	127

Table 6. The results for the face 6

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	0.33	10.2	1.05	32.6
Feb	0.59	16.4	1.66	46.5
Mar	1.02	31.8	2.80	86.8
Apr	1.55	46.5	4.30	129
May	2.12	65.8	6.06	188
Jun	2.34	70.3	6.88	206
Jul	2.34	72.5	6.91	214
Aug	1.92	59.5	5.68	176
Sep	1.31	39.3	3.82	114
Oct	0.74	22.9	2.18	67.4
Nov	0.41	12.2	1.28	38.3
Dec	0.36	11.2	1.16	36.1
Yearly average	1.26	38.2	3.66	111

Table 7. The results for the face 7

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	0.59	18.2	1.52	47.1
Feb	0.86	24	2.18	61
Mar	1.33	41.3	3.40	106
Apr	1.82	54.5	4.80	144
May	2.36	73	6.44	200
Jun	2.53	75.9	7.11	213
Jul	2.57	79.8	7.27	225
Aug	2.23	69.1	6.30	195
Sep	1.67	50.1	4.60	138
Oct	1.09	33.7	2.90	90
Nov	0.73	21.9	1.92	57.5
Dec	0.61	18.9	1.59	49.3
Yearly average	1.54	46.7	4.18	127

Table 8. The results for the face 8

Month	E_d (kWh)	E_m (kWh)	H_d (kWh/m^2)	H_m (kWh/m^2)
Jan	1.07	33.1	1.05	32.6
Feb	1.90	53.3	1.66	46.5
Mar	3.33	103	2.80	86.8
Apr	5.04	151	4.30	129
May	6.90	214	6.06	188
Jun	7.62	228	6.88	206
Jul	7.60	235	6.91	214
Aug	6.24	193	5.68	176
Sep	4.26	128	3.82	114
Oct	2.40	74.5	2.18	67.4
Nov	1.32	39.5	1.28	38.3
Dec	1.18	36.5	1.16	36.1
Yearly average	4.08	124	3.66	111

Table 9. Site and source energy

	Total energy (GJ)	Energy per total building area (MJ/m^2)	Energy per conditioned building area (MJ/m^2)
Total site energy	89.04	593.07	593.07
Net site energy	88.27	587.96	587.96
Total source energy	281.14	1872.64	1872.64
Net source energy	281.14	1872.64	1872.64

Table 10. Site to source conversion factors

	CF
Electricity	3.185
Natural gas	1.092
District cooling	0.762
District heating	1.647
Steam	0.585
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel oil	1.158
Propane	1.151

Table 11. Total end usage of the electricity

	Electricity (GJ)	Water (m^3)
Heating	30.92	---
Cooling	13.67	---
Interior lighting	12.32	---
Interior equipment	20.13	---
Fans	2.01	---
Water systems	9.99	50.73
Total end uses	89.04	50.73

The total annual electricity production and the total annual global irradiation per square meter received by panels for each face can be seen from Figure 6 and 7. As can be seen from Figure 6, the maximum amount of total annual electricity production has occurred in face number 5. Whereas, as can be seen from Figure 7, the amount of total annual global irradiation per square meter received by panels are close to each other for all faces. The total amount of electricity production in a year varies from 382 to 7190 kWh among all surfaces. The amount of total global irradiation per square meter varies from 1340 to 1700 kWh/m^2 among all surfaces. As understood from Figure 6 and 7, although face 3 and 4 receiving more global irradiation, face 5 produces more electricity because of the higher number of panels that used in face 5 and also the surface area of the panels is higher than face 3-4. Furthermore, the lowest electricity production occurs in faces 1 and 6 due to the lowest global irradiation amount received by panels. This result reveals that the direction of the photovoltaic panels is also an important parameter on electricity production in a house with photovoltaic panels. The photovoltaic panels placed through south-facing produces more electricity than which of placed through north-facing because of the angle of the sun.

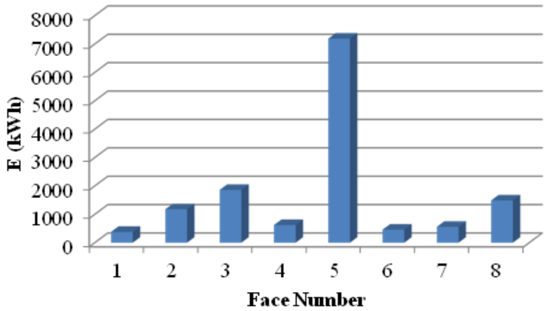

Figure 6. The total annual electricity production for each face

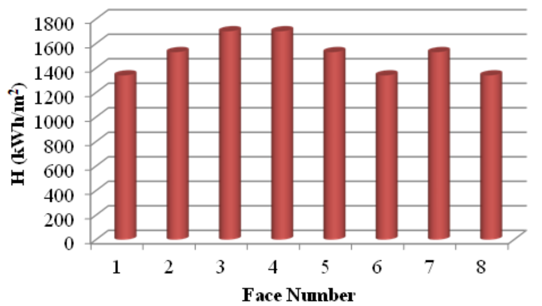

Figure 7. The total annual global irradiation per square meter received by panels for each face

4. CONCLUSIONS

The main purpose of this study is to demonstrate an application of photovoltaic panels on a real house in Turkey. First of all, an existing house is chosen to create a computer model and then to be performed an energy analysis in this study. The house is chosen in Istanbul where the highest energy consumption occurred in Turkey. Furthermore, Sketchup software program is used for modeling and also Skelion plugin program is used for the implementation of the energy analysis in photovoltaic panels. With the help of this plugin program, placing photovoltaic panels on the house, the amount of energy produced with photovoltaic panels is calculated. For the exact electricity production calculation, the coordinates of the house are entered into the program in order to determine the amount of sunlight received by the house.

As can be seen from the results, the yearly average amount of daily electricity production is varied between 1.05 kWh as the minimum value and 19.7 kWh as the maximum value for all facades. The yearly average amount of monthly electricity production is varied between 31.8 kWh as the minimum value and 599 kWh as the maximum value for all facades. The value of the daily sum of global irradiation per square meter is varied from 3.66 to 4.66 kWh/m^2. Moreover, the total site energy of the house is calculated as 89.04 GJ while the net site energy is 88.27 GJ and the total source energy and the net source energy is calculated as 281.14 GJ. The total end usage of the electricity for heating application is calculated 30.92 GJ as the maximum value and it is followed by interior equipment as 201.3 GJ. Some suggestions, which can be made according to the obtained results, are listed below.

- It has been observed that the amount of energy produced through the photovoltaic panels is affected by the solar angle received by the panel, and panels that receive sunlight at a steeper angle will generate more energy.
- The direction of the surface on which the panels are placed has been observed as another parameter affecting the amount of energy generation. The reason for this situation can be stated as the amount and duration of solar rays received by the panels. Accordingly, it can be said that it is more accurate to place the panels on the south-facing surfaces than on the north-facing surfaces.
- Another way to improve the energy generation is to reduce the losses associated with photovoltaic panels. In this study, heat losses and shading losses are the most important factors in energy production, especially due to the application region. These losses are dependent on the region and it is not possible to reduce them by any change. However, in order to reduce the effect of these losses on energy production, it is recommended to minimize the other losses such as cable losses and inverter losses.
- Apart from all external factors, with the development of technology, in terms of electricity production, more efficient panels are produced with different materials day by day. As long-term electricity generation will increase and the need for electricity will decrease with the selection of panels for more efficient electricity generation, more economical results can be obtained in the future.

As future work, it can be suggested that the implementation of the building-integrated photovoltaic system in a house for different inclination angles can be investigated in order to obtain the most efficient inclination angle.

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