QATAR UNIVERSITY

COLLEGE OF ENGINEERING

USING SOLAR ENERGY IN ELECTRIFICATION: A CASE OF AN OFFICE BUILDING IN QATAR

BY

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ABSTRACT

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Title: Using Solar Energy in Electrification: A Case of an Office Building in Qatar

Supervisor of Project: Shaligram, Pokharel.

Solar energy is being converted to electricity either for grid transmission or for localized use in houses, offices or in community places. In this project, the availability of solar energy in Qatar in studied and its potential to meet some of the lights during daytime for an office building is explored. The availability of solar energy for conversion to electricity is dependent on many factors: solar irradiance, latitude of the place, the shade angle, the area available for solar PV installation, the type of solar PV cells used, the watt-peak module selected and the efficiency of the inverter. As the focus of this project is on day time provisions for meeting lighting energy, the system does not consider any battery. The analysis shows that in an office building (3 floors; basement, ground, and first floor, with 4133 m^2, 18127 m^2, 9940 m^2 area respectively, with 407 offices and the rest for hallways. The total annual demand is 16,000,000 kWh. The roof area is chosen for the installation of the solar PVs using monocrystalline type of solar PV. The available roof area considered in this report is 21274 m^2 for PV installation. The analysis shows that if the PV system, it can meet about 93% (or 5904 kWh) of daily electricity demand for lighting during daytime. The economic analysis of two scenarios were done to calculate the PV system installing cost and the payback period; the first was considering 893 USD/KW (3259.4 QR/KW) which resulted in 14 years as a payback, while the second scenario was Considering 932 USD/KW (3401.8 QR/KW) which resulted in 19 years as a payback. Comparing both Scenarios, it is

indicated that the higher the costs are, the larger the payback period gets

DEDICATION

To my beloved family, husband, and son, I dedicate this project to you. Your support has been my guiding light throughout this journey. Thank you for being my source of inspiration, motivation and for always standing by me.

ACKNOWLEDGMENTS

I would like to thank Prof. Shaligram Pokharel, my supervisor, for supporting me on this project. During my project, my supervisor provided me with tremendous advice, guidance, inspiration, and knowledge.

I also would like to thank my parents for their never-ending support, encouragement, and care. I am also thankful for all the support and encouragement from my husband during the whole period of my Master program in the university.

Finally, I acknowledge that this project work for the Master in Engineering Management was solely done by myself, although some of the data used in the project are based on my work organization. All the analyses, outcomes, and recommendations are the sole responsibilities of the author.

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CHAPTER 1: INTRODUCTION

The energy required in the buildings, specifically in the office buildings, may be reduced by using renewable energy. Governments have been attempting to conserve energy where possible (Hewitt et al., 2019) to reduce their carbon footprint and utilize alternative energy sources. Energy consumption can also be reduced by using architectural and structural principles for maximum use of solar light during the daytime and modern insulation materials on the structure. These energy initiatives can support energy conservation (Haffaf et al., 2021).

Depending on the resources available and the technology available, different types of renewable energy technologies such as solar, wind, ocean wave, and biogas could be considered. However, their use depends on the feasibility of the technology and the continuity in terms of resource availability. In Qatar, solar can be the promising energy source, due to higher irradiance, longer daytime hours, a drier environment, and reduction in the technology cost.

1.2 Problem Statement

Consumption of electricity has been a challenge due to the cost of electricity and the awareness of carbon footprint. The grid electricity in Qatar comes from burning natural gas The recent global interest in climate change has also created some renewed focus on reducing carbon footprints (Gueymard et al., 2019). A move to reduce carbon footprint is also considered ethical and part of the social responsibility mandate for organizations (Rosales-Asensio et al., 2019).

The problem being addressed in this project report is to evaluate the possibility of reducing grid-based electricity consumption in an office building through solar energy.

1.3 Objective

The objective of this project report is to evaluate the prospect of using solar photovoltaics to generate and supply daytime electricity for an office building in Qatar.

1.4 Scope

Scope in:

- The study will consider the electricity consumption for the lighting the day shift only (8-hours).

Scope out:

- The study will exclude the use of batteries.
- The study will exclude the analysis of electricity consumption from the grid for nighttime lighting and other electricity-use.

1.5 Project Report Organization

This rest of the project report is organized as follows. The next chapter provides literature review which refers to multiple studies on implementing solar energy in one of the office buildings in Qatar. The third chapter provides data collection and analysis chapter, which presents the data collected from various sources and analysis done for solar PV-based electricity generation. The analysis of electricity generation and economic analysis is also provided in this chapter. The last chapter provides the conclusion. The project outcomes and limitations are also given in this chapter.

CHAPTER 2: LITERATURE REVIEW

Various aspects of solar energy are reviewed here. The technical and financial analysis are also given.

2.1 Solar Photovoltaic (PV)

Photovoltaics (PV) cells are made of different materials and convert solar irradiance electricity (Sultan & Efzan, 2018). The production of these PV cells has evolved significantly in recent years due to the advancement in technology.

The cost of photovoltaics has also steadily decreased due to technological improvements, and the increased scale of manufacturing (Sultan & Efzan, 2018). It is estimated that the investments in solar can be recovered to as little as three years, when total lifecycle costs of other sources are compared.

2.2 Solar Energy

Four steps for noting how solar panels make electricity are explained below (Solar 101: How Solar energy works, Step-by-step, 2022). Each of these steps are briefly mentioned below.

The stimulation of the panel by sunlight is the initial phase. Each panel comprises a wire, silicon cell layers, a metal border, a glass case covered in a clear glaze, and a glass casing. For best results, the meetings are set up in "arrays" (an ordered series) and held outside in large open spaces or on rooftops to capture solar lights.

In the second step, the cell creates an electrical current: each solar cell entails a thin silicon semiconductor device with two silicon layers. Two positively and negatively charged layers combine to form an electric field. Solar light energy stimulates a photovoltaic solar cell and causes electrons to "loosen" from atoms within the semiconductor cracker. The electric field around cracker alters those unrestricted electrons, and this progression results in an electric current.

In the third step, solar energy is converted to direct current (DC) electrical energy DC is converted into the alternating current (AC) through an inverter.

In step four, generated electricity is integrated with the electrical system. If this electricity does not meet the demand, additional electricity needs to be obtained from other sources such as grid connected electricity. However, if it is more, there could be an option to transmit the extra electricity to the grid system.

2.3 Solar Energy in Qatar

Qatar receives about 2,140 kWh per m^2 per year of horizontal irradiance (Zafar, 2021). The country is geologically well-positioned to utilize solar energy maximum normal irradiance (DNI) of about 2,008 kWh per m^2 annually(Zafar, 2021). Figure 2.1 is a map of solar radiation in Qatar

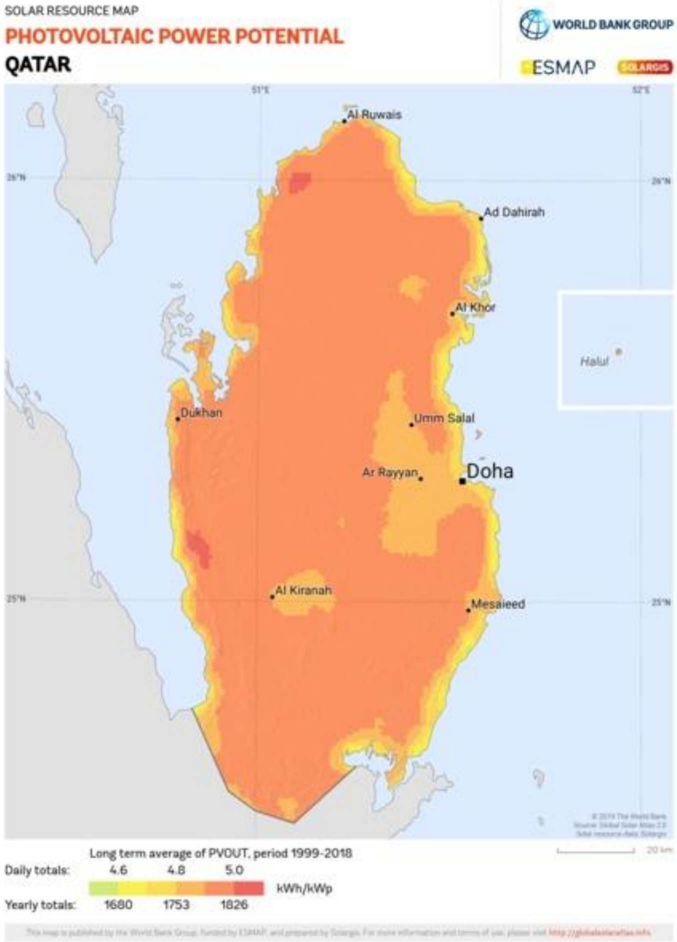


Figure 2.1 Map of solar radiation in Qatar (Solar Resource Maps of Qatar, 2022)

The daily irradiation in Qatar is approximately 9.5 hours; most sun irradiation is received in June, followed by May and July. Sun radiation is at its lowest in December and January(Al-Thani, 2022). The mean global radiation and the daily temperature of Qatar are shown in Table 2.1 below. The impact of temperature on the voltage in a solar electric system comes from an essential feature of crystalline silicon cell-based modules, which produce higher voltage with a drop in temperature and, reverse happens when there is high temperature (Electrical Characteristics of Solar Panels, 2022). Therefore, every solar system or panel has to consider the effect of temperature on electricity generation. Figure 2.2 shows the effect of temperature on the I-V characteristics.

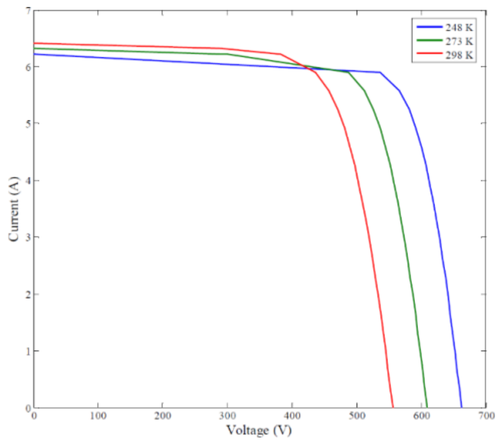


Figure 2.2 Effect of temperature on the I-V characteristics of the typical module at an irradiance of 800 W/m^2 (Darwish, Abdulrahim & Sharif, 2014).

Table 2.1 Mean Daily Global Radiation and Mean Daily Temperature.

Month	Daily Global Radiation (W/m^2)	Mean Daily Temp. (°C)
January	374.9	17.7
February	436.6	18.6
March	489.3	21.9
April	596.9	26.6
May	620.4	32
June	646.3	34.7
July	605.1	35.5
August	584.7	35
September	545.8	33
October	481.7	29.7
November	414.9	24.8
December	349.9	19.8

2.4 Climate in Qatar

Figure 2.3 demonstrates that the average daily temperature could reach **43**°during July and **14**°during January. Nevertheless, since the study focuses on the generation of electricity by solar panels, which depends significantly on temperature, it is worth mentioning that the temperature reached 48° C on June 9, 2022. (Past Weather in Doha, Qatar, 2022).

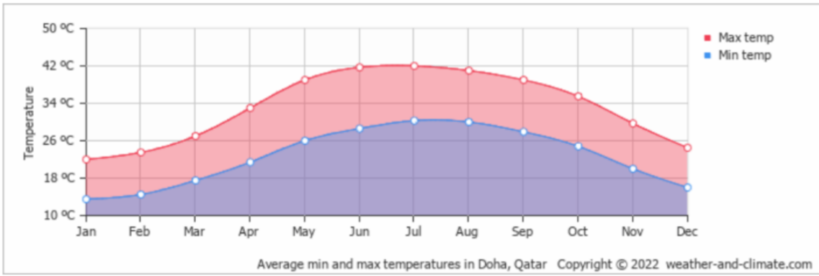


Figure 2.3 Average min and max temperature in Doha, Qatar (Climate and Average Monthly Weather in Doha, Qatar, 2022)

The average monthly sunshine hours in Doha are displayed in (Climate and Average Monthly Weather in Doha, Qatar, 2022). With 343 hours of sunshine, June typically has the largest hours, and with 224 hours, February typically has the least hours of sunshine. Figure 2.4 shows that the longest hours of sunshine is received in June, whereas the shortest is received in February. Therefore, average daily sunshine received is about 9.6 hours.

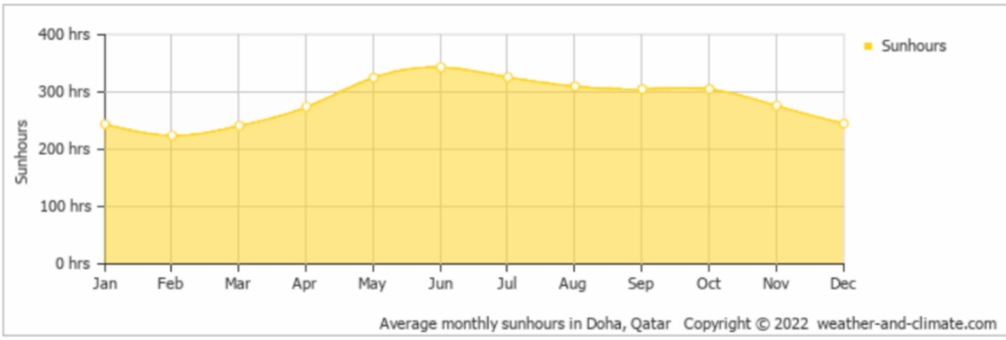


Figure 2.4 Average monthly sun hours in Doha, Qatar (Climate and Average Monthly Weather in Doha, Qatar, 2022)

2.5 Solar Photovoltaic (PV) in Office Buildings

Using solar energy to power office buildings can help reduce emissions, conserve energy resources obtained from the grid, and improve environmental sustainability. The use of solar photovoltaic (PV) energy in office buildings should be encouraged, as it is a cost-effective and environmentally friendly alternative to other forms of energy generation. It is also important that the grid of an office building can handle fluctuating power usage from various sources and uses.

Solar photovoltaic (PV) systems can provide energy on a large scale at an affordable price. Solar energy can be used in office buildings as a service source to supply electricity and hot water (Ebhota & Jen, 2020). There can also be incentives by the governments for the use of this type of renewable energy (Peters et al., 2018).

2.6 Types of Solar panels

Solar panels are developed from semiconductor-based solar cells. Types of solar panels available for use in office buildings are given below.

Among all the panel types, the one with the highest efficiency is the monocrystalline solar panel. Monocrystalline panels provide about 15 - 20% efficiency (Anteneh, 2020). These cells can convert a broader spectrum solar light wavelengths to absorption and conversion into electricity (Nexamp, 2021). Due to monocrystalline panels' space and energy efficiency, their average costs range from £350 to £375 for a 250 watt-peak panel (Anteneh, 2020).

Polycrystalline solar panels have efficiency between 13% to 16%, but they are priced lower, about £225 to £250 for a 250-watt panel due to the use of a simpler cell manufacturing process (Anteneh, 2020). Another type of PV, the thin film solar panels, have the lowest efficiencies and power capacities, getting to 7% - 13% with a price £200 to £250 for a 250-watt panel (Anteneh, 2020). The price of thin film solar panels might vary depending on the solar cell material used (Nexamp, 2021). Amorphous cell type solar panels have an efficiency range of 6% to 8%, with an average cost of £95 to $£110 for a 250-watt panel (Nexamp, 2021).

2.7 Consideration for Solar Electricity

Various factors are considered for the generation of electricity using solar energy. A few of them are discussed below.

2.7.1 Rooftop area

The rooftop area is used to arrange solar panels in a fixed, orderly pattern (Yan et al., 2020). The most important parameter is the area available to install solar PV and accessories. Compared to the electricity required, the area available in the high-rise office building may be small to generate the electricity required for major end-uses in the building. Also, other facilities, like chillers or water tanks, might further reduce the available space for solar PV installation.

2.7.2 Optimum Tilt

The optimum tilt is a different worldwide concept that refers to tilting solar panels based on where they are placed. This is for areas far from the equator; thus, depending on the latitude, the solar panel will be slanted at varying angles during the year to capture more direct sunlight (Gueymard et al., 2019). This implies that the tilt of the solar panel model will vary with the latitude.

2.8 Costs of Solar Panels

According to the International Renewable Energy Agency, in 2021, there was a decrease in the global weighted average cost of newly commissioned solar photovoltaic (PV) costs, even with increased equipment and materials costs. The levelized cost of electricity (LCOE) of new utility-scale solar PV reduced by 13% to $0.075/kWh, and the weighted average LCOE of newly commissioned utility-scale solar PV projects declined from 2010 to 2021 by 88%, as indicated in Figure 2.5 below. In 2022, there will be significant benefits from renewables amid the fossil fuel price crisis, with an indication that new renewable capacity added globally in 2021 could cause a reduction in the electricity generation costs in 2022 by about $55 billion (IRENA, 2022). From January to May 2022 in Europe, wind and solar generation alone avoided imports of fossil fuel of an average of $50 billion.

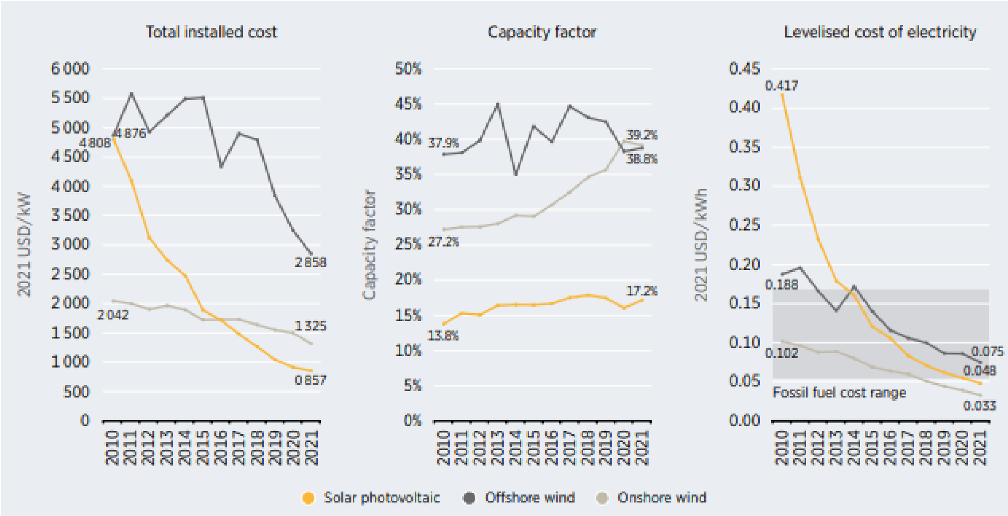


Figure 2.5 Global weighted average total installed costs, LCOE, and capacity factors of newly commissioned utility-scale solar PV, onshore and offshore wind, 2010-2021.

2.9 Solar Panel Orientation

Just as vital as the category of solar panel utilized in a specific circumstance is the positioning and orientation of solar panels. The rays from the sun must hit the surface of a solar panel perpendicularly for it to generate the most power. Solar panels will create the most energy if they are pointed in the right direction and are adequately tilted to receive the most sunlight for the longest time (Naraghi & Atefi, 2022). Some solar arrays use solar tracking devices to monitor the sun, significantly increasing energy output. Only "fixed" or non-tracking systems are discussed in the following sections.

2.10 Effects of Weather on Solar Panels

There is a relationship between the photovoltaic panels' efficiency and the module temperature. Rahman, Hasanuzzaman, and Abd Rahim (2017) noted that increased module temperature decreases electrical efficiency because the PV modules convert part of the solar energy to heat. The module temperature, in this case, is a function of environmental factors like ambient temperature, wind speed, solar irradiance, and PV factors of glass transmittance and materials. In higher temperatures, there is less cooling which affects the efficiency of the panels because when they get too hot, there is less energy getting through in the form of electric currents.

The produced energy of a PV module is also controlled by the wind conditions like direction and speed (Abiola-Ogedengbe, Hangan, & Siddiqui, 2015). Depending on these factors, the wind can cool the solar panels to ensure efficiency, where the wind flow and direction over the PV panel surface enhances heat extraction, generating higher output power (Leow et al., 2019).

Humidity tends to lower the efficiency of solar PV panels because the water vapor in the atmosphere or the tiny water droplets collect on the panels and refract or reflect sunlight away from the cells (Mekhilef, Saidur, & Kamalisarvestani, 2012). This causes a reduction in the amount of sunlight the panels receive, thus reducing their efficiency. Moreover, having consistently hot, humid weather degrades the lifespan of the panels (Abiola-Ogedengbe, Hangan, & Siddiqui, 2015).

2.11 Solar Installation Process

To install solar panels on a building, the following steps are generally used:

1. Assessing the energy demand that can be replaced through daytime or 24 hours electricity availability through a solar system
2. Determining the usable building's rooftop area and shading.

3. Obtaining the solar irradiance and temperature data around the location of the building. It is ideal to get the temperature data at the place where PVs are to be installed.
4. Calculating the number of solar panels required.
5. Installing solar panels on the building.
6. Connecting the solar panels to the inverter to link with the building's electricity connection.
7. Monitoring and maintaining solar panels.

2.12 Efficiency of Inverters

The efficiency of an inverter shows the conversion of DC power to AC power. In this case, some of the power can be lost as heat, and some standby power is used to ensure the inverter is powered. This is based on the inverter efficiency formula $\eta_{inv}=P_{AC}P_{DC}$, where P_{AC} defines the AC power output in watts, and P_{DC} defines the DC power input in watts. Figure 2.6 indicates a typical inverter efficiency curve where power output below 10-15% makes the efficiency low while high output power enables a steady increase with minute variations.

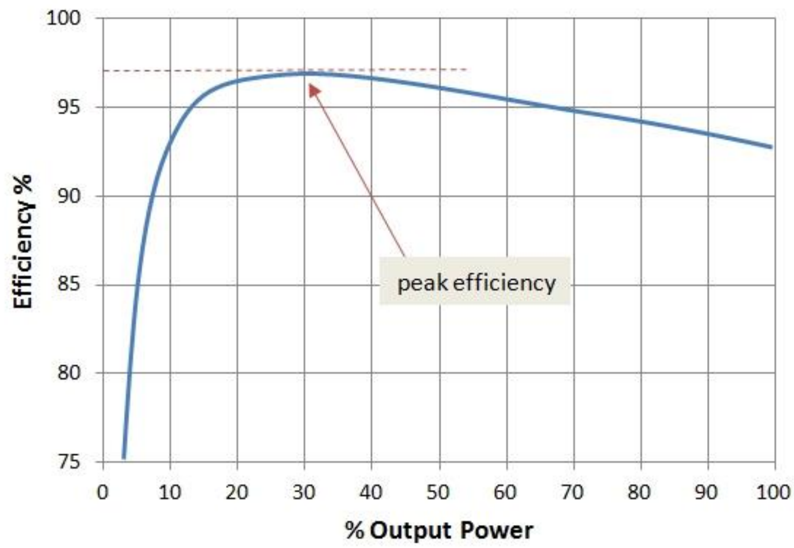


Figure 2.6 Generic inverter efficiency curve

2.13 Summary of Literature Review

Unlike other renewable energy sources, solar can be harvested on small and big scales depending on use. This review has indicated that the mechanism of solar energy is based on four steps of the initial phase, creation of electrical current, conversion of electrical energy, and use of the power in an electrical system.

Qatar has high solar irradiance all year. There are various types of solar panels; monocrystalline, polycrystalline, thin-film, or amorphous cells. The crystalline panels are most efficient due to the broad-spectrum wavelengths received but with a high average cost. The rooftop area can be considered for electricity generation. The review has also shown that solar panels can be affected by changing weather conditions such as rain, sun, clouds, temperature, and wind.

CHAPTER 3: DATA COLLECTION AND ANALYSIS

This chapter presents the data collected from various sources and analysis done for the solar PV based electricity generation. The focus is on analysis on the electricity generation and the economic analysis.

3.1 Data Collection

According to alternative energy tutorial site (Solar Irradiance and Solar Irradiation, 2022), the daily amount of solar irradiance received during the summer months equals the average solar energy which falls on a surface during the summer months times the available sun hours per day. The irradiation is 407.5 W/m^2 in Qatar (Astudillo, 2014).

So daily irradiance received during the summer months

=407.5 W/m^2 x 9.56 hours

= 3896 Wh/m^2 or 3.89 kWh/m^2 (Solar Irradiance and Solar Irradiation, 2022)

3.1.1 Electricity Demand

Regarding the office designated for the study, the following data is used for the calculations. Considering the number of lights and the average working hours, the light load is around 133,000 kWh/ month, 1,600,000 kWh yearly which indicates the daytime demand to be about 5542 kWh. The building has 3 floors (basement, ground, first) with 407 offices. The lights of the offices and the hallways are shut off during the evening.

3.1.2 Solar Panels

Three different types of PV panels are considered here: monocrystalline, polycrystalline, and thin film. Each has pros and cons regarding cost, effectiveness, appearance, and lifetime. Figure 3.1 shows the features of each type.

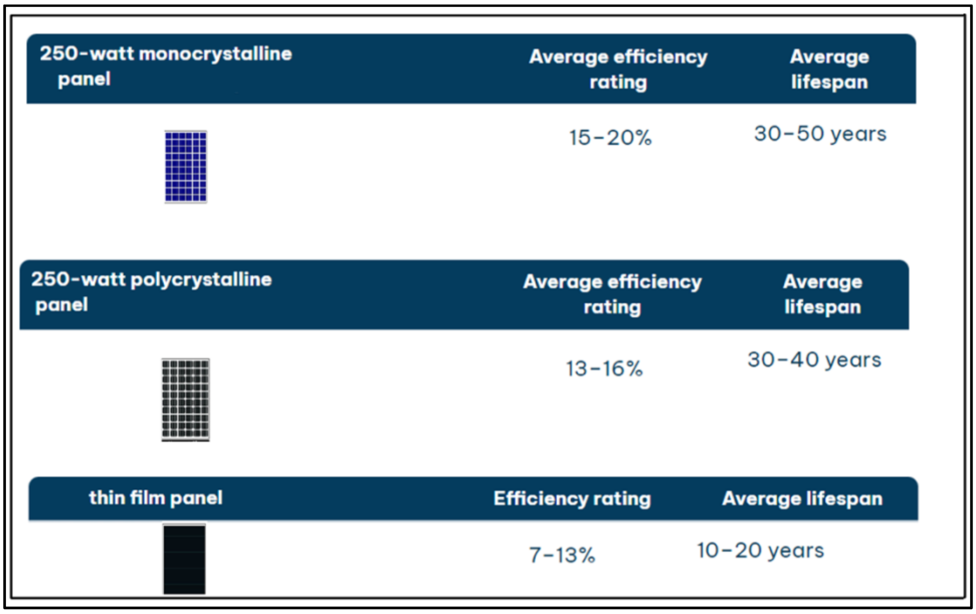


Figure 3.1 Comparison between the three types of solar panels. (Howell, 2022)

According to The Eco Experts group (Howell, 2022), monocrystalline solar cell has the highest efficiency rating between 15% to 20%, and may exceed 24% efficiency in some circumstances, this makes them the best choice in the market. Therefore, in this project, this type of solar cells is used.

3.1.3 Current Electricity Tariff

The current tariff for electricity use is shown in Figure 3.2 and Figure 3.3. The office building falls on the commercial category as per the Kahramaa classification. Therefore, the monthly tariff to be paid is calculated for the current demand (133,000 kWh) and is shown as Qatar Riyal 28,600.

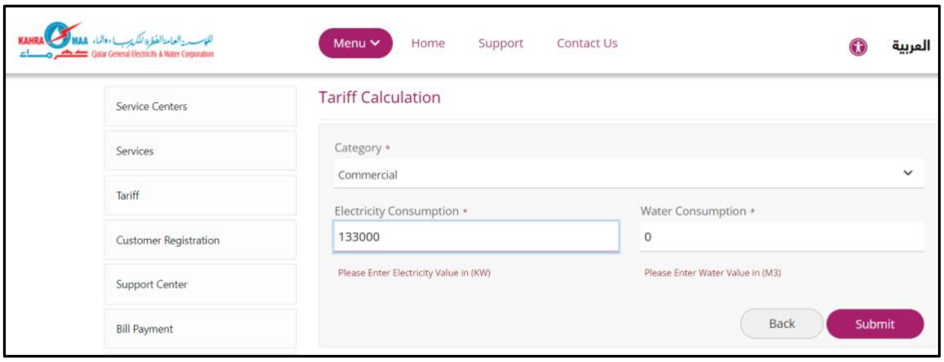
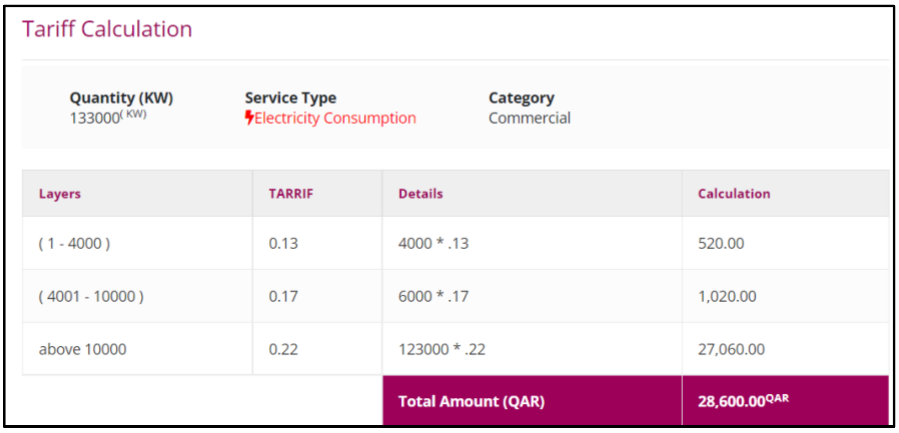


Figure 3.2 Kahramaa online tariff calculator for electricity loads.



Tariff Calculation

Quantity (KW): 133000(KW)
Service Type: Electricity Consumption
Category: Commercial

Layers	TARRIF	Details	Calculation
(1 - 4000)	0.13	4000 * .13	520.00
(4001 - 10000)	0.17	6000 * .17	1,020.00
above 10000	0.22	123000 * .22	27,060.00
		Total Amount (QAR)	28,600.00QAR

Figure 3.3 Kahramaa online tariff calculator for electricity loads.

3.2 Data Analysis

3.2.1 Analysis of Panel Tilt Angle

A solar panel should be mounted to avoid shading to the next panel. Although the irradiance to be considered is global, direct irradiance has a greater impact on the electricity generation of a PV panel. Therefore, the title angle is dependent on the latitude of the area. The tilt angle calculation is shown based on the different geographical values in Figure 3.4, where the latitude is 25.3, and the solar declination angle is -23.01 (Sun Position Calculator, 2022).

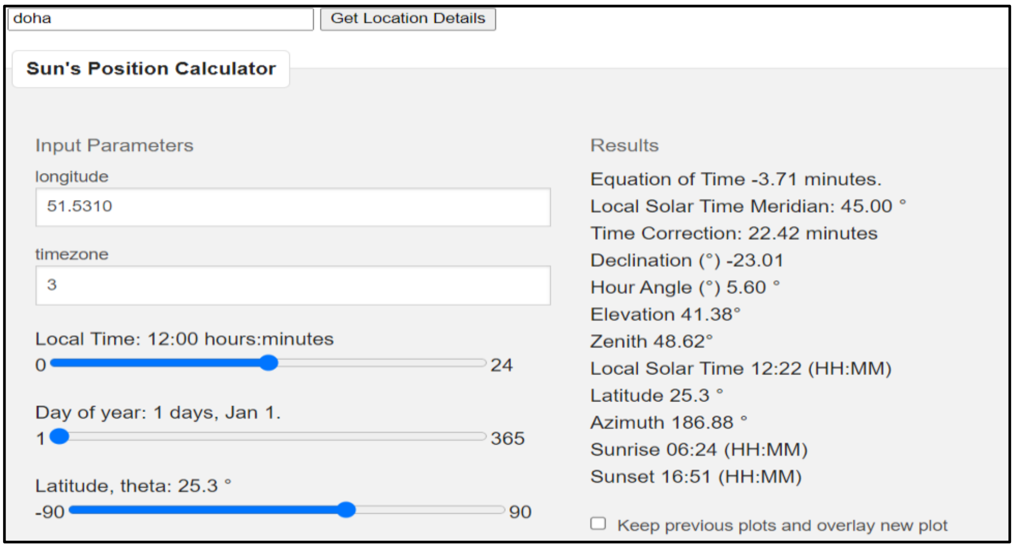


Figure 3.4 Qatar location details (Sun Position Calculator, 2022).

According to light equipment sale company (How to Calculate Solar Panel Tilt Angle, 2019), which specializes in energy efficient products, solar panel tilt angle can be calculated by the latitude value in Table 3.1.

Table 3.1 Calculation of Solar Panel Tilt Angle According to Latitude

Latitude	Tilt angle
Less than 25	Multiply by 0.87
between 25 and 50	Multiply by 0.87 and add 3.1

Since the latitude of Qatar is 25.3 so

Tilt angle is 25.3*0.87 + 3.1= 25.11 º

(How to Calculate Solar Panel Tilt Angle, 2019)

3.2.2 Solar Panels Placement Analysis

The spacing between each row is calculated to avoid shading due to the panels placed in adjacent rows. Although the electricity generation from a solar panel depends on global horizontal irradiation, the direct incidence has a larger contribution. In a project conducted by The University of Jordan to design photovoltaic systems, the shading analysis was processed as demonstrated in Figure 3.5 (Design of Photovoltaic Systems, 2022)

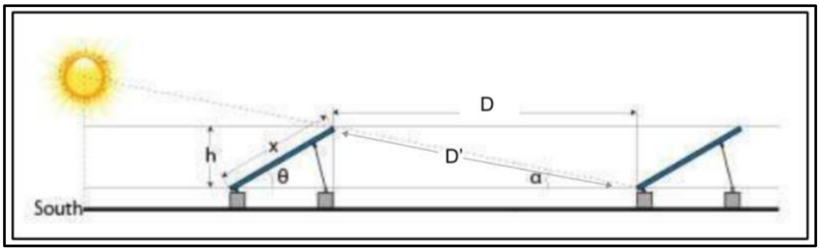


Figure 3.5 The relationship between the tilt angle and the panel height (Design of Photovoltaic Systems, 2022.)

$$h = x\sin(\theta)$$

Where x is the panel's height, and θ is the tilt angle. (Gagliano, 2021) that each PV/T module (39 inches X 66 inches) has 60 monocrystalline silicon cells connected in series, which give 250 Wp (peak power)

$$x = 39\ inches = 0.99\ m$$

h; is the height of the obstruction created by the solar panel.

$$h = 39 \ x \sin(25.11) = 16.55 \ inches = 0.42 \text{ m}$$

$$D' = \frac{h}{\tan(\alpha)}$$

Where D' = maximum shadow length

α = solar altitude angle, 23.01

$$D' = \frac{16.55}{\tan(23.01)} = 38.97 \ inches = 0.99 \text{ m}$$

Figure 3. 6 below shows the minimum array row spacing.

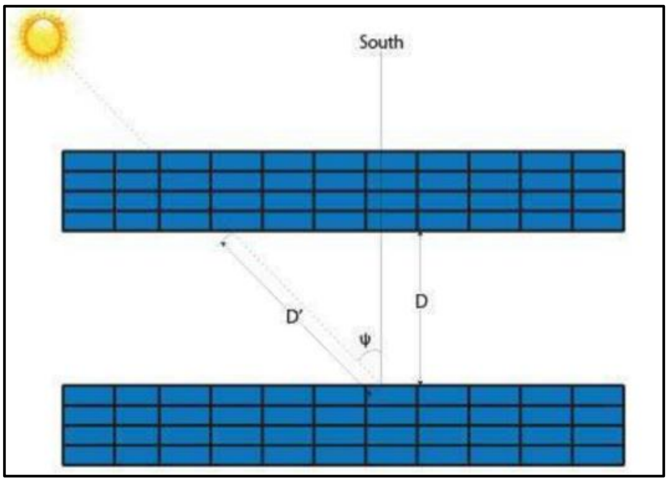


Figure 3. 6 Minimum array row spacing (Design of Photovoltaic Systems, 2022)

$$D = D' \times \cos(180 - \psi) \text{ where;}$$

D = Minimum array row spacing.

ψ = solar azimuth angle, extracted from Qatar information as 186.88.

$$D = 38.9 \ \times \cos(180 - 186.88) = 38.69 \ inches = 0.99 \ meters$$

3.2.3 Module Layout and Number of Panels

The total roof area for the office building is 21274 m^2. Chillers, AC system, and water tanks occupy 2556 m^2 of the rooftop, which is about 12%. Since the occupied area is 2556, the available area will be 18718 $m^{2.}$

The panels are $65\ inches\ \times 39\ inches$ which is $1.651m \times 0.99m$ will be mounted considering the cosine angle of the length of the panels, and the horizontal spacing between the panel rows to form a square of almost 135 by 135 meter. Figure 3.7 shows how the panels are distributed on the roof.

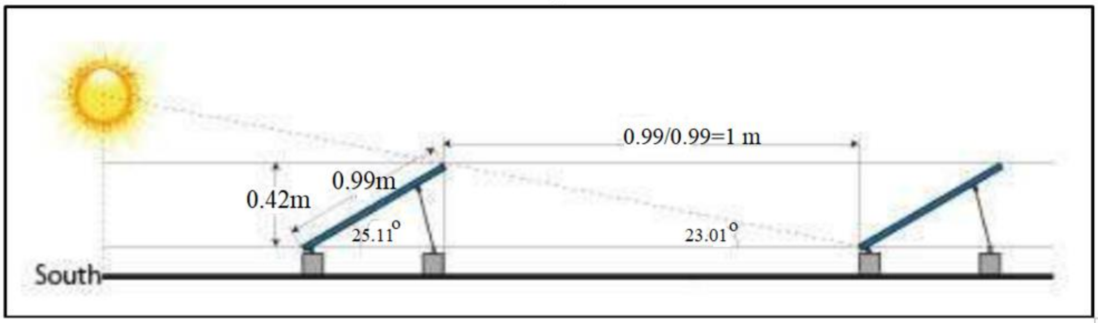


Figure 3.7 Layout of how the panels are distributed on the roof (Design of Photovoltaic Systems, 2022)

To get the number of the panels when fixing them as a square of side length 135 m

$$Length\ 1 = 0.99 \times \cos(25.11) \times x + 0.99 \times (x - 1) = 135\ meter$$

$$Length\ 2 = 1.651 \times y = 135\ meter$$

This means that: $x = 72\ rows$ and $y = 82\ columns$.

Hence, $Number\ of\ panels = 72 \times 82 = 5904\ panels$.

3.2.4 Effect of weather condition factors on the PV cells

Environmental conditions like temperature, wind, dust, and rain have a significant negative impact on the PV cells. Among these factors the most important one is the pollutants and dust accumulation on top of the surface, which may act as a barrier to the solar irradiation and hence decreases the light transmission.

In a study conducted by (E Elshazly et al, 2021) a comparison of dust and high-temperature effects on monocrystalline and polycrystalline photovoltaic panels is given. It shows that dust accumulation effects are different from one country to another and it may cause 40% degradation in the cell electrical efficiency. However, it is reported that the degradation reaches 30–35% (average is 32.5%) in Qatar, due to its high relative humidity and its location in the desert area.These figures match with the results extracted by (Farid Touati et al, 2017) in their study about power prediction of PV technology in the State of Qatar . It is presented that the degradation is 50% when cells are exposed to the summer natural factors for eight months without cleaning and 20% degradation in winter. This implies that the average degradation in cell electrical efficiency is rather the same as concluded above.

Regarding the wind and humidity effects, Bing Guo et al.) 2015 point out that humidity has a negative impact on the PV module as a higher humidity levels make the dust particles sticky to the cells. On the other hand, winds may improve the PV performance, hence higher wind speeds may cause a stronger cooling of PV. However, it is also mentioned that the combination of the humidity and wind can also increase the PV performance, since their observations demonstrate that daily peak of wind speed occur at the same time of the daily minimum of the relative humidity. This observation implies that the low humidity makes the dust less sticky due to low moisture, which makes the dust carried away.

EylulSimsek et al. (2020) have investigated the Effect of dew and rain on photovoltaic solar cell performances and found that the water droplets have no effect on the performance, if the tilt incident angle is less than or equal 30°, however for incident angle greater than 30°, the PV cell efficiency decreases. Since the tilt angle in the study is only 25.11°, the rain effect is not considered. To sustain a steady performance of PV panels, regular cleaning is required. Shenouda et al. (2022) explain several ways of cleaning in their review, such ways as manual cleaning, self-cleaning, mechanical cleaning and electrodynamic cleaning. It is mentioned the different type of surfaces and coating as well to repel water droplets and prevents them from sticking on the surface, as the hydrophobic surface and the hydrophilic surface. The more advanced is the cleaning method, more expensive is the process. .

3.2.5 Solar Panels Output

Figure 3.8 shows how the relationship between solar irradiance and solar panel output.

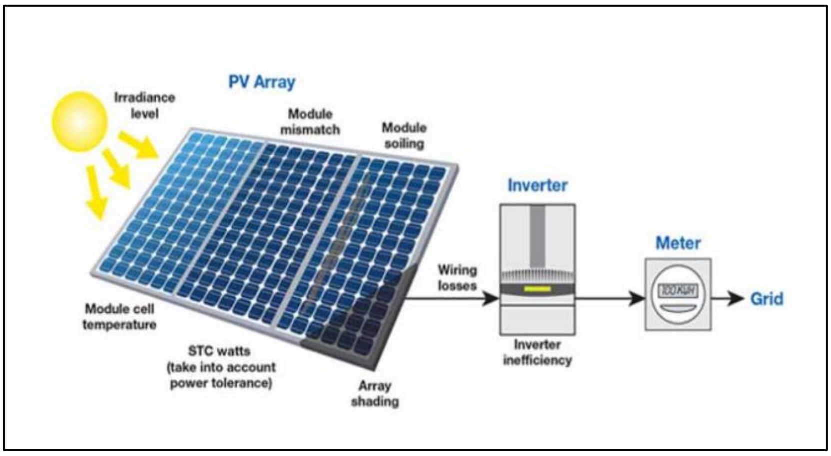


Figure 3.8 The relationship between solar irradiance and the solar panel output (Saur News Bureau, 2016)

According to Saur Energy International Company (Saur News Bureau, 2016) the formula to calculate the electricity generated in the output of a photovoltaic system is

$$E = A \times r \times H \times PR$$

where E is Energy (kWh),

A: is the total area of the panel (m^2); for the used panel 65 inches X 39 inches the area is 1.6 m^2.

r: is solar panel yield (%), electrical power (in kWp) of one solar panel divided by the area of one panel, for the used panel (250/1000)/1.6= 15.6%.

H: is annual average solar radiation on tilted panels, which is 3.89 kWh/m^2.

PR = Performance ratio, constant for losses (0.9, default value = 0.9).

E= 1.6*0.156*3.89 *0.9 = 0.874 kWh = 874 Wh
For the whole number of panels E=0.874*5904 = 5160.1 kWh

Taking the natural factors into consideration, 32.5% performance degradation is expected to change the term E in case of no cleaning, E becomes

E = 874*(1-0.325) = 590 kWh
E=875*0.675=590 kWh
For the whole number of panels E = 0.675*5904 = 3985.2 kWh

However, Al-Housani et al. (2019) in their assessment of different photovoltaic cleaning techniques and frequencies in Doha, found that a microfiber & vacuum cleaner combination provide the best enhancement to the PV cells performance, which reaches to almost 6% improvement for a period of a week, and cleaning a panel by this method costs 0.29 US $/time

As a result, we can get the resultant of worst-case impact of the dust (32.5% down) and the improvement scenario by cleaning the panels weekly (6% up), the performance will be degraded by 26.5%. So, the E becomes

$$E = 874*(1-0.265) = 642.39 \text{ kWh}$$

$$E = 874*0.735 = 642.39 \text{ kWh}$$

For all of the panels $E = 0.735*5904 = 4339.44$ kWh

3.2.6 Number of Inverters

The main function of solar inverters is to convert the direct current (DC) solar panels generate into an alternating current (AC). For the 250-Watt panels and the quantity of 5904 panels, 1.5 MW-peak capacity is needed. Therefore, considering the resilience of the system, 4 inverters of 500 KW output power each will be used. The specifications of the inverters are shown in Figure 3. 9. The cost of 500 KW inverter is about 30,000$ and for the four inverters the price would be 120,000$ which is equal to 438,000 QR.

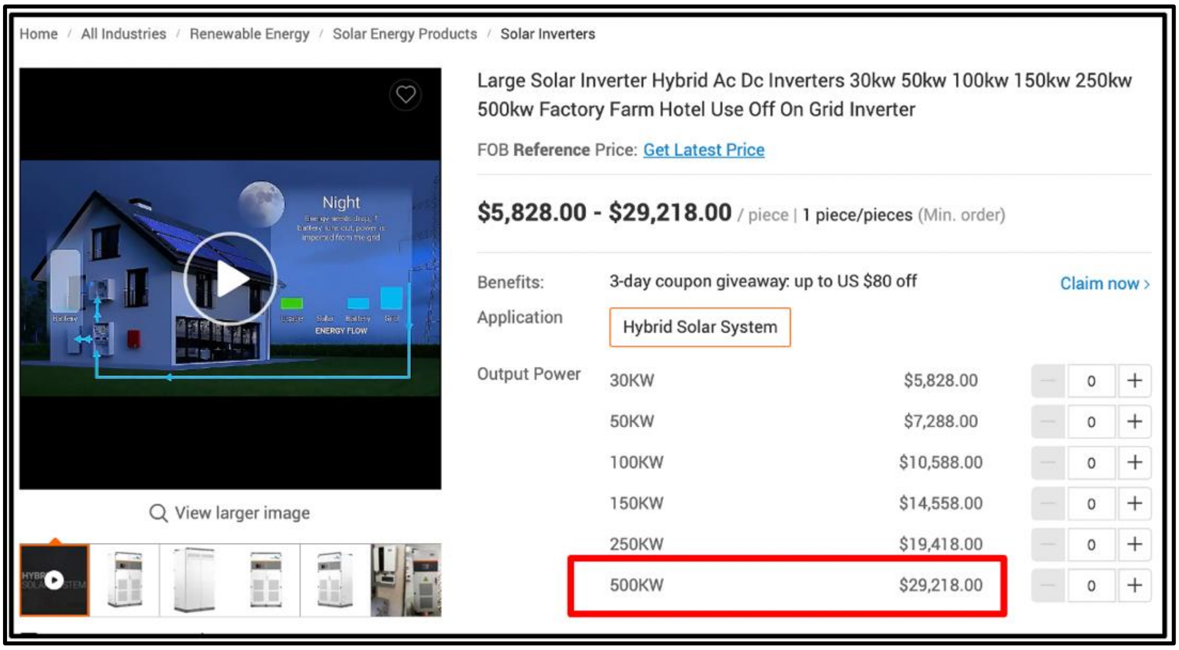


Figure 3. 9 Specifications of the Inverters (Alibaba, 2022)

3.2.7 Inventor Efficiency

Inverter efficiency (η_{inv}) is an indicator calculated by finding the ratio of the AC energy generated at the output terminals of the inverter to the DC energy at the input terminals of the inverter (Aghaei, 2020)

$$\eta_{inv} = \left(\frac{E_{ac}}{E_{DC}}\right) \times 100 \quad \text{(Aghaei, 2020)}$$

$\eta_{inv} = \left(\frac{1476 \text{ KW}}{4 \text{ inverters} * 500\text{KW}}\right) 100 = 73.8\%$ (Aghaei, 2020). Regarding whether the solar panel system could fulfill the demand, the output of the suggested solution is 5160 kWh with regular advanced cleaning ways, so comparing this number with daytime demand 5542 kWh, the solar panel would provide a close amount of output to what the office needs, about 93.11%, which implies that it fits the demand and saves a lot of money on the long run.

So, the suggested system will have 5904 panels, covering area of 18718 m^2 with max output 5160 kWh per day. However, in case of weekly brush cleaning the daytime demand 5541.7 kWh will not be satisfied as the panel will provide only 4339.44 kWh, about 78.31% of the demand, which is far from the required.

3.3 Economical Evaluation

3.3.1 Initial and Maintenance Cost Estimation

The following calculations are based on mounting 5904 monocrystalline solar panels. ($0.14/Watt - $0.20/Watt) with an average cost of $0.17/Watt ($42.5/250 w panel) which is QR 155 and using four inverters of size 500 KW with an average cost of QR 438,000 QR.

Another issue to be considered, is the life span of the panels and the inverters, panel life is about 25 years, while inverters are only 10 years. Since the panel life is 25 years, inverters must be bought three times, in the 1st year, in the 11th year, and the 21st year.

Bhatia (2023), suggested that the solar PV system's cost depends on various factors such as system configuration, equipment options, labor cost, and financing cost. The cost also depends on the system's size and the amount of electricity it produces. Solar PV systems typically have high capital costs, and it may take a long time to recover these costs. The operating costs for solar PV installations' operating costs are negligible. However, there is an annual maintenance costs of 0.5-1% of the capital cost.

The prices of monocrystalline PV panels range from ($0.14/W - $0.20/W) with an average of $0.17/W which is equal to QR 0.6205/W (Alibaba, 2023). For the 5904 panels of a 250-W, the cost would be $250,920 which is equal to QR 913348.8.

The Structural BOS racking ranges from ($0.11/W - $0.18/W) with an average of $0.145/W which is equal to QR 0.52925/W (Nearby Engineers, 2023). For the 5904 panels of a 250-W, the cost would be $214,020 which is equal to QR 779,032.8.

The Electrical BOS ranges from ($0.13/W - $0.45/W) with an average of $0.29/W which is equal to QR 1.0585/W (Nearby Engineers, 2023). For the 5904 panels of a 250-W, the cost would be $428,080 which is equal to QR 1,558,065.6.

Figure 3.10 represents the total cost of the PV module, Structural BOS, Electrical BOS, and the inverters.

Components	Cost			
PV module	$0.14-0.20/W	Average ($)	For all panels ($)	For all panel (QR)
		0.17	250920	913348.8
Structural BOS (racking)	$0.11/W - $0.18/W	Average ($)	For all panels ($)	For all panel (QR)
		0.145	214020	779032.8
Electrical BOS	$0.13/W - $0.45/W	Average ($)	For all panels ($)	For all panel (QR)
		0.29	428040	1558065.6
Inverter		Price (QR)	Quantity	For all inverters
		109,500	4	438000
		Total (QR)		3688447.2
		Total (USD)		1010533.479
		Total (QR) /Watt		3259377.219
		Total (USD) /Watt		892980.06
		Total (QR) / KW		3259.37722
		Total (USD) / KW		892.9800603

Figure 3.10 Initial costs estimation

3.3.2 Costs of the Current and the Suggested System

Comparing the current fees and the estimated cost when fixing the solar panel system by calculating the annual average after one year with the suggested solar panel solution cost.

Yearly Kahramaa fees = 28600*12= QR 343,200 yearly

The current situation after one year= QR 343,200

Case 1: Considering 893 USD/KW (3259.4 QR/KW)

(Initial cost + 1year* maintenance cost of 1% of the initial cost) = 3688447.2 * 1.01= QR 36884.5 QR.

In figure 3.11, a cost of 893 USD/KW (3259.4 QR/KW) was considered for the whole system which has a capacity of 1476 KW. The total cost of the system was $1010533.478 which is QR. 3688447.2. The payback period of the suggested system would be 14 years from installing the PV system.

CASE (1)											New Inv.		
	1	2	3	4	5	6	7	8	9	10	11	12	13
Kahramaa	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200
Cum. Kahramaa	343200	686400	1029600	1372800	1716000	2059200	2402400	2745600	3088800	3432000	3775200	4118400	4461600
Solar	3688447.2	36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	474884.5	36884.5	36884.5
Cum. Solar	3688447.2	3725331.7	3762216.2	3799100.7	3835985.2	3872869.7	3909754.2	3946638.7	3983523.2	4020407.7	4495292.2	4532176.7	4569061.2
Ratio	0.093047286	0.18425205	0.273668485	0.361348677	0.447342709	0.531698759	0.614463185	0.69568061	0.775394008	0.853644774	0.83981193	0.90870244	0.97648069

							New Inv.				
14	15	16	17	18	19	20	21	22	23	24	25
343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200
4804800	5148000	5491200	5834400	6177600	6520800	6864000	7207200	7550400	7893600	8236800	8580000
36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	36884.5	474884.5	36884.5	36884.5	36884.5	36884.5
4605945.7	4642830.2	4679714.7	4716599.2	4753483.7	4790368.2	4827252.7	5302137.2	5339021.7	5375906.2	5412790.7	5449675.2
1.0431734	1.10880644	1.17340487	1.236992966	1.29959424	1.36123149	1.42192681	1.35930093	1.41419167	1.4683292	1.5217289	1.574405764

Figure 3.11 Payback period for case 1

Case 2: Considering 932 USD/KW (3401.8 QR/KW)

In Figure 3.12, according to (Renewable power generation costs in 2021, 2023) it costs $932/KW to install a PV system in Saudi Arabia. For the required capacity 1476 KW the total cost would be $1,375,632 which is equal to QR 5,021,056.8. The payback period of this system would be 19 years from installing the PV system.

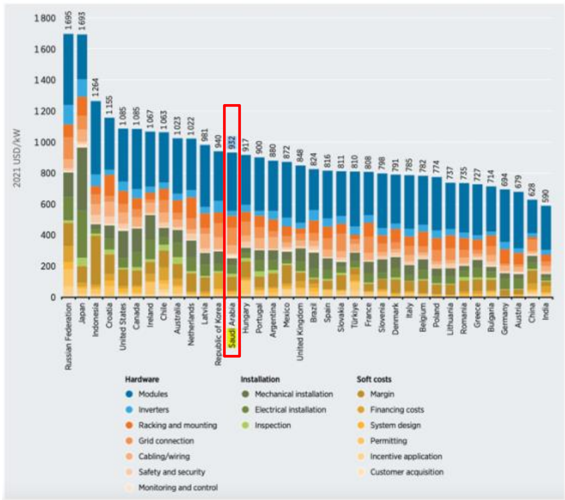


Figure 3.12 Detailed breakdown of solar PV total installed by country 2021 (Renewable power generation costs in 2021, 2023)

In Figure 3.13 the payback period of the suggested system would be 19 years from installing the PV system.

CASE (2)											New Inv.		
	Year 1	2	3	4	5	6	7	8	9	10	11	12	13
Kahramaa	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200
Cum. Kahramaa	343200	686400	1029600	1372800	1716000	2059200	2402400	2745600	3088800	3432000	3775200	4118400	4461600
Solar	5021056.8	50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	488210.6	50210.6	50210.6
Cum. Solar	5021056.8	5071267.4	5121478.0	5171688.6	5221899.2	5272109.8	5322320.4	5372531.0	5422741.6	5472952.2	5961162.8	6011373.4	6061584.0
Ratio	0.0683521	0.1353508	0.2010357	0.2654452	0.3286161	0.3905837	0.4513821	0.511044	0.5696012	0.6270839	0.6332993	0.6851013	0.7360452

14	15	16	17	18	19	20	21	22	23	24	25
343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200	343200
4804800	5148000	5491200	5834400	6177600	6520800	6864000	7207200	7550400	7893600	8236800	8580000
50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	50210.6	488210.6	50210.6	50210.6	50210.6	50210.6
6111794.6	6162005.2	6212215.8	6262426.4	6312637.0	6362847.6	6413058.2	6901268.8	6951479.4	7001690.0	7051900.6	7102111.2
0.7861521	0.8354423	0.8839358	0.9316517	0.9786085	1.0248242	1.0703162	1.0443297	1.0861573	1.127385	1.1680255	1.2080915

Figure 3.13 Payback period for case 2

Comparing the two cases, the first case which considered 893 USD/KW (3259.4 QR/KW), resulted in having a payback period of 14 years. On the other hand, the second case which considered 932 USD/KW (3401.8 QR/KW), resulted in having a payback period of 19 years. This compassion indicates that the higher the costs, the larger the payback period gets.

CHAPTER 4: CONCLUSION

This chapter summarizes the important findings, examines the work's limits, and makes recommendations for future work.

4.1 Conclusions

This project report focused on understanding the use of solar energy for lighting in office building, the report reviews the solar energy concept, irradiance, and formulations that should be considered for the design of solar energy systems. The application chosen is for an office building with the daily lighting load of around 133,000 kWh/ month or 1,600,000 kWh yearly which indicates the daytime daily demand of about 5541.7 kWh. The solar panels occupy the roof top area of 18718 m^2.

The solar panels system used in this project is monocrystalline type due to its high efficiency despite the high price. The panels have a tilt angle of 25.11^o degree, giving the spacing distance of 1 m between the panels to avoid shading. The system uses 72 rows and 82 columns of solar panels. The total number of panels to be installed is 5904 panel. The solar panels receive 407.5 W/m^2 of irradiation and that coverts to the availability of 5541.7 kWh of electricity on a daily basis.

The calculations shows that cleaning scenario with brushes and vacuum cleaners would satisfy only 78.31% of the demand, however using more advanced cleaning techniques or coated panel surfaces prevents the dust accumulation effect and hence the total electricity generated by the panels is 5160 kWh and fulfills 93 % of daily light demand for the chosen office building.

The economic analysis shows that the initial cost is high, as it includes the cost of the 5904 panels, the 4 inverters of size 500 KW. Two scenarios were done to calculate the PV system installing cost and the payback period; the first was considering 893 USD/KW (3259.4 QR/KW) which resulted in 14 years as a payback, while the second scenario was Considering 932 USD/KW (3401.8 QR/KW) which resulted in 19 years as a payback. Comparing both Scenarios, it is indicated that the higher the costs, the larger the payback period gets.

4.2 Limitations

Data used in this report is based on various sources. Also, the space available for the study is obtained from the office administration. The electricity demand is also provided by the office administration and therefore, the assessment is based on the lighting load provided.

4.3 Future work

The use of solar panels has substantially increased in recent years since they are an economical and ecologically good way to produce electricity. The popularity of flexible solar panels, a novel technology that could replace conventional solar panels, is growing. These panels are ideal for use in integrated photovoltaics since they can be twisted or curved to accommodate the curves of a building's front (BIPV). These panels can be shaped to meet the contour of the building, enabling them to mix in with the design more naturally (Xiang et al., 2017). This can be especially helpful for structures in cities where conventional solar panels might not be as aesthetically pleasing.

Before choosing to employ flexible solar panels, it is crucial to thoroughly weigh their possible costs and advantages (Hadavinia & Singh, 2019). All things considered, the use of flexible solar panels in building integrated photovoltaics (BIPV) represents a potential direction for future work on integrating solar technology in office buildings. However, more investigation and a cost study will be required to decide whether this technology is practical in a particular architectural setting.

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