Future Energy
Open Access Journal
ISSN 2832-0328

February 2024| Volume 03 | Issue 01 | Pages 01-12

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.3.1.1

Future Publishing LLC

Article

Technical feasibility study of the integration of the solar photovoltaic system for a hospital: a case study of Qom City, Iran

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ARTICLE INFO

Article history:
Received 06 March 2023
Received in revised form
09 April 2023
Accepted 15 April 2023

Keywords:
Photovoltaic systems, Solar panels,
Energy saving, Hot and dry climate, Building

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DOI: 10.55670/fpll.fuen.3.1.1

ABSTRACT

The purpose of the study is to investigate the overall effect of photovoltaic (PV) systems located on the roof and window shades on reducing the amount of heating and cooling energy consumption of a hospital in Qom, Iran. The use of solar panels on the roof and windows, in addition to producing Electric power and reduction of electricity consumption, causes shadows on the roof and windows. The created shadow can reduce the energy consumption of heating and cooling systems in particular. In addition, the electrical energy obtained from the solar panels can be used for the purpose of using the hospital lighting system. The thermal simulation for a six-story hospital with an area of 5000 thousand square meters in Qom, located in Iran, was modeled by the Energy Plus simulation engine. Given that 80% of the roof can be used for solar panels. The obtained results show that the use of photovoltaic systems on the roof and window shades can save cooling energy consumption by 18% per year and 32% in summer. In addition, the use of solar panels saves 15% of the electric energy consumption of the fan coil and 30% of the chillers.

1. Introduction

Air conditioning systems (HVAC) are milestones in the construction of mechanical building systems that provide comfort for occupants, along with indoor air quality. Ventilation systems can be classified into central and local systems according to different regions, locations, and distribution. Basic HVAC equipment includes heating equipment, ventilation equipment, and cooling or air-conditioning equipment. The discussion of the use of air conditioning systems and energy sustainability is one of the most used and also popular fields in the world. Especially in large and multi-storied buildings, where the need for air conditioning and comfort for the residents is very important [1]. In the past decades, in Iran, we have seen the rapid growth of the population and the increase in energy demand, which has made the energy supply for this country a challenge [2]. Accordingly, according to the reports of the Energy Information Administration of the United States of America (EIA), according to the latest statistics provided under the title of energy balance, household electrical energy consumption in Iran in 2022 is estimated to be 1058 kilowatt hours per person [3] and about 12 gigawatts of additional capacity. It is required to consume electrical energy to meet the estimated growing demand. The residential sector in Iran alone accounts for 42% of the electricity consumed [4]. In 2017, Khan et al. [5] used a plan based on the use of clean energy and air conditioning systems in Saudi Arabia, and the results obtained in these studies showed that this country, throughout history, has used energy to meet all its energy needs. It has been relying on fossil fuels [6], which causes enormous energy, environmental and economic tensions in Saudi Arabia. In the research conducted by Homan Azad Gilani et al. [7], installing a PV system on a five-floor building in Cyprus reduces approximately 14 tons of CO_2 every year. According to Hutchins's research [8], solar energy will become the most important renewable source by 2030. Meng Li's research [9] showed that the maximum temperature difference between the exterior and interior is approximately 16 degrees Celsius in summer and 35.03 degrees Celsius in winter. Research by Alessandro et al. [10] shows that the use of photovoltaic glass reduces high values (DGP > 0.45) in energy consumption by about 12-23%, depending on the location. An economic analysis by MG Surgato et al in 2018 showed that replacing conventional building materials with PV modules is not only an innovative approach but also has economic benefits [11]. In the research and design conducted by Ricardo Mateos et al. [12] in Portugal, from the results, it can be concluded that annually and for the climate of Portugal, it is possible to meet many energy needs for adaptation and preparation by using photovoltaic systems. Domestic hot water production prevailed. In a 2021 survey conducted by Hassan Alhammi et al. [13] in the UAE for a typical residence, a rooftop photovoltaic system covers 11-20% of the annual electricity demand. Evaluating the potential of solar energy through the installation of photovoltaic systems on the roof was the basis for research researchers to investigate and study the way to produce electrical energy and reduce the cooling load and energy loss. Among the researchers, Gautam et al. [14], Heng et al. [15], Kartris et al. [16], Asif et al. [17], Modaser Hassan Arslan et al. [18] investigated the overall contribution of using solar panels for the production of electrical energy. Moreover, Peng et al. [19], Zhang et al. [20], and Wang et al. [21] investigated the effect of using PV solar panels on the roof in terms of reducing the cooling load. In the research of Aiman Albatayneh et al. [22], the results showed that the PV roof structure caused a 10.87% reduction in heat gain during summer and a 3.8% increase in heat loss during winter in Jordan. According to the research of I. Montero et al. [23] in 2022 on hospitals in southwestern Europe, by using 30-50% of the roof surface to use solar panels, an average of 25-30% of the annual electricity demand can be covered. and potentially reduced CO_2 emissions. According to Dengjia Wang et al. [24], in the country of Pine, buildings with horizontally installed PV roofs have the highest efficiency in the summer season, while buildings with sloping PV roofs have the highest efficiency in the winter season. In another review, JunchenYan et al. [25], PV systems can help an average office in Atlanta to reduce 46% of the impact of global warming, 98% of water consumption, 93% of the impact of acidification, etc. reduce. In all the research, the way to produce electrical energy and reduce the cooling load has been done by installing solar panels on the roof. But solar panels have the ability to be installed on different parts of the building, including windows, window shades, on the wall... for different uses.

In this study, a hospital with an area of 5000 square meters and six floors in the city of Qom, Iran, was investigated. Modeling was done with the help of a variety of computational and analytical software on the hospital building for modeling cooling and heating loads and the amount of electrical energy consumed. Also, the issue of using photovoltaic panels on the roof and windows as shades and their effect on reducing the cooling load of the hospital and the electrical energy produced by the panels was studied and investigated. Due to the high initial cost of buying and maintaining panels, it may reduce the tendency to use solar panels. In this study, the discussion of economic evaluation for the use of panels was also examined.

The key objectives of the study are:

- Application of PV on the roof of the hospital
- Calculation of energy output from PV systems
- Estimate the effect of PV on the heating and cooling loads of the hospital.

The geographic location and weather information have been estimated with the help of Meteonorm software, and the direct and indirect benefits of solar panels (PV) were measured in terms of saving the cooling load of the hospital, and the roof modeling was done with the help of SketchUp software, and the analysis and calculations of heating loads and Cooling was done by EnergyPlus software, and economic evaluation has been done.

2. Research approach

In this study, a multi-step research approach to determine the application prospects of photovoltaic (PV) systems in the hospital building was investigated. The studied hospital, located in Qom province of Iran, was evaluated in four research blocks, which are:

- Evaluation and estimation of roof area and window size for the use of PV systems.
- Electric power generation
- Reducing electrical energy consumption.

Adopting a detailed approach based on advanced computational and modeling techniques along with a systematic detailed examination of the nature of the hospital roof and the effective feature on the application of solar PV systems.

3. The ability to use the roof of the building for PV application

During the last few decades, the use of PV systems has gained many fans in urban buildings around the world. All over the world, due to the reduction of pollution, extensive regulations and policies have been adopted for the use of PV systems in buildings [26], PV systems can be installed on the roof, on the facade of the building, on the window shades and on the windows. Used as a thin and layered coating. In this article, the conditions of the roof and the location of the hospital were first studied through satellite photos and field visits. Then the area of the hospital was measured, and the materials used in the hospital were examined and validated, and the main limitations of using PV and installing it on the roof were identified and divided into five main categories [27]:

- Structural constraints;
- Limitation of services;
- Access restriction;
- Maintenance limitation;
- Shadow limitations.

All the barriers and their sub-branches have been examined in Table 1.

In order to calculate the heat transfer coefficient (UF) for the hospital building, five categories of quantitative barriers are shown. Structure coefficient (Cstr), service coefficient (Cser), maintenance and access coefficient (Cacc), shade coefficient (Csh), and finally, a coefficient for other types of roof use are shown for several floors of the building in Table 2 has been calculated.

4. Weather data

The city of Qom is located 140 km south of Tehran, the capital of Iran, which has a regional meteorological station. In the study conducted, Qom city has a desert climate and a dry and semi-arid climate with very hot summers and mild and cool winters. Geographically, Qom province with an area of 11238 square kilometers in the central corridor of Iran between the geographical coordinates of 50 degrees and 6 minutes to 51 degrees and 58 minutes of eastern longitude compared to the Greenwich meridian and 34 degrees and 9 minutes to 35 degrees and 11 minutes of northern latitude compared to the equator. The average temperature in the last

38 years shows that the hottest month is July, with an average temperature of 34 degrees, although with the climate information in 2022, this temperature has reached 42 degrees, and the coldest month of the year is January, with an average temperature of minus 3 degrees Celsius. According to statistics and information, the average annual rainfall in Qom province is 135 mm. The weather information of Qom City is shown in Table 3.

Table1. Classification of main constraints

Components	Classification
Structural limitations	The parapet wall Attachments Vestibular shafts Stairway, pillar The rebar's The geometry of the roof
Limitations of the service	Water tanks (AC) Package units Dish antennas (AC) Condensers Water boilers
Access limitations	close access Row spacing
Shading restrictions	Effect of the height of parapet walls attachments The walls of the vestibule shaft Stairway Components of the Service
Other services	The yard

Table2. Heat transfer coefficient (UF) classification

Coefficient	Value
C_{str}	0.85
C_{ser}	0.57
C_{acc}	0.67
C_{sh}	0.90
other	0.75

In Figure 1-a, the amount of global radiation and the amount of its dispersion in different months of the year for the past years of Qom city have been measured and calculated. Figure 1-b shows the duration of intense and astronomical sunlight for different months of the year, which with an average of 12 hours of daily sunlight and 7.5 hours of astronomical sunlight, shows the high potential of Qom City in the field of using solar panels. Figure 1-c shows the maximum and minimum daily temperature of Qom City in different months, the lowest temperature in winter reaches minus 5 degrees, and the maximum temperature reaches 45 degrees in summer. The average of the hottest month of the year reaches 34 degrees, but in the last 5 years, due to the overheated earth, the average of the hot summer months reached 42 degrees. Figure 1-d shows the amount of precipitation and the number of days of precipitation in different months of Qom province, the highest precipitation is in January, with 24 mm, and the lowest is in August, with less than 2 mm. The average rainfall of 135 mm per year and the average rainfall of 2.2 days per month indicates that Qom City is dry and low in rainfall, which causes the installed panels to become dusty and dirty and increases the cost of maintenance. Figure 1-e shows the temperature of Qom City in different months in the form of candles, the highest temperature, 45 degrees, was recorded in July, and the lowest temperature, minus 5 degrees, was recorded in January. Figure 1-f shows the daily radiation of the sun in different months; the highest radiation is related to the hot months of the year and in summer, which shows an average of 7.5-kilowatt hours per square meter.

5. Hospital structural details

The desired building consists of six floors flat roof, and insulated by Izogam, with an area of 5000 square meters and the height of each floor is 3 meters. In Table 4, the key features of the hospital building are given. Figure 2 represents the real image of Imam Reza Hospital in Qom City with a stone facade and glass windows with iron frames and lighting from four sides in an area of 5000 square meters. The specifications of the walls and ceiling and the materials used, and other specifications are shown in Table 5.

6. Total energy contribution from PV systems

The overall contribution of the energy resulting from the use of photovoltaic systems includes the output power in the production and saving of electrical energy, and as a result, the reduction of the cooling load due to the shadow effect created by the panels, which is modeled by TRNSYS software and the results of the modeling are measured. The hospital building was designed using Sketch Up software with the Openstudio plugin.

- Calculation of building thermal loads
- Features of calculating the thermal load of windows by EnergyPlus are:
- Layer-by-layer glass entrance
- External and internal windows
- Modeling of frames and partitions
- Internal and external mobile awning devices
- Electrochromic simulation
- Anisotropic sky model for radiation calculation
- Direct solar shade
- The shadow of the long sky wave
- Tracking where sunlight enters the room from windows.
- Daylight through the windows

The solar radiation that is refracted by a system of glass layers of the window and the solar radiation absorbed in each layer depends on the properties of the sun's passage and its reflection. In EnergyPlus, the optical properties of individual glass layers are provided with the following values.
Normally:

- (T) Transfer
- (R_F) radiation reflection from the outside of the glass
- (R_b) radiation reflection from the inner side of the glass

Table3. Weather information of the city of Qom

Months	G_h(kWh/m²)	D_h(kWh/m²)	B_n(kWh/m²)	T_a(°C)	T_d(°C)	FF(m/s)
January	106	23	196	4.9	2.9-	0.9
February	116	32	164	8	2.3-	1.2
March	150	56	159	14	-0.7	1.8
April	175	70	161	19.3	3.2	1.9
Fog	210	78	188	25.5	5.4	2.1
June	237	68	236	31.1	5.4	2
June	236	70	232	33.7	7.3	2.1
August	221	60	233	32	6.5	1.8
September	189	41	242	27.4	4.9	1.4
October	146	38	196	20.5	4	1.1
November	104	29	167	11.5	1.4	0.9
December	95	22	174	6.3	1-	0.8

Table4. Key characteristics of the model building

Features	Value
The number of floors	6
Roof area (m²)	5000
The height of the parapet wall (m)	3
Annual cooling energy consumption (kWh)	72/21
Annual energy use for heating (kWh)	52129/29

Assumptions:

- The glass layers are thin enough (a few millimeters).
- The heat flow is perpendicular to the face of the glass and one-dimensional.
- The glass layers are opaque to the long wave radiation.
- Glass panels are isothermal. This is generally a good assumption because glass has a very high conductivity.
- The short-wave radiation absorbed in a glass layer can be divided equally into two layer surfaces.

The four equations for double glazing are as follows. (The single-wall equations are N=1 and for N=3 and N=4. The characteristics of hospital walls are shown in Table 5. The thermal balance of the thermal zone of the building without an HVAC system can be expressed by Eqs.1-2.

$$Q_{STB} = Q_{inf} + Q_{s.i} = C_a \frac{dT}{dt} \quad (1)$$

$$Q_{s.i} = Q_s + Q_w + Q_n + Q_e + Q_f + Q_r + Q_{g.i} \quad (2)$$

Eq.3 shows the thermal balance in the inner surfaces.

$$q_{sol.i} + q_{lw.i} + q_{cv.i} + q_{cd.i} = 0 \quad (3)$$

Table5. Basic hospital characteristics

Building feature	Description
Location	Qom
Tendency	Main elevation facing north
Exterior walls	15 mm internal stone facade / 30 cm reinforced concrete wall / 25 cm external stone facade
Roof	5 mm false ceiling / 30 cm ceiling unolite / 5 cm concrete / 25 mm granite stone
Windows	Single pane window with iron frame
lighting	6.78 (w/m²)

where $q_{sol.i}$ is the solar radiation transmitted through walls and windows that is absorbed by the interior surface, $q_{lw.i}$ is the net heat flux of long-wave radiative exchange between building surfaces, $q_{cv.i}$ is the convective flux to the air in the area, and qcd.i is the conduction heat flux through the wall at the surface of the interface with the air in the region. The internal convective heat flux is calculated as a function of the convective heat transfer of the internal surface. which is expressed in Eqs.4-5:

$$q_{cv.i} = h_{cv.i}(T_{s.i} - T_{a.i}) \quad (4)$$

$$h_{cv.i} = k(T_{s.i} - T_{a.i})^Y \quad (5)$$

The radiation absorbed by a surface that is absorbed by another general surface, taking into account all possible paths, as well as multiple reflections. The net long wave radiation absorbed is calculated in the form of a matrix, which is expressed by Eq.6:

$$Q_{lw.i} = \left(I - G_{lw}^T\right)A\varepsilon\sigma T^4 = \{I - [(I - F_{\rho lw})^{-1}F_{\varepsilon lw}]^T\}A\varepsilon\sigma T^4 \quad (6)$$

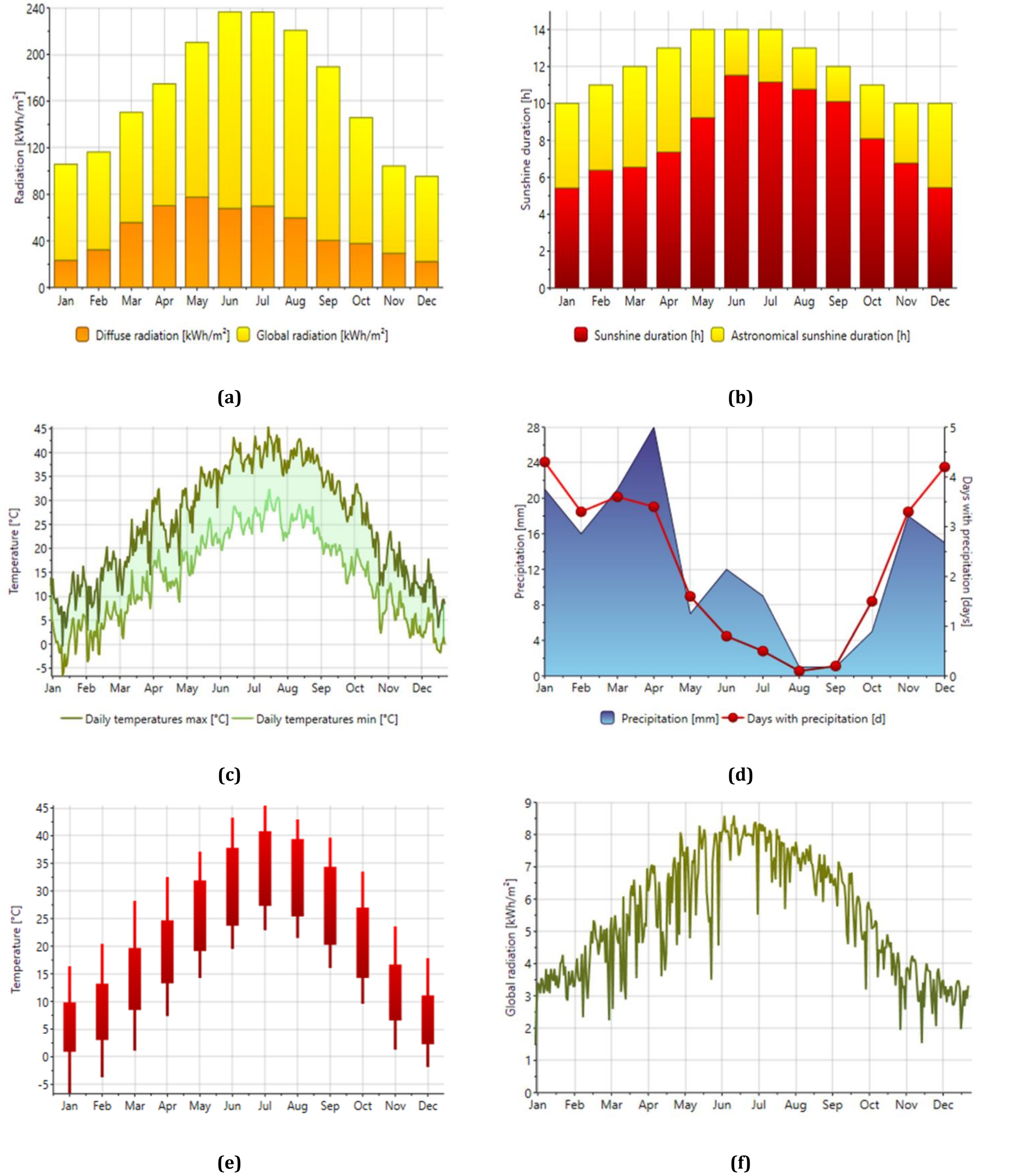


Figure 1. Weather information of the city of Qom

(a) Amount of radiation in Qom city, (b) Qom sunshine period, (c) Maximum and minimum daily temperature of Qom city, (d) Amount of precipitation in Qom city, (e) Qom city temperature, and (f) Daily radiation of Qom

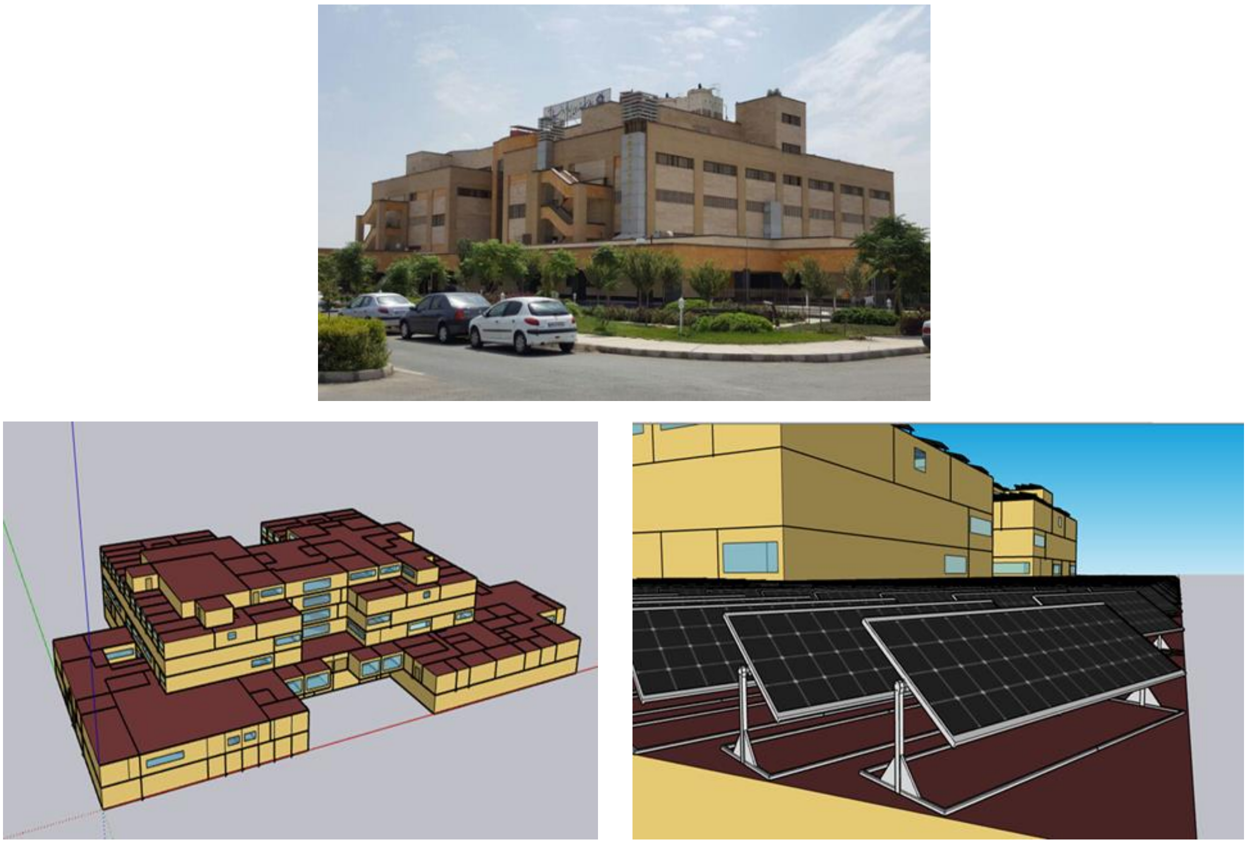


Figure 2. Imam Reza Hospital, Qom (a) Main view, (b) The modeled view of the hospital by Sketchup and (c) View of panels installed in the model

Eq.7 shows the thermal balance on the outer surfaces:

$$q_{sol.e} + q_{lw.e} + q_{cv.e} + q_{cd.e} = 0 \quad (7)$$

Eqs.8-9 show the external convective heat flux as a function of the convective heat transfer of the external surface.

$$q_{cv.e} = h_{cv.e}(T_{s.e} - T_{a.e}) \quad (8)$$

$$h_{cv.e} = 5.678\left[a + b\left(\frac{V}{0.3048}\right)^{c}\right] \quad (9)$$

The local wind speed V on the lee side is calculated as a function of the free stream wind speed by Eq.10:

$$V = 0.3 + 0.05V_f \quad (10)$$

7. Modeling of photovoltaic systems

Photovoltaic system design and simulation were done with the help of TRNSYS 18 software, this software allows the user to perform two-dimensional or three-dimensional modeling. The software requires user inputs for the array and inverter details, such as the number of modules, installation conditions, tilt, and direction, as well as shading. On the other hand, the 3D design option provides the possibility to create the complete geometry of the building. The hospital roof was considered a normal flat roof, and the space occupied by the obstacles on the roof was calculated and included in the modeling. The next step included the selection of PV systems, including PV module type, orientation, and tilt angle for roof and windows.

The type of module was selected based on performance as well as regional considerations and which among the wide range of PV modules available in the market is suitable for the type of hospital building and the city's climate. The modules (PV) are monocrystalline silicon type with 15.2% efficiency and 961 kW output, and the module area is 3 square meters. Table 6 shows the details of the solar panel. In terms of installation (PV), the geographical direction at the optimal tilt angle of 34 degrees and also the tilt with the horizon angle of 0 degrees were examined and according to the dimensions (PV) the distance between the rows was optimized (Table 7, Figure 3) [21].

Table6. PV modules technical details

Parameter	Description
Cell type	monocrystal
Output power of the panel	961 Kwh
Panel area	3 m^2

8. Results and discussion

The impact of PV on the energy performance of the building was investigated and different scenarios and factors were considered to determine the energy savings associated with photovoltaic systems. In order to evaluate all the energy, a building model was designed according to the hospital data in Sketch Up software, then, despite the different rooms and corridors, each of the spaces was considered as a thermal zone, and the type of building designed in the software was considered as a hospital. was taken, and Energy Plus software was used for appropriate analysis and modeling. Modeling in Energy Plus starts by entering the weather information and the location of the desired city, and then by entering the desired data, the energy required for the cooling and heating load, and the electricity required for the fan coil and chillers for a full year and monthly output. Table 8 shows the loads and electricity consumption of different months of the hospital, expressed in kilowatt-hours. In addition to the production of electrical energy by the panels on the roof and windows, their performance on the energy of the building was also investigated due to the shadowing on the roof and windows. Photovoltaic systems, in this case, act as a barrier and an additional layer against direct sunlight and penetration on the roof structure and windows. monthly output became. Figure 4 shows the amount of energy savings for the hospital air conditioning systems. According to the obtained results, the use of solar panels on the roof can save up to 28% in the cooling energy of the fan coil in the hot summer months. In addition, using solar panels on the roof and windows saves 16% on average in the hot months of the year.

Of course, this amount of savings is also available for the rest of the months of the year. Another advantage of using solar panels is reducing the power consumption of chillers. For example, in the case where the panels are installed as shades on the windows, it brings about 30% reduction in consumption for a year. Of course, the use of solar panels on the roof increases this amount to about 40 percent. This indirect contribution of photovoltaic systems has rarely been studied, which can be used in hot and semi-arid regions due to the global approach to the use of clean energy and energy saving, which results in reducing the cooling load. In the Energy plus simulation environment, the performance of using the photovoltaic system as a shade was evaluated, and then by entering the required data, the required energy for the cooling and heating load and the electrical energy required for the fan coil and chillers for a full year and monthly output became. The ready-hand result from the simulation shows an 18% saving in the cooling load and a 15% reduction in electric energy consumption by fan coils and 30% by chillers throughout the year, which are shown in Tables 9-11 for different months of the year separately and also the simultaneous use of panels on the roof and window shades has been shown.

Table7. Structural features of the solar panel

Referral	Value
Module installation width (b)	3 m
Panel height (h)	1 m
Panel angle (ß)	34°
Module orientation	180°
Distance between rows (d-d1)	0.72 m
Mounting support distance (d1)	0.4 m
row spacing (d)	1.1 m

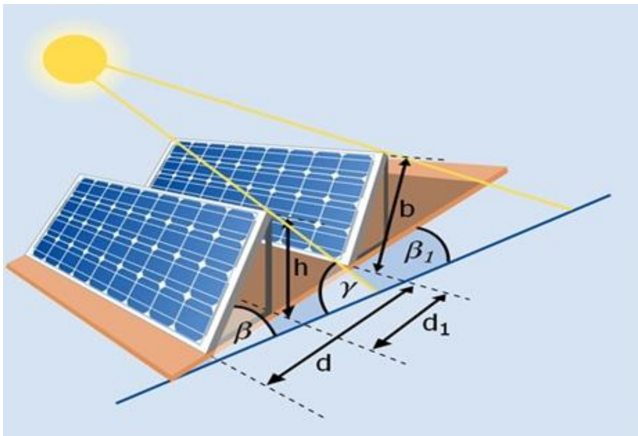


Figure 3. Solar panel structural form

Table8. The amount of the loads and the annual electric energy consumption of the hospital in different months (kWh)

Months	Fan coil heating energy	Fan coil cooling energy	Fan coil electrical energy	Chiller electrical energy
January	6981.52	127416.45	3848.04	5103.98
February	3349.40	119856.92	3475.65	9273.64
March	571.5	146031.67	3849.12	22298.07
April	250.5	166399.36	3723.91	37902.6
May	1362.91	194241.24	3847.36	62426.37
June	2367.6	231082.67	3730.91	78173.39
July	3342.9	258775.74	3848.04	90117.4
August	3145.12	241893.70	3848.04	83185.52
September	1316.66	209895.61	3723.9	67974.56
October	366.52	176108.73	3848.04	47619.1
November	1063.25	139328.52	3723.9	17539.7
December	5389.64	130426.10	3848.04	8132.44

Table9. The amount of the loads and annual electrical energy consumption of the hospital using PV on the roof (kWh)

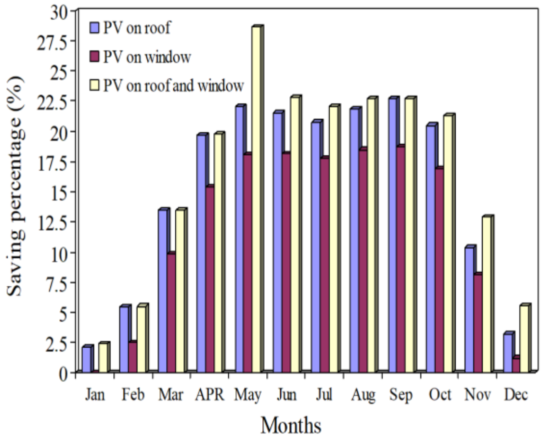
Months	Fan coil heating energy	Fan coil cooling energy	Fan coil electrical energy	Chiller electrical energy
January	6287.95	124675.43	3333.86	1230.05
February	3279.91	113285.46	3011.23	3905.87
March	624.72	126375.84	3333.86	12052.40
April	270.85	133689.63	3226.31	24981.32
May	1397.92	151387.88	3333.86	46749.59
June	2414.13	181345.31	3226.31	66361.21
July	3397.37	205059.70	3333.86	76852.08
August	3199.02	188957.10	3333.86	70665.18
September	1344.55	162256.41	3226.31	58245.53
October	373.99	140041.30	3333.86	30138.97
November	1120.09	124886.51	3226.31	9118.11
December	4975.56	126211.82	3333.86	2133.68

Table10. The amount of the loads and the annual electrical energy consumption of the hospital using PV above the windows (kWh)

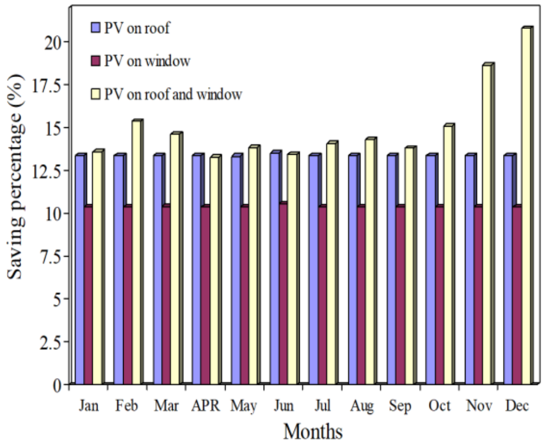
Months	Fan coil heating energy	Fan coil cooling energy	Fan coil electrical energy	Chiller electrical energy
January	6052.9	127770.38	3448.38	2347.7
February	3135.96	116814.9	3114.67	5813.07
March	599.79	131685.33	3448.38	15100.2
April	250.9	140831.66	3337.15	28533.77
May	1347.53	159243.96	3448.38	51007.19
June	2328.25	189090.05	3337.15	69053.13
July	3312.07	212768.78	3448.38	79356.02
August	3124.44	197169.54	3448.38	73329.23
September	1305.16	170553.98	3337.15	58018.77
October	367.97	146326.63	3448.38	33880.45
November	1131.34	128023.21	3337.15	11136.82
December	4855.61	128831.3	3448.38	3823.69

Table11. The amount of the loads and the annual electrical energy consumption of the hospital using PV on the roof and windows (kWh)

Months	Fan coil heating energy	Fan coil cooling energy	Fan coil electrical energy	Chiller electrical energy
January	6636.77	124324.04	3325.28	1186.01
February	3306.55	113245.14	2942.31	3899.90
March	654.05	126315.39	3287.28	12029.27
April	264.68	133460.24	3229.62	23672.90
May	1383.43	138618.97	3315.28	42512.78
June	2374.11	178312.57	3229.62	62190.26
July	3368.26	201719.78	3306.28	73815.30
August	3194.38	186898.34	3298.28	68684.42
September	1343.14	162145.96	3209.62	44316.53
October	378.99	138603.06	3267.28	30127.73
November	1189.13	121397.91	3029.62	8428.05
December	5023.09	123206.17	3047.28	2137.90



(a)



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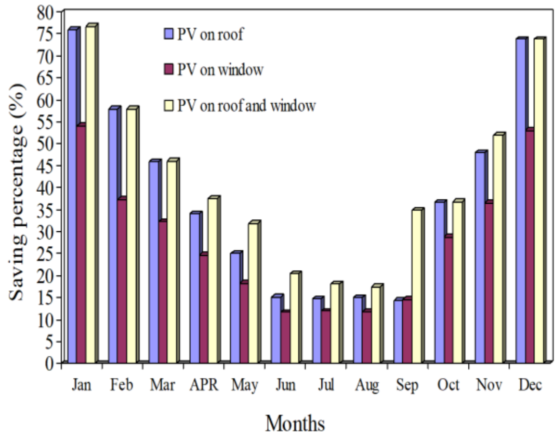

(c)

Figure 4. The energy saving rate of the hospital (a) Cooling energy, (b) Electric energy of the fan coil and (c) Chiller electrical energy

8.1 Energy production at the unit scale

You can see the modeled view of the hospital in the Sketch Up software, with the help of which the specific thermal spaces and the thermal and cooling loads were calculated in Figure 3. According to the simulation of solar panels for the hospital using TRNSYS 18 software, electricity generation was done according to the weather conditions of Qom province of Iran and the slope of 34 degrees of the panel and zero degrees of the roof. The production of electricity from photovoltaic systems in a sample building with dimensions of 3:1 and according to the daily solar radiation throughout the year for each panel is 961 kWh [28]. Figure 5 shows the power of producing electrical energy by a panel with the dimensions and characteristics specified in Table 7 according to the temperatures and heat transfer rates at different times of the year, and according to the climate diagrams, the most electrical energy production takes place during the peak of the solar radiation.

8.2 The share of net energy in using photovoltaic systems

In the energy simulation performed for the hospital building as shown in Table 8, the total cooling and heating load was calculated for the whole year, and it was calculated according to the shading on the roof and windows by photovoltaic systems, and the saving in the field of reducing the cooling load was investigated. The electric energy produced by the photovoltaic systems installed on the roof and the window awnings was calculated and the results obtained were placed in Table 12. According to the obtained results, the electrical energy produced by photovoltaic systems produces 43% of the electricity used for the cooling and heating load for a six-story hospital with an area of 5000 square meters, and also from the indirect use of PV panels, 18% of the cooling load is saved. This amount alone is equal to 51% of the electrical energy produced by photovoltaic systems in the building.

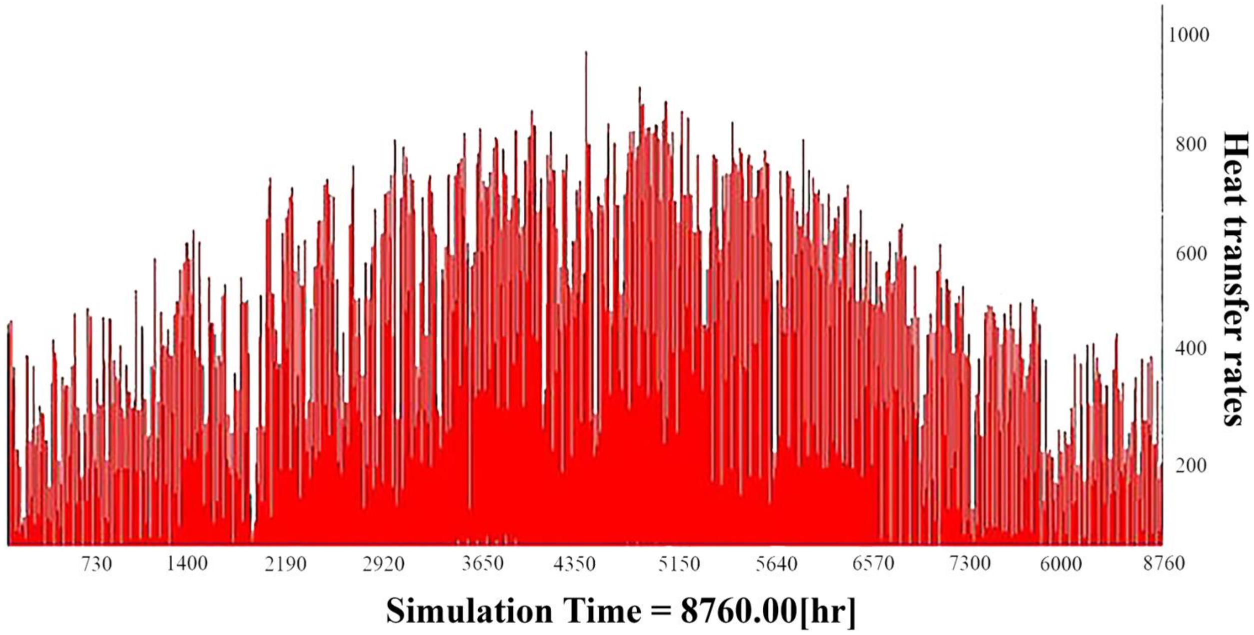

Figure 5. Power generation

Table12. Annual energy consumption of the hospital and production power by panels (kWh)

Cooling and heating load of the hospital	Cooling and heating loads with PV on roof and windows	Energy saving rate (%)	Electricity produced by solar panels
2170967.24	1777364.16	18.13	76800

Considering that only PV panels can be placed on the roof and window awnings in the hospital, this system has a much higher efficiency in buildings with a large area, so it can't only supply all the electricity required for the cooling, heating and electrical loads. but you can sell the extra electricity produced by the panels [29].

9. Conclusion

This modeling examines the overall contribution of energy produced by photovoltaic systems on the roof and window canopy in a six-story hospital in a hot and dry climate, as well as the impact on the building's cooling and heating energy performance. By examining the power of photovoltaic systems in producing and saving electrical energy and reducing the cooling load due to the shading effect of the panels, Imam Reza (AS) Hospital in six floors and an area of 5000 square meters in the city of Qom, Iran was studied. At first, the conditions of the roof and the location of the hospital were studied through satellite images and field visits, then the area of the hospital was measured, and the materials used in the hospital were examined and validated, as well as the main limitations for the use of solar panels (PV) and Installation on the roof were identified and divided into five main categories: 1- Structural limitations 2- Service limitations 3- Access limitations 4- Maintenance limitations 5- Shadow limitations etc.

The results of detailed modeling done with the help of TRNSYS software show that the PV systems in the designed dimensions produce 961-kilowatt hours per year. The results obtained from building energy modeling, which was done by Energy Plus software, show that the effect of shadows created by photovoltaic panels on the roof and above the windows reduces the cooling load by 18% per year and by 32% in the hot months. Considering the high costs of installing photovoltaic systems, it seems that it is not a good idea to use them in buildings, but the obtained results of modeling the use of panels in buildings, it shows that the initial capital returns in the early years. In buildings with fewer floors and more infrastructure, the effect of using photovoltaic systems is more visible, as it not only has the ability to produce all the electrical energy required for the load of cooling, heating, and electrical appliances, Rather, it is possible to sell the excess electrical energy produced by the panels.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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