

University of Bahrain

College of Science

Postgraduate Programs



The Study of Using Rooftop Solar PV for Khalifa Town Houses

A Thesis Submitted in Partial Fulfillment of the Requirements for the Master Degree in Environment and Sustainable Development- Sustainable Urbanism

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May/ 2021



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The student is awarded a grade A in the thesis subject.

- ☒ Without making any changes to the thesis.
- ☐ After making the modifications attached with this decision.

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Abstract

Bahrain is facing rising electricity demands as a result of various factors such as population growth, rising urbanization rates and rising living standards in which the current rate of growth is projected to hit a demand peak of 9,500 MW by 2030. The fast-growing construction industry, in general, and residential buildings, in particular, create massive energy and environmental burdens to the country. Therefore, Bahrain has been setting a national renewable energy target of 5% by 2025. Thus, the aim of this study is to study the potential of photovoltaic systems in Bahrain's residential sector, with a focus on building rooftops. Southern New Town (Khalifa Town) has been chosen as a case study to investigate its utilizable rooftop areas for PV application and assess its energy production. The assessment of the rooftop area and the PV system modeling has been carried using AutoCAD and PVsyst software, respectively. We found that installing 17 kW -PV panels for each villa - with PV panels tilted 5°, due south - will produce , annually, 3,129 MWh for the 120 housing units, i.e., 44,953 MWh for 1,724 housing units (total number of villa in Khalifa Town), which is sufficient to meet about 43% of the total town's electricity needs. Such installation on rooftop will cut CO₂ emission by 34,794 tons, i.e. reducing 21% of the town's total CO₂ emissions.

The financial analysis of such initiative (installing PV at roof top) indicates that it is considered as a decent investment only if the government (EWA) purchases each kWh generated from PV system for 29 fils, i.e. the tariff for commercial use. The payback under such incentive will be 9.6 years. However, if government purchases the unit at a cost equal to the highest subsidized tariff for electricity for a household (3fils for monthly consumption of no more than 3,000 kWh) then the investment will be considered as a big loss since the payback period of the system will be about 84 years! Therefore, establishing feed-in-tariff policy (FIT), particularly assuring the payback is not more than 6 years, will encourage households to vastly install PV systems on their rooftop houses and consequently helping the country to meet its renewable energy target. It will also boost local PV manufacturing and hence creating more green - collar jobs. Such successful FIT policy will assure sustainability of the Khalifa Town and to the other existing and planned clean sustainable cities in the country.

Dedication

This dissertation is dedicated to His Royal Highness, Shaikh Khalifa bin Salman Al Khalifa's soul, who was an inspiring leader and global symbol whose legacy will live on in the hearts and minds of everyone, whom I was excited to show my proposal of developing "Khalifa Town" to after finishing it. I pray to Allah the Almighty to rest his soul in eternal peace.

To my family, my father and mother, who have been a steady source of inspiration and guidance throughout the numerous struggles I've encountered throughout my studies. To my sisters, who have never left my side despite my erratic studying moods. Thank you for giving me the courage to reach for the stars and pursue my dreams, for bearing with me through all of my setbacks.

To my grandfather's soul, my source of strength and motivation, who I am sure is proud of the person I have become today. I would like to express my endless gratitude to all the love and care you have shown to me.

To all my friends and coworkers in Kingdom University who have supported me throughout my studying period physically and mentally. I will always be grateful for what they have done for me.

Last but not least, to my precious friends, Borhene and Hajer, who have shown me the true meaning of friendship and who have never hesitated to bring a smile to my face even though they are thousands of miles away. For the times we had together, I am forever thankful. No words can describe by gratitude to all what you have done for me and the time you have saved just to be by my side.

Acknowledgments

In the name of Allah, the Most Gracious and the Most Merciful...

First praise is to Allah, the Almighty, on whom ultimately we depend for strength and guidance, by whose mercy I was able to reach this stage, Alhamdulillah.

Second, my sincere appreciation goes to my supervisors, Prof. Waheeb Alnaser & Dr. Naser Alnaser, for their constant support and invaluable help of constructive comments and suggestions throughout these years. Prof. Waheeb Alnaser was more like a father to me. His never-ending motivation gave me the boost I needed to get to this stage. Thank you for your trust and faith.

My special thanks and appreciation goes as well to my Instructors from Prince Charles Foundation, Dr. Matthew, Mr. Simon and Mr. Aaron, as well as my instructors from University of Bahrain, Dr. Lama, Dr. Humood, Dr. Hanan, Dr. Sawsan, Dr. Arbab and Prof. Mukesh, who have provided me with a fantastic learning opportunity and were eager to share their insight and information in the most efficient way possible.

Also, my gratitude is extended to the Dean of College of Science, Prof. Mohammed El-Hilo, who have facilitated all the problems and challenges I have faced by providing all the care and support I needed.

My deepest gratitude is for my family members, who have offered all the guidance and inspiration in my thesis work. Thank you for taking the time to listen to my concerns and provide advice. Without you, I will not be who I am today.

I am also deeply indebted to my line manager and colleagues from Kingdom University for their kindness, patience, care and moral support that helped me since my first day at this college to become who I am today.

Last but not the least, I am truly grateful to all my friends, especially Aysha, Balqees, Asmaa and Ola who were by my side when the obstacles of my studies felt too great to conquer.

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Chapter One

Introduction to the Study

- 1.1 Introduction
- 1.2 Research Problem
- 1.3 Research Questions
- 1.4 Research Objectives
- 1.5 Research Significance
- 1.6 The Study's Setting
- 1.7 Research Terminology

1.1 Introduction

Over the last century, the world has been experiencing huge changes that led to significant environmental and energy challenges. These changes were mainly due to the rapid economic development and significant population growth since it has risen dramatically from below billion a century ago to over 7 billion today (Roser, Ritchie & Ortiz-Ospina, 2019). Above all of these challenges comes the issue of increased energy demands Especially the Arab region where 5.1% of the world's total primary energy supply and 7.8% of its carbon dioxide emissions has been accounted, much of it is generated in the GCC countries (Saab, 2017).

The Gulf Cooperation Council (GCC) nations (Saudi Arabia, Bahrain, Kuwait, Oman, United Arab Emirates and Qatar) confront the problem of growing energy demands owing to different aspects like developing population, escalating rates of urbanization, rapid economic and industrial development, and increasing living standards (Ahmed, Fardan & Asif, 2017). According to International Energy Outlook (IEO, 2017), energy consumption in non-OECD countries (among them the GCC countries) rises 41% between 2015 and 2040 compared to a 9% increase in OECD countries. In terms of per capita energy consumption, the average figure for the GCC countries is over seven times higher than the worldwide average (Asif, 2016a). Statistics indicate that the building sector has a substantial role in this respect as it accounts for around 80% of the total electricity consumption especially residential buildings where it reaches, for example in Bahrain and Saudi Arabia, over 50% of the total electricity produced in the country (Asif, Hassanain, Nahiduzzaman & Sawalha, 2019).

Moreover, the excessive consumption of fossil fuels and electricity gets converted into proportionately greater amounts of environmental emissions where the GCC countries are amongst the highest in terms of CO₂ emissions per capita (Sharples & Radhi, 2013).

However, the recent trends in the GCC region propose that there is a substantial degree of comprehension to shift towards sustainability especially in the building sector. Over the last decade, the GCC countries have been endorsing countless aspects of sustainable urban development and energy efficiency through several types of policies and legislative instruments. This has encouraged the rapid application of different sustainable technologies and renewable energy to overcome the various environmental challenges. Solar energy and wind power have always been the prominent sources of clean energy. Solar photovoltaic (PV) particularly is considered one of the most efficacious renewable technologies in which its global installed capacity has reached 402 GW today (REN21, 2018). Given the fact that the GCC countries' geographical location is well fitted to receive an abundant amount of solar energy (nearly 500-600W/m²) that is equivalent to 1.5 million barrels of crude oil (Alnaser & Alnaser, 2011), gives it tremendous potential for solar electricity generation.

It is very important to apply the concept of sustainable construction specially in Bahrain and shift towards promoting sustainability and developing appropriate solutions that are centered on the application of PV system. These type of applications have always been recently targeting large scale projects with a slight negligence of small scale ones, especially residential projects.

1.2 Research Problem

Limited studies and researches have addressed the issue of deployment PV systems in Bahrain's building sector. The assessment of PV application on building rooftop in Bahrain especially in residential buildings is a zone which has not been tended to up to this point. Therefore, this gap of information was targeted to be tackled through this research.

The aim of this research is to study the potentials of PV systems in the residential sector of Bahrain concentrating on the building rooftop areas. The Southern New Town (Khalifa Town) has been selected as a case study to examine its utilizable rooftop areas for PV application and determine its energy output as well taking in consideration various disruptive structural, architectural and utilities features. Moreover, this research attempts to establish a descriptive economic and environmental assessment of using PV system on the rooftop.

1.3 Research Questions

This study is aiming to answer the following questions:

- What is the net utilizable rooftop area for PV application on residential buildings?
- What is the most appropriate layout of the roof that will maximize PV utilization as well as holding the other structural and mechanical features?
- How much is the actual energy generation potential of the rooftop PV application?

- What is the economic impact in using tilted PV panels at the roofs?
- How much reduction in greenhouse gas emissions will result in using PV application installed at the rooftop of Khalifa Town houses?

1.4 Research Objectives

The main goal of this study is to investigate and examine the prospects of utilizing PV system on residential building rooftop areas and its effect on the environment. This goal is to be reached through achieving the following objectives:

- To review relevant research studies and literature dealing with Building Integrated Photovoltaics, its application on residential projects and its power output.
- To set up the significance of PV application in the building sector in Kingdom of Bahrain.
- Calculate and re-develop the utilizable rooftop area for PV application considering obstructive elements, for example, parapet walls, heat ventilation and air-conditioning (HVAC) systems, water tanks, sky light openings, satellite dish antennas, staircases and vents for plumbing or mechanical installations.
- Verify the actual energy generation potential of the rooftop PV application using PVsyst software to endorse the findings of the estimations at the national level.
- Provide a detailed economic assessment of the applied PV system including the payback period.
- Calculate the consequent environmental emissions savings.

1.5 Research Significance

Addressing the issue of installing PV panels on residential building rooftop areas is an important concern to study since it works parallel with the sustainable energy transition anticipated in the Economic Vision 2030 of Kingdom of Bahrain. Bahrain do need to utilize the high solar potential in Bahrain but the land limitation and cost set as a barrier. It makes no sense to use a land that costs BD 100 per ft² (BD 300 per m²) to install a PV system that will provide daily solar electricity of 28 kWh per day (annually 10,220 kWh which worth BD30 – if unit price is 3 fils per kWh – and BD 300 – if unit price is 30 fils per kWh), therefore, using the rooftop of buildings stands as a proper solution bearing in mind Bahrain's total area is 730 km² only!

Because there is no study conducted in Bahrain dealing with this issue, then this study will be the first of its kind to actually examine the power generation potential of PV system on the rooftop of residential buildings in Khalifa Town (classified as smart city) including an economic and environmental perspective. The study will help in developing awareness of the positive impact of PV applications on the long-term. It will encourage Bahraini authorities to be involved with sustainable building projects waiving out the ambitious consequences.

1.6 The Study's Setting

This study will take place in Southern New Town (Khalifa Town) in which Khalifa Town's (phase 1) has been undertaken as the field of the study with a sample of 120 residential units only to be tested.

1.7 Research Terminology

- **Sustainability:** The Brundtland Report of 1987 gave birth to the idea of sustainability as a policy concept. It can be described as a state of being happy for an extended period of time, perhaps indefinitely. Sustainability entails fulfilling our own needs without jeopardizing future generations' ability to fulfill their own (Rankin, 2014).
- **Solar Energy:** is the massive amount of radiation from the sun reaches the earth's surface every day. This energy can either be absorbed and used as heat in "solar thermal" applications or directly converted to electricity using photovoltaic cells (Byrne, Taminiau, Kurdgelashvili & Kim, 2015).
- **Solar Photovoltaic (PV)** cells are devices that have the advantage of being able to convert solar radiation directly into energy, without the need for a heat transfer step in the middle. Electrons are discharged and an electric flow is generated as daylight strikes a properly prepared semiconductor material (typically silicon-based) (Gautam, Li, & Ru, 2015).

Chapter Two

Theoretical Framework and Literature Review

2.1 Literature Review and Theoretical Framework

2.1 Literature Review

Over the past few years, world energy demand has been increasing dramatically by around 1.8% since 2011 as the constant populations' consumption of electricity rises (REN21, 2018). Nowadays, due to the rapid population growth, industrial evolution and perverse subsidies, the Arab region specifically is facing an increasing demand for electricity, water, food and other scarce resources. The consumer trends of this region have seen drastic changes fueled by the economic and technical development alongside cultural and social factors (Abdel Gelil & Saab, 2015). According to International Energy Outlook (IEO, 2017), the net electricity generation in non-OCED countries is rising twice as rapidly as in the OCED as shown in Figure (1). As rising living standards in those countries increase the demand for various appliances and equipment, energy usage in buildings increased by 2% annually between 2015 and 2040 especially in residential and industrial buildings. Figure (2) shows that the per capita residential energy use is huge in the Middle East as the

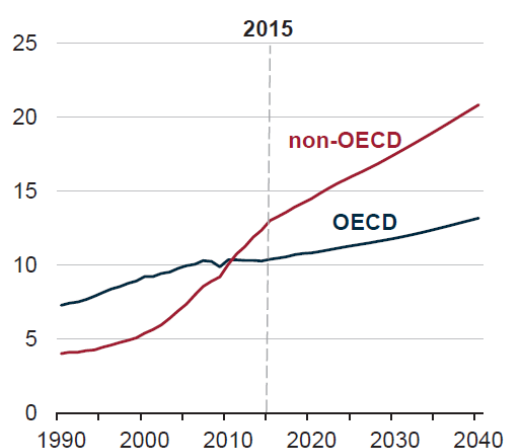


Figure (1): OCED and non-OCED net electricity generation in trillion kwh. (IEO, 2017)

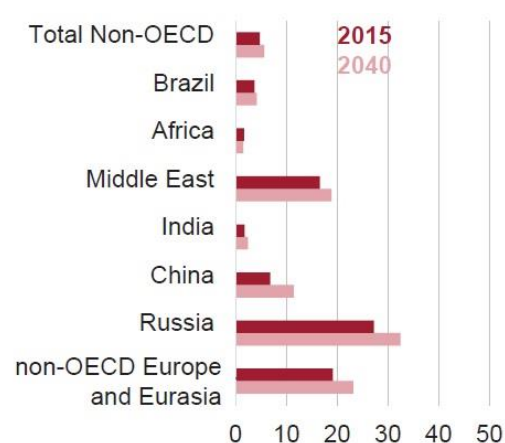


Figure (2): Residential sector energy consumption per capita. Million Btu per person (IEO, 2017)

recent patterns in energy demand have put the Arab economies among the least effective worldwide while contributing as well to the rise in associated greenhouse gas (GHG) emissions (Saab, 2017). Consistent with Arab Forum for Environment and Development (AFED) report, energy consumption in the Arab countries has increased by 8% which is double the average rate of the economic growth. Looking at the GCC countries' status, although the climatic conditions play a significant role in increasing the energy demand, yet the governments' strategy of subsidizing electricity and resources in general through state- imposed tariffs and tax- free legislation is just another main aspect that promotes electricity penetration. Kuwait and Qatar, in particular, provide free electricity to their residents, while Saudi Arabia, Bahrain, and Oman subsidize the costs in order to maintain comparatively low prices. More aware pricing policies has been conducted across the UAE which are typically double those provided in Bahrain and Oman. A research done by Strategy & Middle East organization (Anouti, Kombargi, Elborai & Hage, 2020) estimates that energy subsidies have cost the GCC countries over the past 20 years more than \$120 billion, and as demand grows, leaving these policies in effect until 2030 would cost an additional \$150 billion. Therefore, energy efficiency represents a crucial opportunity for Arab countries to gain energy savings.

In recent decades, renewable energy has played an increasingly significant role in fulfilling global energy demands. It has undergone a dramatic growth worldwide as it is not only a key component in offering an integrated approach to reduce greenhouse gas (GHG) emissions, but also a notable prospect to promote innovation and stimulate economic growth while improving access to reliable, environmental- friendly and affordable energy.

Renewable technologies have drawn new investments of more than \$333 billion internationally, leading to more than 23% of electricity generation, twice as much as fossil fuel- based technologies (Louw,2018).

Although several Arab countries have made major strides in supporting renewable energy, their contribution to the energy mix remains marginal, at around 3.5% (Saab, 2017). In the Arab region, the forecast for wind and solar power is largely optimistic, as further policy reform tends to drive investments in new energy sources. Therefore, most Arab countries have appointed specific commitments for renewable energy for 2020 or later, placing solar energy a priority for achieving these goals.

Solar photovoltaics (PV) has always been an attractive renewable technology to the countries in the Middle East that are aggressively developing their energy systems away from reliance on fossil fuel sources for power generation as it become a cost effective tool against conventional power generation. Diversity in scale is one of the main benefits of renewable energy systems that compared to other sources of energy, has helped them enter a broader customer base. For instance, solar PV projects range from less than 100 Watts in domestic applications to hundreds of Mega Watts (MW) seen in industrial and utility projects. A substantial contribution has been made by small- scale systems to the performance of solar PV applications. In order to encourage the small- scale application of renewable technologies, many forms of policy incentives have been established, especially in developing countries, including feed-in-tariffs (FIT), renewable obligation certificates (ROC), net metering and renewable heat incentives. One of the most effective of these initiatives, FIT, initiated by Germany in the 1990s, is now being introduced in over 50 countries (Ahmed, Fardan & Asif, 2017).

The GCC region has one of the world's highest solar capacity, considering the geographic, environmental and economic characteristics of this region. The average Global Solar Radiation (GSR) available to photovoltaics cells in the area is calculated to be approximately 6KWh/m²/day (Alnaser & Alnaser, 2009) while the Direct Normal Irradiance figures available for solar concentrating technologies are approximately 4.5KWh/m²/day. The abundance of solar energy represents a significant potential that can be used to generate the required energy meeting the rapid growth in demand as in term of energy consumption, the GCC countries are among the highest in the world (Asif, 2016a) as shown in Figure (3).

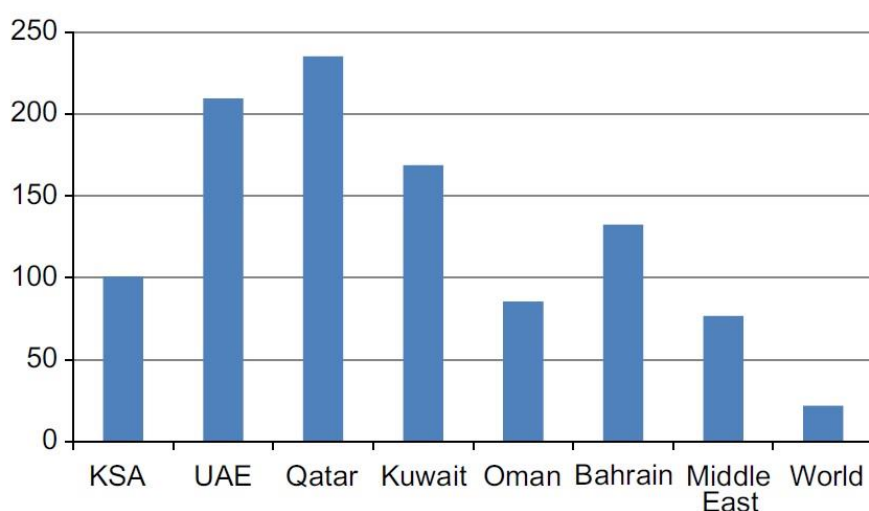


Figure (3): Annual per capita electricity consumption (Asif, 2016a)

Looking into the case of Bahrain, many studies affirmed that the majority of Bahraini buildings lack sustainable measures as they are built without any environmental consideration which generate huge energy crisis as it consumes around 80% of the total electricity consumption (Asif et al., 2019). These studies shows that the current electricity demand peaks at a maximum of 2,234 MW/day and expected to surge to 5,700 MW a day by 2030 (Alnaser & Alnaser, 2011).

This rapid growth in energy demand and the quick development in the building sector is set to significantly expand the energy and the environmental loads it faces. This circumstance requests a change in perspective regarding energy utilization practices and patterns of construction. The authorities in Kingdom of Bahrain have been constantly investigating for new energy alternatives that harmonize with the local environment. According to the Sustainable Energy Unit in Bahrain, the country targets to develop 5% of renewable energy projects by 2025 and 10% by 2035 (SEU, 2018). Accordingly, the Ministry of Electricity and Water established a net-metering policy to allow users to produce grid-connected electricity from renewable sources for self-utilization and feed overabundance to the national network (EWA Resolution NO. 2, 2017).

Whilst the aspects of the net-metering policy are being shaped by the authority, it is vital to develop specialized details on the potential and use of PV. Given the fact that the building sector especially residential buildings account for the biggest share of the total generated electricity reaching about 50% for example in Saudi Arabia (Asif, Hassanain, Nahiduzzaman, & Sawalha, 2019), has encouraged several studies throughout the world to explore the power output potential of PV systems in diverse types of buildings.

Reviewing such studies aids to conduct similar approaches in Bahrain since there aren't any similar studies studying this problem. The idea of what is called 'Sustainable City' or 'Solar City' (Byrne, Taminiau, Kurdgelashvili & Kim, 2015) derives its influence from the realization that over the last decades, solar PV energy technology has matured substantially, represented by sharply declining costs and increasingly growing global penetration rates (REN21, 2018). Supported by the awareness that solar radiation levels nevertheless have substantial energy

potential even in areas with modest solar supplies, advocates of solar cities have urged greater study commitment to the promise of the idea. Studies in the U.S. (Denholm & Margolis, 2008), the European Union (Defaix, Sark, Worrell & Visser, 2012), Spain (Izquierdo, Montañés, Dopazo & Fueyo, 2011) and Canada have all found that extensive urban PV installation could account for 15-45% of national electricity usage.

Correspondingly, significant projections of future PV power as 664 gigawatts (GWp) for the U.S. and 951 GWp European Union are influenced by these results. Major research grants on the application of PV on buildings have been issued as an act of change towards more sustainable communities where assessment of rooftop PV systems has been carried out worldwide. In Nepal, researchers have found that the estimated residential solar rooftop PV generation capacity using all available roof area is 6,126 MW, although utilizing mere 10-15% of the area will solve the existing energy problem (Gautam, Li & Ru, 2015). Likewise, Khan and Arsalan (2016) realized that 12.24 MW of solar power can be generated with higher performance rooftop PV panels, which is 122.4% of DHA phase's peak power demand in Pakistan. The effect of PV rooftops in terms of reducing cooling load was also analyzed through a research in China that noticed that the normal load of horizontal and tilted overhead PV roofs were decreased by 77.4% and 69.4%, while integrated energy efficiency was 63.35% and 62.73%, correspondingly.

Main studies in the GCC were focused on large and medium- sized PV applications. The output of these installations were investigated in order to calculate the daily kWh produced by each kW. In Kuwait, the efficiency of 85.05 kW and 21.6 kW thin-film, grid-connected PV systems installed on the roofs of two Kuwaiti campuses were assessed (Al-Otaibi et al., 2015), reporting a regular yield of 4.5 kWh/kW. Another study has

analyzed the solar energy output (kWh) from 1 kW PV plants in five different locations around Kuwait (Shagaya, Kabd, Sabriya, Mutribah and Umm Gudair), and revealed that the daily average reporting output for fixed system was 4.90, 4.86, 4.80, 4.78 and 4.90 kWh/kW respectively (Al-Rashidi & El-Hamalawi, 2016).

Meanwhile, in 2013, on the roofs of various buildings in Abu-Dhabi seven PV systems were installed (AlAli & Emziane, 2013). Amorphous silicon PV panels with a power output of 296.4 kW (tilted 22°) were found to produce 1,725 kWh/kW/year, i.e. 4.7 kWh/kW/day on average, while polycrystalline silicon PVs with a power output of 305.76 kW on the same tilted angle produce 1,624 kWh/kW/year which is an of average 4.44 kWh/kW/day. Also, an annual yield factor of 1875.1 kWh/kWp (daily average of 5.13 kWh/kW) was observed in a 1 MW PV installation in Oman (Kazem et al., 2017).

However, regionally, limited scholarships were conducted on PV applications or residential rooftops. In KSA, Khan, Asif and Stach (2017) concluded that the residential PV power generation capacity can participate to 30% of total residential electricity demand. Another research found that for PV applications, an average of 25% of the villa rooftops can be utilized (Dehwah, Asif & Rahman, 2018). From an economic view, Asif (2016b) has stated that the simple payback period for such application especially horizontal and tilted application of PV is found to be around 8 to 9.5 years. Furthermore, installing PV on rooftop of buildings at King Fahd University of Petroleum and Minerals (KFUPM) was found to reduce about 40,199 tons of CO₂ emissions annually and reduce conventional consumption by 16 to 20% (Asif et al., 2019). The modeling results have a net annual production of 37,750 and 46,050 MWh from 21.44 and 28.51 MW of tilted

and horizontal PV panel applications, sufficient to satisfy 16 and 20% of the overall electricity requirements of the campus, respectively.

In Bahrain, in consistent with the national renewable energy target which is 5% by 2025, various strategies and policies were put on action. In 2018, the Ministry of Electricity and Water has launched Bahrain's first "solar home" project in Jidhaffs with 24 solar panel installed on the rooftops while producing about 7.8 kW of electricity which is connected to the governmental power grid through a net metering scheme. The results of two-year installation in Figure (4) show that the system is producing about 11.9 MWh/ year, i.e. each 1 kW -PV is producing, on average, 4.6 kWh per day (Alnaser, 2021).

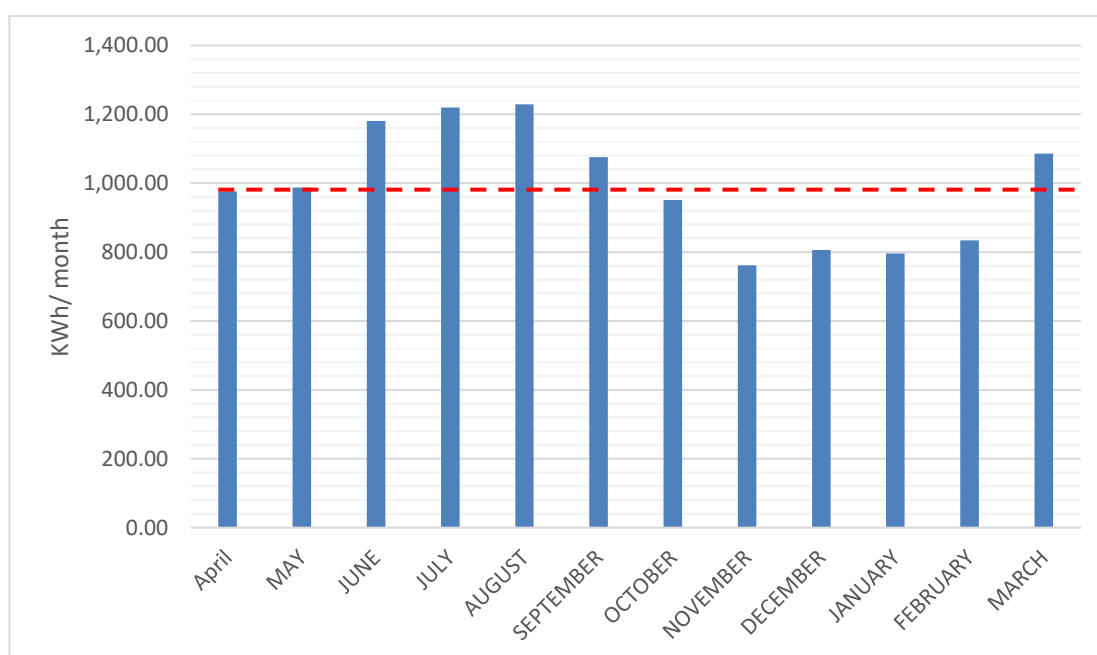


Figure (4): Annual solar electricity from 7kW rooftop Solar PV of one of four houses of Ministry of Housing project. (Alnaser, 2021).

All in all, most literature studies agreed that PV application on buildings acts as a key strategy to achieve the government's renewable goals in which it can drastically boost building's environmental performance as well through the huge reduction of greenhouse gas

emissions. Therefore, it is important to further study the impact of rooftop PV systems to ensure its effective application and encourage decision-makers to work towards a sustainable future.

The lack of such studies in Bahrain was the main reason to conduct this research which aims to study the potential of PV systems concentrated on the building rooftop of Southern New Town "Khalifa Town" as a case study. Investigations on the various types of structural, architectural and utilities-related features affecting the use of building roofs for PV as well as the modeling tool which is the PVsyst software was inspired by the previous literatures. It is expected that making use of the roof area of the 1,724 houses in Khalifa Town to be used for installing PV panels will lead to production of solar electricity not less than 20% of conventional electricity consumed, i.e. reducing 20% of the CO₂ emissions in this city.

Chapter Three

Methods and Procedures

- 3.1 Methodology
- 3.2 Research Study's Tools
- 3.3 Data Collection and Procedures

3.1 Methodology

The Kingdom of Bahrain is blessed with high solar radiations; making solar utilization is favorable. According to a Gulf Research Centre report (Alnaser & Alnaser, 2014), the Kingdom has the capacity to produce 33 Terawatt - hours (TWh) of solar energy per year, which is more than double the power demand in Bahrain in 2013.

The Southern New Town, so- called Khalifa Town, (Figure 5) has been selected to be a study area for an initiative by the Government of Bahrain and a blueprint in developing a modern planning, urban design and Architectural Innovations that utilizes clean energy such as solar energy, including walking neighborhoods style considering Bahrain's heritage and contemporary comfort.

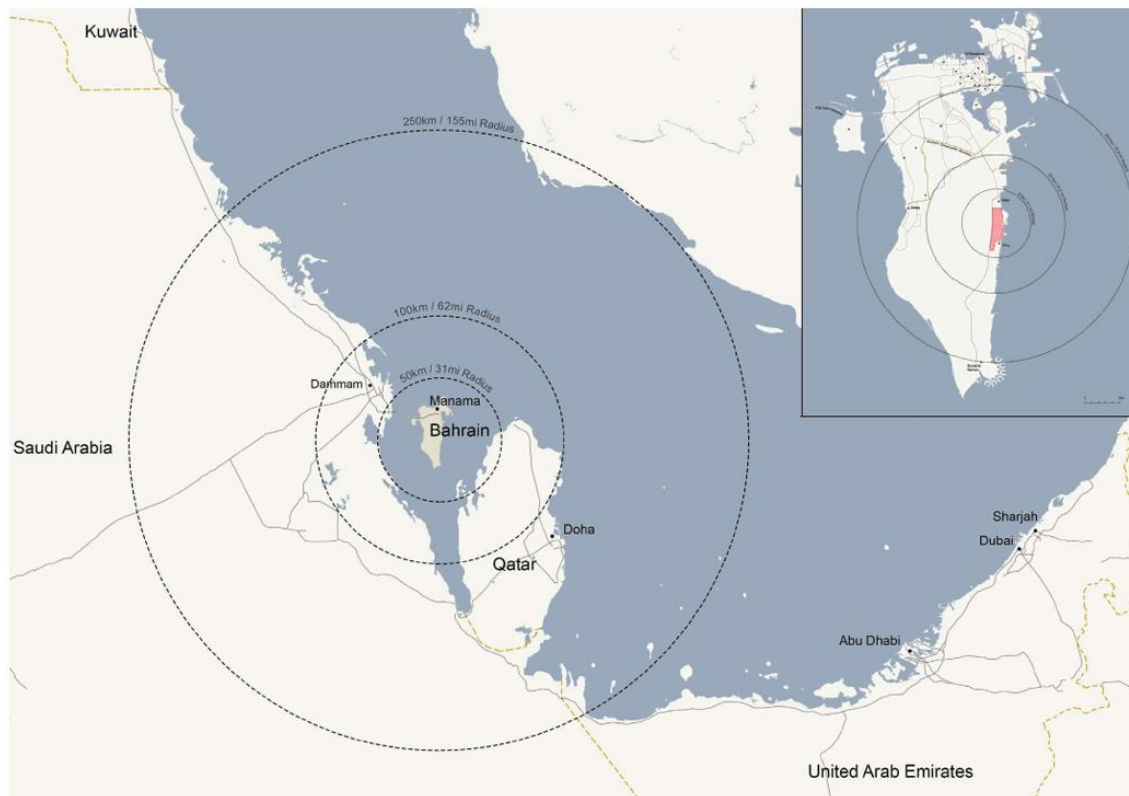


Figure (5): Khalifa Town location.

The town is suitable for the study due its large size as it is expected to deliver over 4,600 new villas and flats. Therefore, it's an opportunity to investigate the use of building's rooftops, of various sizes, to install PV panels to electrify part of the house. This is an important investigation since electricity consumption in Bahrain has drastically increased to reach 29.21 TWh in 2018 (IEA, 2021) as shown in Figure (6).

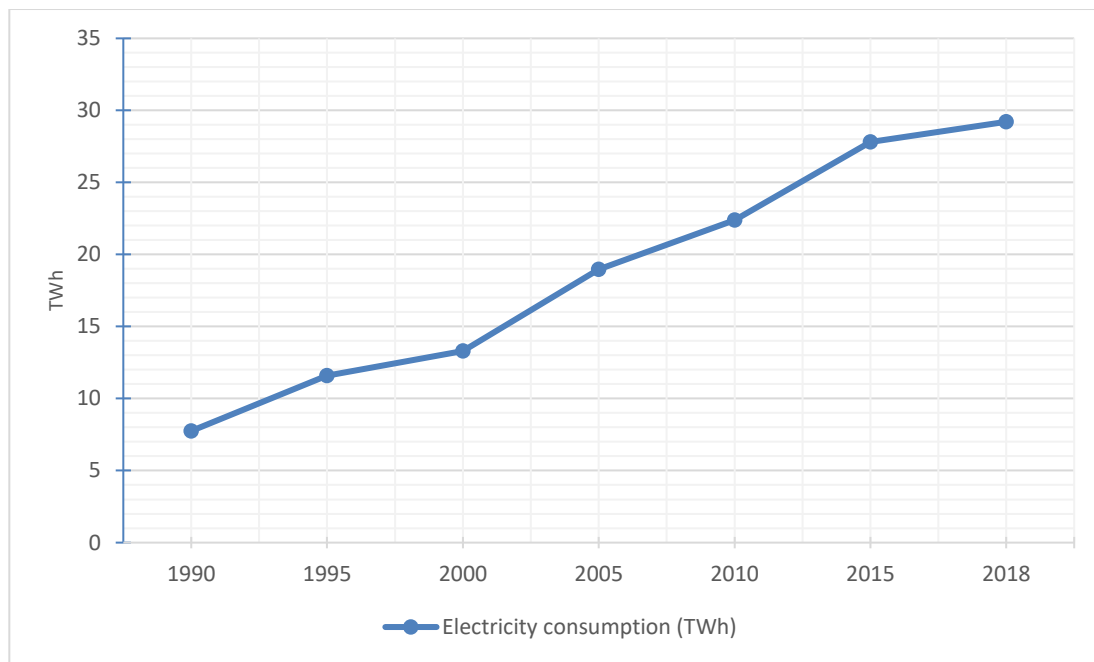


Figure (6): Electricity consumption in Bahrain 1990-2018 (IEA, 2021).

Aiming to meet Bahrain's growing housing demand, Phase One of the project was designed to include 1,700 units along with various public facilities. Thus, 120 units were constructed first as a prototype to investigate its functionality as shown in Figure (7). These units consist of five villa types (A1, A2, B1, B2 & C2) with approximate roof area of 100 m² per villa.

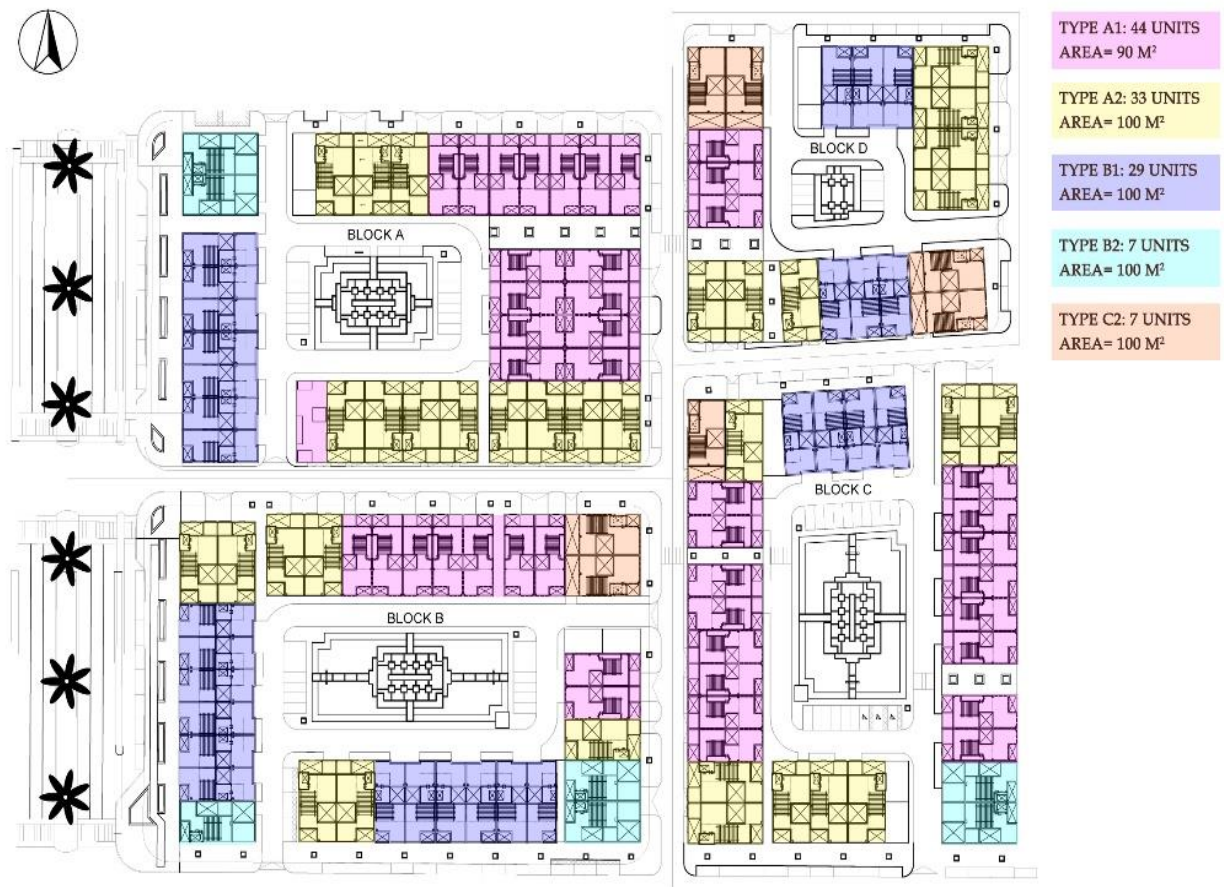


Figure (7): Khalifa Town master plan with houses classification.

The design of the villas was inspired by the Bahraini traditional culture. Therefore, the various house spaces were articulated to respect the strong family ties. The roof was designed to be treated as a green roof having a small pergola to provide shade for the residents to communicate. However, it has been seen that it needs to be modified to embrace both tradition and sustainability.

Figure (8), explains the structure of examining the 120 houses' rooftop spaces for PV installation through different activities which include solar resource assessment, rooftop area valuation, PV calculation and system modeling along with economic and environmental assessment.

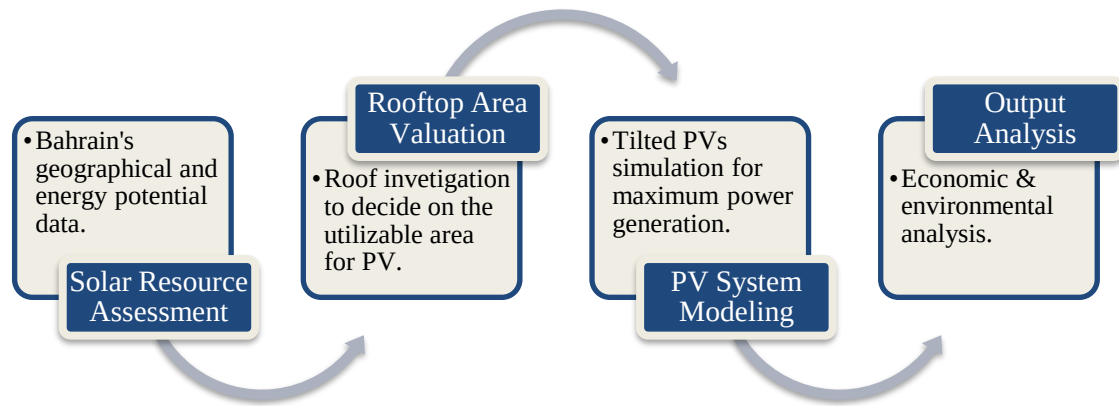


Figure (8): Methodology of the study.

The typical nature of building roofs of these villas is flat with high parapet walls, this will require some minor alteration in the roof area to consider the tilt angle and the orientation of the panel to maximize the solar electricity yield. This include elevating the panels on pillars facing the south orientation which will serve as both an insulation and shading element as well as a power generation tool.

3.2 Research Study's Tool

Since the main aim of this study is to explore the residential rooftops in Bahrain viability for producing energy through the PV systems, it is important to employ an accurate tool for obtaining realistic figures. Based on the reviewed relevant literature (e.g. Sharma, Kurian & Paragond, 2018, Asif et al., 2019 & Rout& Kulkarni, 2020), the system design various calculations are carried out by a modern software tool, known as PVsyst, which is believed to be one of the effective solar industry's energy modeling methods for simulating the energy harvest of a future project site. The software includes customizable solar module parameters which allows it to study, size, design, and analyze data of complete PV systems. For several locations all around the globe, PVsyst has an extensive

meteorological database. It also allows manual insertion of calculated data for locations not included in the app. The findings are presented in the form of a complete report with exclusive charts and tables.

The findings of the program are obtained through four main stages. The first stage enquires defining the project in terms of geographical location and meteorological data. The second section is where defining the plane various parameters like orientation, tilt angle and shading is essential. The third stage is where the PV module type is chosen along with various system information needed for the design like the load power and inverters. The fourth stage comes when the software runs the simulation of the inputted information of the system chosen and the outputs are summarized in a comprehensive study that includes unique charts and tables.

3.3 Data Collection and Procedures

Solar resource evaluation, PV utilizable rooftop area estimation, system modules and simulation are the four key stages of the PV system design in this report.

3.3.1 Solar resource assessment

Bahrain, like other GCC countries, is endowed with an abundance of high solar radiation due its special location within the arid zone. According to statistics (Alnaser & Alnaser, 2011), the average solar radiation level in Bahrain is 6 kWh/m²/day with a maximum solar yield of 6.8 kWh/m²/day in summer and nearly 5 kWh/m²/day in winter. Consequently, the annual solar radiation level reaches an approximate value of 2,180 kWh/m² as the clear sky days are more than 80% throughout the year as shown in Figure (9).

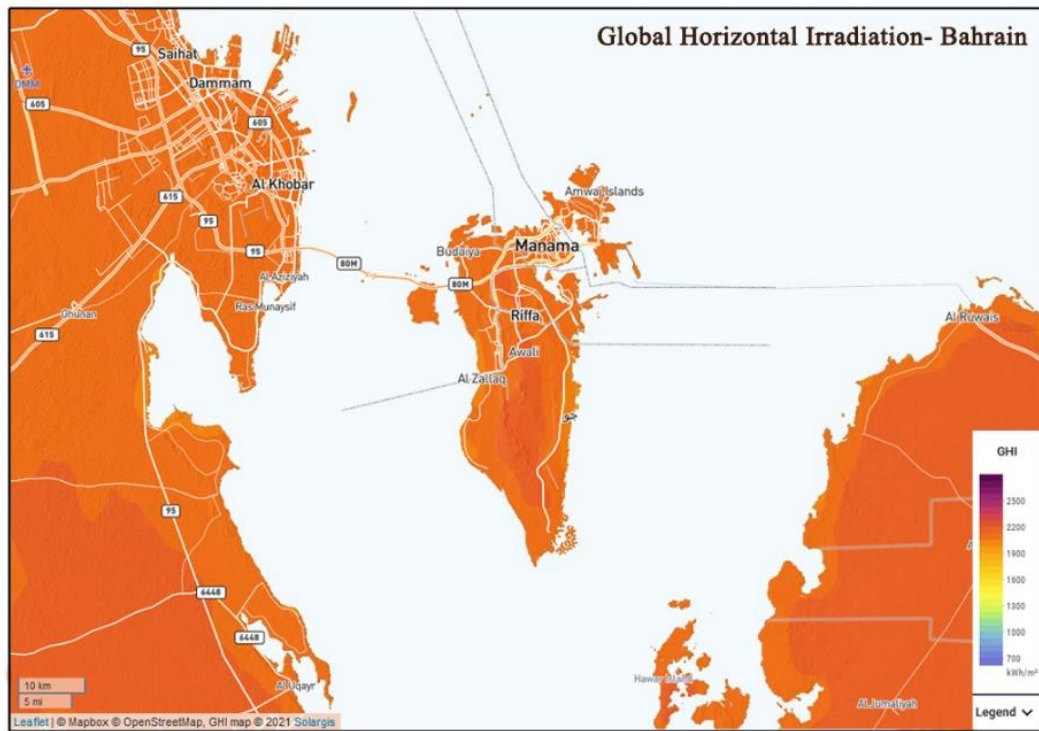


Figure (9): Solar map of Kingdom of Bahrain.

Khalifa Town is a new town situated in the Southern Province of Bahrain. According to the software estimates, it has an annual solar radiation level of about 2,016.1 kWh/m². Table (1) shows the monthly distribution of solar radiation which is very important to determine the solar electricity production as well as other metrological parameters that affect the performance, availability and ageing of a PV system. These figures are based on high- resolution solar and meteorological database developed and operated by Solargis. The data parameters presented in this report are computed by Solargis models and algorithms which are attached in the appendix.

Table (1): Annual solar data of Khalifa Town, Kingdom of Bahrain.

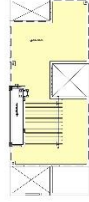
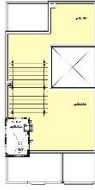
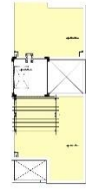
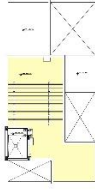
Month	GHI (kWh/m ²)	DNI (kWh/m ²)	DIF (kWh/m ²)	TEMP (°C)
January	113.0	108.6	55.3	17.1
February	123.2	104.4	60.5	17.8
March	163.0	119.2	80.2	20.5
April	177.5	113.1	92.0	24.4
May	215.7	146.3	101.7	28.9
June	224.4	165.9	97.4	31.9
July	218.2	142.8	106.4	33.3
August	209.0	145.4	98.1	33.8
September	186.9	147.9	81.3	32.5
October	161.2	141.6	72.2	29.5
November	116.7	107.6	57.4	24.4
December	107.3	106.7	53.4	19.4
Yearly	2016.1	1549.6	955.8	26.1
Note that : GHI, Global Horizontal Irradiation; DNI, Direct Normal Irradiation; DIF, Diffuse Horizontal Irradiation .				

3.3.2 Rooftop area valuation

Nowadays, photovoltaics technology has been used as an integrated smart solution for the buildings around the world. Architects find it sensational to design these smart building facades taking into consideration the variety of types, shapes and sizes of a PV system. It can either be placed horizontally and tilted on rooftops or vertically mounted on the walls and windows.

This study investigates the scope of PV applications on rooftops where one of the key design considerations is to calculate the available roof space. Areas of the five villas rooftops have been calculated using AutoCAD software and presented in Table (2).

Table (2): Areas of the five villa types rooftops at Khalifa Town, Kingdom of Bahrain.

Villa type	Area of the rooftop (m ²)	Villa illustration
A1	90	
A2	100	
B1	100	
B2	100	
C2	100	

Like all building rooftops in Bahrain, the structure of building roofs is usually occupied with broad architectural and structural features and facilities that limit both the availability and shading of space in terms of PV applications. Figure (10) illustrates the major obstacles that

imposed a great impact on the roof's viability for PV applications like staircase room, high balustrade walls, HVAC (Heating, ventilation and air conditioning) system units, satellite antennas and water heater and tanks.



Figure (10): Main restriction affecting PV application.

Besides, this study aims to maintain and enhance the resident's experience on top of the roof and consider the various possible activities or hobbies that families might do; it is important not to kill the value time they might have together especially that Bahrain weather is 70% moderate throughout the year. From an aesthetic point of view, the overall look of the house is an important factor to be taken into consideration in this study as well. Investigations were made to find an optimum solution to balance between energy production and the architectural presentation of the system simultaneously. As a result, the study has considered using an elevated PV panels on a 3 m high metal structure. This configuration has many advantages as it helps to maximize the space available for PVs, insulate the rooftop floor from direct sun radiation thus reducing the cooling and heating load. Also, having a shaded roof is a pleasure that the resident usually looks for.

Since the orientation and inclination angle of the mounted panels have a significant impact on the output of the PV system, the panels are designed to be facing the south orientation through studying the

orientation of the house and creating various design alternatives. Alnaser (2010) performed an analysis in which the incident solar power on surfaces with various tilt angles ($16^\circ, 26^\circ, 36^\circ$) facing south was measured and summarized in Table (3). It was discovered that solar gain for south facing PV panels fixed at a tilt angle equal to Bahrain's latitude of 26° N produces the highest solar electricity. However, taking into consideration the height of the installed panels in this study, the wind load coming from the north induced on the panels as well as the overall aesthetic look of the house, it has been decided to fix the panels on 5° angle facing the south orientation. A comparison between 26° and 5° tilt angle was made in this study to calculate the difference energy outcome.

Table (3): Monthly sums of Incident solar radiation at specified tilt angle ($16^\circ, 26^\circ, 36^\circ$) (Alnaser, 2010).

Monthly sums of the incident solar energy [kWh/m²]			
Month	Surface slope [°]		
	16	26	36
January	124.2	134.0	140.8
February	149.6	157.1	161.2
March	142.4	143.6	142.0
April	167.9	164.2	157.4
May	162.5	155.8	146.3
June	172.9	163.9	152.0
July	158.8	151.7	142.1
August	159.2	155.1	148.1
September	164.3	164.6	161.6
October	143.4	148.5	150.4
November	141.8	152.1	158.8
December	112.2	120.7	126.5
Σ	1799.2	1811.3	1787.1

3.3.3 PV system modelling

PV panels of 460 Wp mono crystalline type were used in this research. The main characteristics of the PV module used are summarized in Table (4). Following that, system components such as the PV array circuit combiner, fuse switches, inverters, wires, and racking were utilized to stabilize the system. This will be elaborated in the following chapter.

Table (4): Key features of PV module used in the study.

PV module appearance	Key features	Description
	Cell type	P type Mono-crystalline
	Dimensions	2182 × 1029 × 40 mm
	Maximum Power (P max)	460 Wp
	Module Efficiency STC (%)	20.5%
	Lifetime Power Yield	2.5% 1 st year degradation, 0.6% linear degradation
	Warranty	25 year warranty

Chapter Four

Results, Discussion and Recommendations

- 4.1 Results
- 4.2 Discussion
- 4.3 Conclusion and Recommendations

4.1 Results

The evaluation of using PV systems particularly on residential buildings rooftops in Bahrain is an area that has not yet been tended towards. As a result, this study was designed to address this information gap through examining the rooftop areas of the Southern New Town houses (Figure 11) for PV application and determine its energy output.



Figure (11): Khalifa Town satellite map.

The main findings of this study are divided into four main categories which are the following:

- a- rooftop area estimation.
- b- PV power generation
- c- PV system economics
- d- PV system environmental analysis.

The study area consists of 120 villas of five types (A1, A2, B1, B2 & C2) with approximate roof area of 100 m² per villa. According to the results of the rooftop area analysis, the total net available roof area on all

houses is 11,560 m². However, building rooftops in Bahrain are usually characterized by being dominated by a variety of architectural and structural features and facilities that restrict the amount of space available for PV applications especially those elements impose substantial shading effect constraint like the high parapet walls and the staircase room. Therefore, this study envisages the use of elevated PV panels on a 3 m high metal frame to optimize the space available for the photovoltaics and minimize difficulties related to shadow avoidance. This design will play an important role in reducing the high direct solar input to the roof - which is transmitted at a later time (evening) to the interior of the house, i.e. acting as an insulation since air is a good heat insulator. These elevated PV panels will reduce the cooling load for the house and will provide the luxury of having a shaded roof where the resident can enjoy their time underneath them after fitting an artificial grass with comfortable and neat furniture Figure (12).

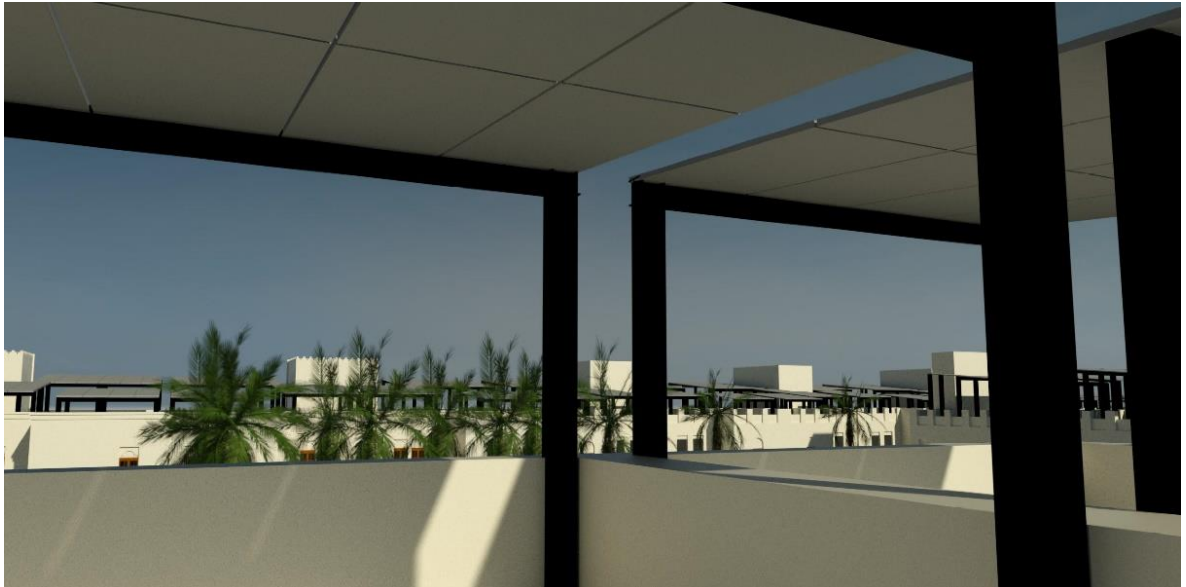


Figure (12): Rendered view from one of the rooftops at Khalifa Town, Kingdom of Bahrain.

Based on the relevant literature reviews (Zang, Guo, Wei & Sun, 2016; Yunus et al., 2019), many research papers have reported that the south facing tilt angle of the PV panels, on the Northern hemisphere, equal to the location's latitude would contribute to improved solar gain. Table (5), shows the difference between the total energy yield from PV panels with different tilt angles of 26° and 5° on one of the villas as been calculated using PV Syst. These results are consistent with previously calculated figures for Bahrain for tilt angles from 0° to 40° at intervals of 10° (Alnaser, 2010) where the author found that angle 26 yield is 1,811.3 kWh/m² while at 5° is estimated to be 1,740 kWh/m², i.e. angle at 26° is larger by 4% while in our calculation the increase is 5%.

Although the energy produced by fixing the panels on 26° is higher, it was decided to sacrifice losing solar electricity (by 5%) compared to panels at a 5° angle (both facing the south) . This is to reduce the wind load casted on the elevated tilted installed PV panels in one hand and consider the neatness of overall architectural appearance of the building, i.e., avoiding visual pollution.

Table (5): Produced energy for 26° and 5° tilt angle installed on one villa at Khalifa Town, Kingdom of Bahrain.

Tilt Angle	26° angle	5° angle
PV No. of Modules	29 module	29 module
PV Power	13 kWp	13 kWp
Produced Energy	24.14 MWh/year	22.95 MWh/year
Performance Ratio	79.03%	80.07%

In this study, the houses' orientation is studied carefully, as it changes according to the design of the neighborhood, to make sure that all the PV panels are designed to face the south direction (180°). Each villa type at Khalifa Town has at least more than three building orientations.

4.1.1 PV system power generation

The performance of the system was calculated and analyzed using the PVsyst software where the villa units were modeled within the software to count for the surrounding shading impact. Herein, some of the core examples of the system output performed by the PVsyst version 6.88 is presented. The annual solar electricity generated from the PV panels of the five villas type, along with their various orientations, are illustrated in Table (6) as well as the area utilized by the PV system on each rooftop.

Table (6): Total produced energy per villa for different villa types at Khalifa Town, Kingdom of Bahrain.

Villa Type	Orientation 1		Orientation 2		Orientation 3		Orientation 4		Orientation 5		Orientation 6	
	PV Area (m ²)	Total Prod. Energy (MWh/year)	PV Area (m ²)	Total Prod. Energy (MWh/year)	PV Area (m ²)	Total Prod. Energy (MWh/year)	PV Area (m ²)	Total Prod. Energy (MWh/year)	PV Area (m ²)	Total Prod. Energy (MWh/year)	PV Area (m ²)	Total Prod. Energy (MWh/year)
A1	60.6	21.3	60.6	21.3	60.6	21.45	60.6	21.45	65.1	22.95	65.1	22.95
A2	76.3	26.97	76.3	26.97	80.8	28.19	80.8	28.19	85.3	29.94	85.3	29.94
B1	76.3	26.92	76.3	26.92	76.3	27.03	76.3	27.03	76.3	26.19	76.3	27.00
B2	85.3	29.91	85.3	30.12	85.3	29.91	85.3	30.12	NA	NA	NA	NA
C2	80.8	28.32	89.9	31.55	76.3	26.66	76.3	26.66	NA	NA	NA	NA

The ratio of the available PV area to total roof area is about 35%, and after elevating the PV panels on metal structure, the ratio becomes approximately 77%, i.e. having the panels elevated gives more freedom of space comparing to those placed directly on the rooftop due to the higher degrees of restrictions. A2 villa type is chosen as an example for addressing the comprehensive findings of the system modeling for tilted PV panel deployment. (Figure 13).

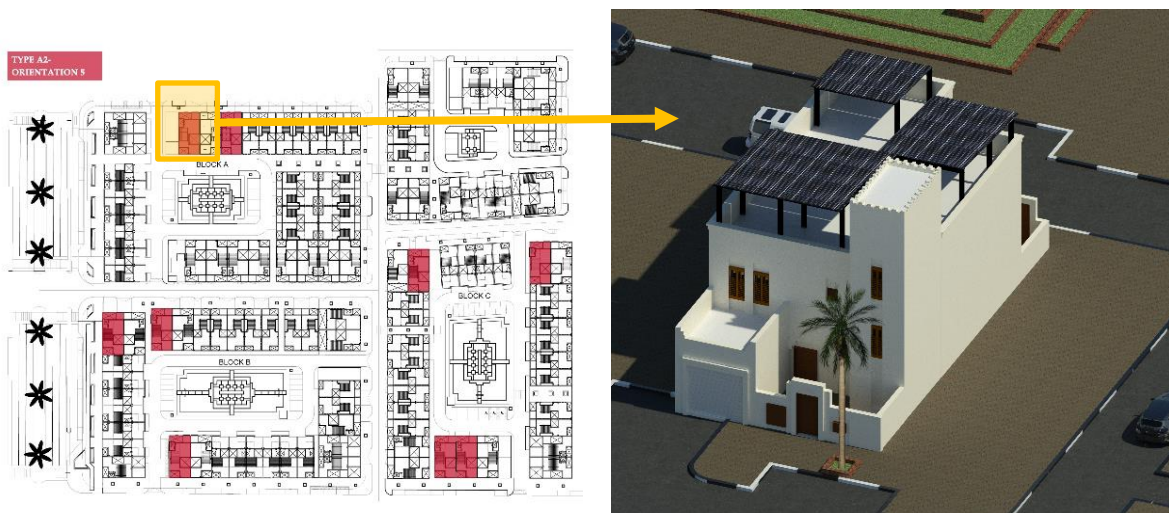


Figure (13): A2 villa type chosen orientation for further analysis.

A 17 kW_p - PV system has been used for this villa unit. A detailed outline of the main parameters for the tilted PV system used for this villa type and orientation is provided in Table (7). According to the simulation, the system is producing about 29.94 MWh/year in which each kW is producing an average of 4.69 kWh per day, i.e. the specific production is 1,713 kWh/kW_p. A detailed summary of the monthly produced energy records is presented in Figure (14). According to the simulation, if each house consumes approximately 5,000 kWh per month, based on EWA data, the electricity consumption per capita in domestic sector in 2018 was 5,189 kWh – which is 62.2 MWh annually-

(EWA, 2018), therefore, the installed 17 kW - PV system on the roof will meet almost 49% of the total resident's needs. Based on the fact that PV panels degrades at a rate of 0.6% annually then the expected electricity yield in year 25 of the installation will be 25.4 MWh which will be meeting 42% of the total resident's needs.

Table (7): Overall parameter outline of PV system used for A2 villa type at Khalifa Town, Kingdom of Bahrain.

Parameter	Value
Total No. of PV Modules	38 modules
Unit Nominal Power	460 Wp
PV Array Total Power	17.48 kWp
Total No. of Inverters	1
Annual Produced Energy	29,940 kWh
Annual Specific Produced Energy	1,713 kWh/kWp

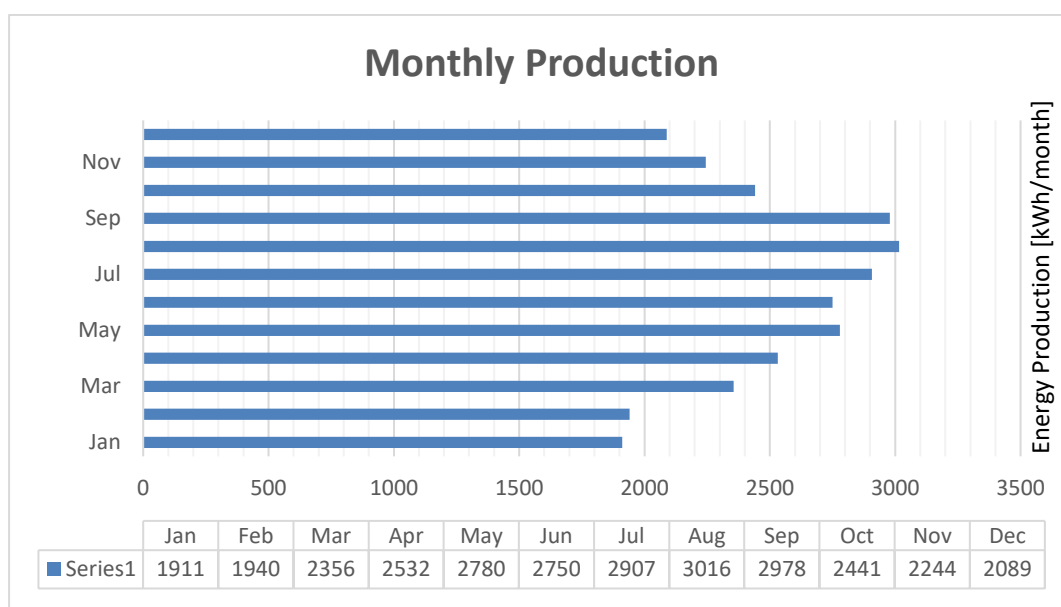


Figure (14): Monthly produced energy for the chosen villa.

In Figure (15), the nominal power values for the 5° tilted PV applications have been given. This is the largest possible value obtained from the 17 kW_p PV panels because it is the energy produced under best practice (1,000 W/m² radiation perpendicular on the PV panels at air mass =1 and Temperature 25° C). It is clear that, although the power production increases in summer, the energy losses are seen to be greater as well. Irradiance fluctuations, temperature differences, weather conditions, inverter quality and wiring, and other factors all contribute to total losses of the system.

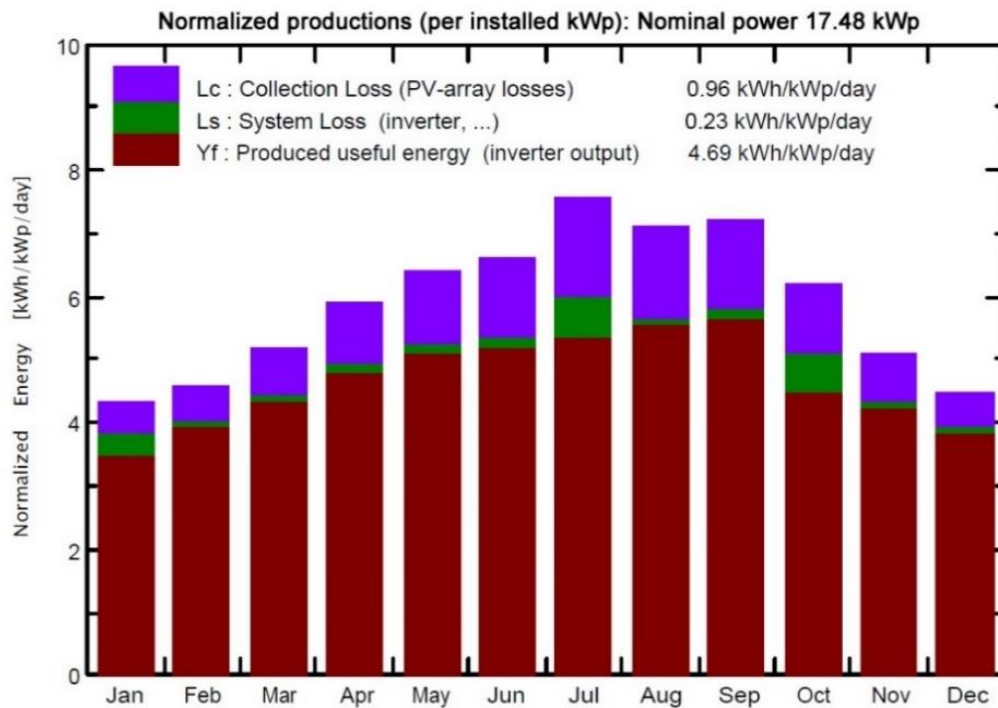


Figure (15): Normalized production values from A2 villa type.

The monthly performance ratio (PR) of the PV system used, which is often referred to as the quality factor (Khalid, Mitra, Warmuth & Schacht, 2016), is demonstrated in Figure (16). The PR acts a tool to measure the quality of a PV system itself independent of its location and specifies how energy efficient and dependable the PV plant is. It can be further described as the percentage that expresses the

relationship between the PV plant's real and theoretical energy outputs, where $PR = \text{Actual reading of plant output (Y}_f\text{)} / \text{Calculated nominal plant output (Y}_r\text{)}$. It thus depicts the percentage of electricity that is currently eligible for grid export after accounting for energy losses.

Knowing the fact that the closer a PV system's PR value is to 100 %, the more effective it is, the PV system used on the villa has an average PR value of 79.74% where it decreases on summer months owing it to the increased losses due to higher atmospheric temperatures. A detailed flow diagram of the power generated from the PV system used, portraying the corresponding losses at different stages has been shown in Figure (17).

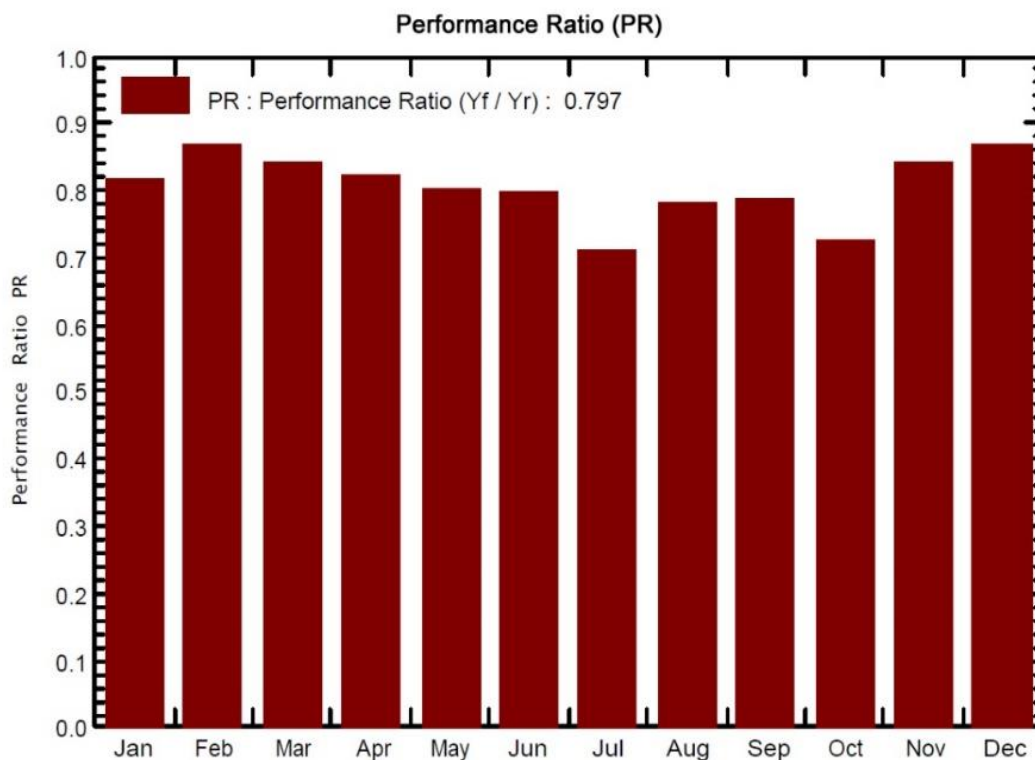


Figure (16): Monthly performance values from A2 villa type.

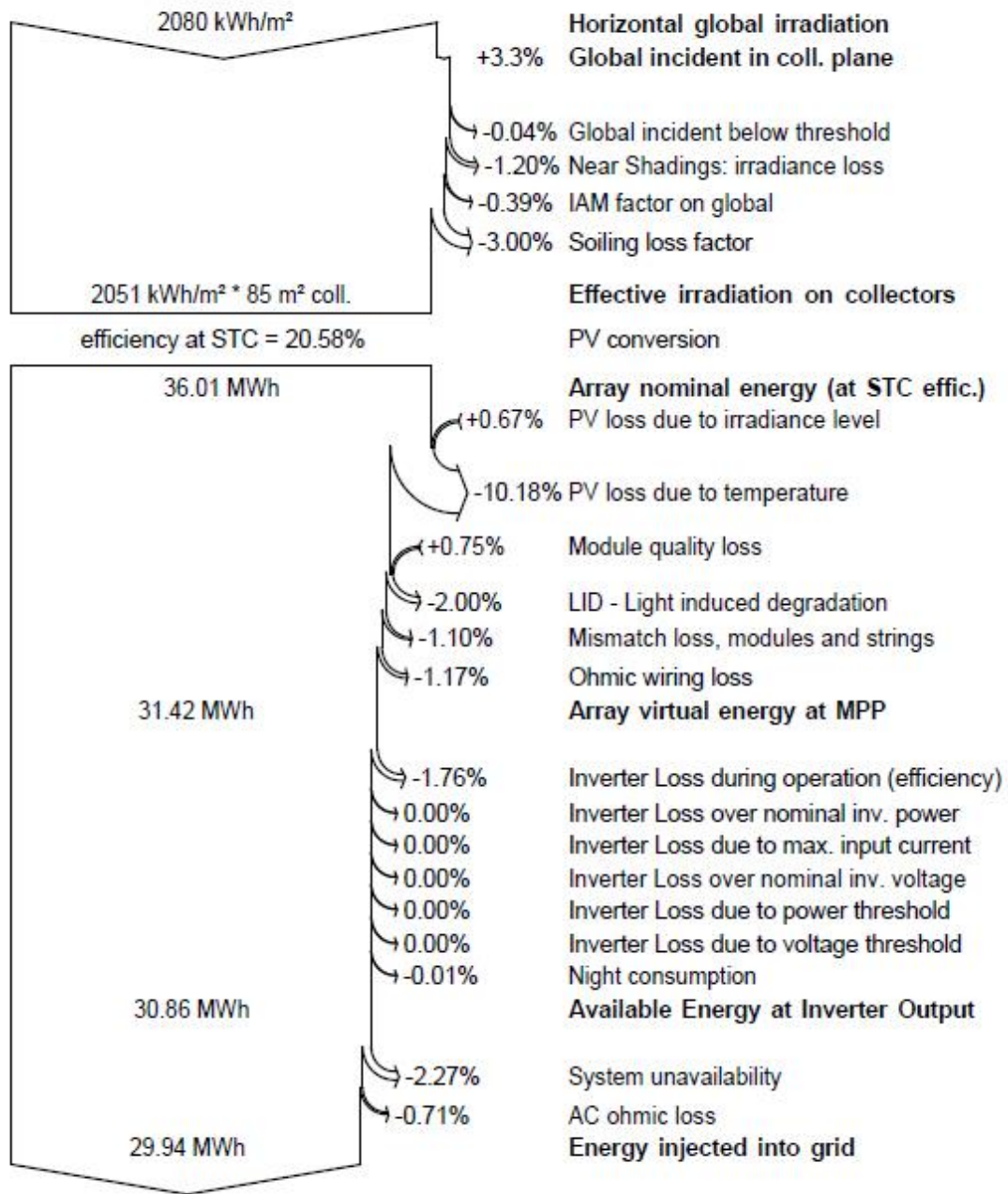


Figure (17): PV system losses diagram.

According to the simulation, the overall output from PV systems, deployed on the 120 housing unit rooftops in Khalifa Town, is estimated to be about 3,129 MWh/ year for 5° tilted PV application as illustrated in Table (8) expecting it to meet 43% of the total electricity need.

Table (8): Summary results of the town's generated energy from tilted PV application.

Villa type	No. of Units	Roof Area per Unit	Total Roof Area (m²)	Total PV. Area (m²)	Total Prod. Energy (MWh/year)
A1	44	90	3960	2733.9	964.1
A2	33	100	3300	2711.4	949.9
B1	29	100	2900	2289	805.1
B2	7	100	700	597.1	210.0
C2	7	100	700	570.3	199.7
Total Electricity Produced on the Study Area					3,128.8

It is important to mention that, in this study, five different PV power capacities (12, 13, 15, 16 and 17 kW) were used for the five housing units to test the various energy outcomes. This is a useful practice because it will enable in knowing which system to be installed based on the user's need and budget. Figure (18) shows an overview on each system and its corresponding solar electricity yield.

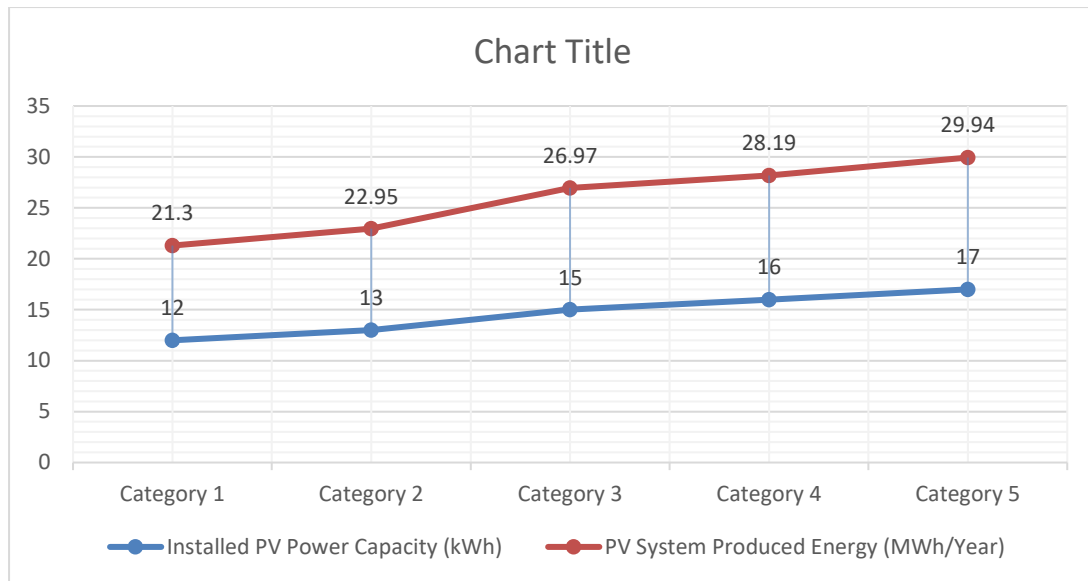


Figure (18): Solar electricity yield from various PV installation capacities (12, 13, 15, 16 and 17 kW).

4.1.2 PV system economic impact

The most important information the household needs to know is when he will get his money back, i.e., when will he receive electricity at no cost. This is called payback period (PBP). Also, the resident will be interested to know whether installing 17 kW- PV is a good investment or not, specially PV panels are not cheap; they are – in general – about BD 0.4 per W (BD 415 / kW) and has a life time of 25 years. This is determined by knowing the Net Present Value (NPV). Therefore, herein, the simple payback analysis (PBP) and net present value (NPV) analysis, were used to evaluate the economic impact of such project. Villa A2 is taken as an example.

Table (9) shows the approximate initial expense of the system, which includes the cost of PV panels, auxiliary components such as charge controllers, inverters, and wire, miscellaneous works, profit as

well as the cost of structure used. Rates for PV device components were collected by quotations from local vendors.

Table (9): Initial investment calculation.

Item	Brand	Quantity	Unit Price (BD)	Item Cost (BD)	Total Sale Price (BD)
PV modules	Jinko Solar	38	43	1,634	1,634
Inverters	Huawei	1	850	850	850
Structure	Chiko	1	440	440	440
BOS components	General	1	450	450	450
Electrical works	NA	1	350	350	350
Mechanical works	NA	1	300	300	300
Miscellaneous	General	1	640	640	640
Overheads					1,750
Profit					850
Total					BD 7,254

Currently, in Bahrain, the electricity tariff is applied as per usage either domestic or non-domestic (commercial). Domestic tariffs are divided into three categories as seen in Table (10), i.e. 3 fils per kWh, 9 fils per kWh and 16 fils per kWh.

**Table (10): Applicable electricity tariff for Bahraini domestic usage in Bahrain.
(EWA, 2018)**

Categories for Domestic Tariff for Bahrainis having one account (Subsides).		Electricity consumption unit	Monthly fixed charge (BD)	Electricity usage charge (Unit)
				Years 2016-2019
Consumption Units	First 3,000	Kilowatt- hour (kWh)	1.000	3 Fils
	3,001-5,000			9 Fils
	Above 5,000			16 Fils

I. Net Present Value

The Net present value (NPV) is a dynamic tool used to assess the profitability of the PV project. As $NPV > 0$, it means that the projects will gain more money if they fulfill the profitability requirements set by the benchmark yield; in other words, the investment in this project is economically viable. The NPV is calculated using the following equation (Haji, Durazi & Al-Alawi, 2017):

$$NPV = V_0 + \sum_{t=1}^n \frac{V_t}{(1 + d)^t},$$

where V_0 is the cash flow value at present, V_t is the cash flow value at the end of period t , n is the number of periods in other the project duration which is equal to the warranty period of the PV system (25 years based on the characteristics of the system used), and d is the discount rate which was assumed to be 3.5% in this study. The findings of the NPV analysis are illustrated in Table (11).

Table (11): NPV analysis calculations for installing 17 kW -PV system at Khalifa Town, Kingdom of Bahrain.

Total Investment = BD 7,254		Unit Production=29,944 kWh	
Unit Price= BD 0.029		Inflation rate, d = 3.5%	
Years	Production (kWh)	Estimated cash flow	NPV (BHD)
1	29,944	868	839
2	29,195	847	818
3	29,020	842	813
4	28,846	837	808
5	28,673	832	803
6	28,501	827	799
7	28,330	822	794
8	28,160	817	789
9	27,991	812	784
10	27,823	807	780
11	27,656	802	775
12	27,490	797	770
13	27,325	792	766
14	27,161	788	761
15	26,998	783	756
16	26,836	778	752
17	26,675	774	747
18	26,515	769	743
19	26,356	764	738
20	26,198	760	734
21	26,041	755	730
22	25,885	751	725
23	25,729	746	721
24	25,575	742	717
25	25,422	737	712
Total	kWh 684,348	BD 19,846	BD 19,175
NPV			+BD 11,921

The table indicates that installing 17 kW -PV will make good investment, i.e. the revenue will be nearly BD12,000 if the cost of kWh is purchased by the utility (EWA) for 29 fils otherwise it will be a loss investment (BD – 5,270) if it is purchased for 3 fils from EWA. If inverters are expected to be changed every 10 years, the final revenue would be about BD10,200 since each inverter costs BD 850. In other words, installing 17 kW solar PV on housing rooftop at a cost of BD 7,254 will save the owner paying approximately BD 10,200 for supplying solar electricity for 25 years - as highlighted in the cash flow diagram in Figure (19).

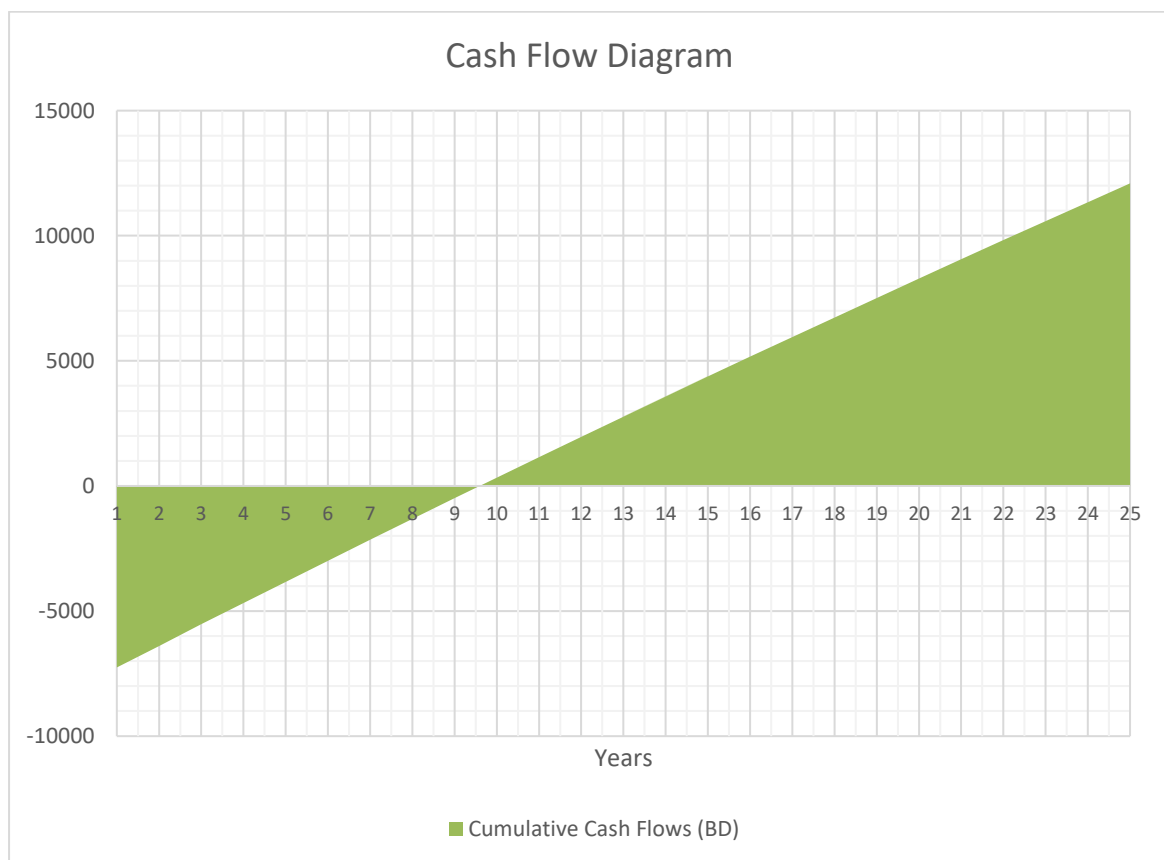


Figure (19): Cumulative savings over 25 years in investing in 17 kW -PV system on villa roof top at Khalifa Town, Kingdom of Bahrain.

II. Payback Period

The payback period is defined as the amount of time it takes for an investment to be fully repaid or amortized. It identifies how long it would take for the cumulative net cash flows to equal the initial expenditure. In this study, the payback period has been estimated twice, once while considering the tariff to be 3 fils (subsidized) and the other using the actual cost of electricity which is 29 fils with the help of the cash flow diagram developed (Fig 19) as well as using the following relation:

$$\text{PBP} = [\text{Cost of total PV system} / \text{System saving (solar electricity produced in kWh x tariff rate)}]$$

It can be observed that PBP of the PV system when tariff is 29 fils is found to be 9.6 years compared to PBP of 83.5 years if the tariff used is 3 fils! This indicates that the low kWh tariff in Bahrain provides no incentive to use PV for electricity production at Khalifa Town as the payback period (PBP) is too high.

4.1.3 Environmental Impact

According to the International Energy Agency latest statistics (IEA, 2021), Bahrain's annual GHG emissions equal 30.2 million tons of CO₂ in 2018, equivalent to around 20 tons per capita. Electricity and heat producers sector account for more than 87% of CO₂ emissions where the residential sector alone consumes more than half of the electricity produced and accounts for 20% of the country's overall CO₂ emissions. Therefore, it is important to invest in the renewable energy as an attempt to minimize CO₂ emissions.

In this study, the 3,129 MWh which is the amount of generated electricity from the installed rooftop PV system of the 120 housing unit is found to equal saving about 2,422 ton of CO₂ emissions as each 1 kWh equal emission of 0.774 kg of CO₂ when using natural gas. This amount of CO₂ saving is equal to saving 979,377 kg of oil or 7,201 barrels of oil (1 barrel = 136 kg of oil) (Alharbi, 2021). Thus, the total CO₂ emissions saving for the total 1,724 units of phase 1 in Khalifa Town is estimated to be equal 34,794 tons of CO₂ emissions, i.e. reducing about 21% of the CO₂ emissions in this city.

4.2 Discussion

This study employs the Southern new town - called "Khalifa Town" - as a case study to look at the future of PV systems in residential buildings rooftops in kingdom of Bahrain. It represents a model of a sustainable community developed by kingdom of Bahrain and Prince Charles Foundation, UK, where 120 houses' rooftops are assessed for this purpose. The total rooftop area available has been calculated using AutoCAD software and was equal to 505,165 m². After accounting for the necessary shadow avoidance spacing as well as other obstructive features on building roofs, a net area of 4046 m² was discovered to be suitable for PV systems if placed directly on rooftop surface which represent almost 35% of the available roof area which is almost equal to the percentage estimated in other researches (Dehwah, Asif & Rahman, 2018; Asif et al., 2019).

It is found, herein, that elevating the PV panels on metal structure will increase the space in the roof to reach 77% of roof area, i.e. total net area of 8900 m², which is larger than before, i.e. 35% with total area 4046m². This arrangement has several advantages, among them is reducing the high direct solar input to the roof, which is then transferred to the interior of the building later (evening), i.e. serving as insulation. According to previous studies on rooftop energy savings due to shading (Wang, Wang, & Liu, 2017; Silva, AbdulKarim, Haji, Mestarehi & Lamela, 2018), it has been found that nearly half of the solar gain on the roof slab could be eliminated through this configuration (shading with PV panels), resulting in 1.7 to 7% reduction in the building's average annual energy consumption.

Regarding the tilt angle of the proposed PV system, although energy generated by mounting the panels at a 26° angle produces more solar electricity, it was agreed to forego a 5% reduction in solar electricity compared to panels at a 5° angle facing the south orientation for the following reasons: On one hand, this will reduce the wind load placed on the elevated tilted PV panels as have been discovered through previous projects in Bahrain where the wind load have been calculated and therefore, panels were placed at 10° angle (Rangan, 2021), and on the other, to maintain the building's overall architectural appearance - as shown in Figure (20 & 21)- which illustrates how the proposed installed PV system would look like.



Figure (20): Rendered views of the proposed PV Installed system in Khalifa Town.



Figure (21): Rendered views of the proposed PV Installed system in Khalifa Town.

The results of the modeling work, which was conducted with PVsyst software to calculate the power generation from 5° tilted PV application on the 120 housing unit rooftops, show that the total annual production is about 3,129 MWh in which each kW is producing an **average of 4.69 kWh per day**. This is consistent with the two- years actual results obtained from Bahrain's first solar home project launched by the Ministry of Electricity and Water, where the 7.8 kW- PV system produces about 11.9 MWh/ year in which each kW is producing an average of 4.6kWh per day as elaborated in Chapter 2 (Alnaser, 2021). Thus, the system is expected to meet about 43% of the total electricity need of Khalifa Town. An overview 3D rendered view of the proposed design of housing units in Khalifa Town is illustrated in Figure (22).



Figure (22): Overall Rendered view of the proposed PV Installed system in Khalifa Town, kingdom of Bahrain.

Bahrain's per capita electricity consumption is 19,592 kWh with 20 tons CO₂ emissions per capita which is considered a very high value credited to the hot and humid conditions that prevails almost all year. Statistics reveals that the energy sector in Bahrain accounts for more than 87% of CO₂ emissions which is high due to the high economic growth rates and the nearly free domestic energy prices. Therefore, installing PVs is an excellent means to reduce the carbon footprint. The findings of the study show that the cumulative CO₂ emissions savings for the total 1724 units of phase 1 in Khalifa town of an annual energy yield **44,953 MWh** is expected to be 34,794 tons of CO₂, which is equivalent to a reduction of around 21% of the city's CO₂ emissions. This indicates that solar photovoltaic systems can help to increase building efficiency by reducing emissions of greenhouse gases.

Findings of the economic analysis indicate that installing PV will be counted as a good investment only if the utility (EWA) buys the cost of kWh for 29 fils, otherwise it would be a huge loss as the PBP was found to be 9.6 years for a tariff of 29 fils opposed to 83.5 years when 3 fils is accounted. However, if the government put a policy for Feed – In – Tariff (FIT) to encourage households to install PV systems on their rooftops – in order to meet its target of having 5% of its electricity produced from renewable energy by 2025 (REN21, 2018), then the investment will be much profitable with relatively short payback period. If a FIT is put as 75 fils to 86.3 fils as suggested by Haji, Durazi & Al-Alawi (2017), then for 75 fils the revenue for the sample villa taken will be BD 42,336 with a PBP of 4.2 years and for 86.3 fils the revenue will be BD 49,808 with a PBP of 3.9 years- which is very attractive. An interesting communication via twitter as shown in Figure (23) by Vincent in Irvine, California, USA (Vincent, 2021) shows that the monthly energy production of an installed PV system in his premises for the month of April is equal to 1,873 kWh (solar electricity) while the user's consumption of conventional energy is 726 kWh. The financial data presented in his tweet shows that tariff per kWh from the utility is US\$16 (= 60 fils) while the purchased kWh generated by the installed PV unit was 100 fils. In other words, the FIT was probably rewarding 40% value compared to the tariff, i.e. 40% profit. This had led the customer to minimize his consumption while maximizing his yield from PV by cleaning the PV panels regularly, as well as maintaining the PV system.

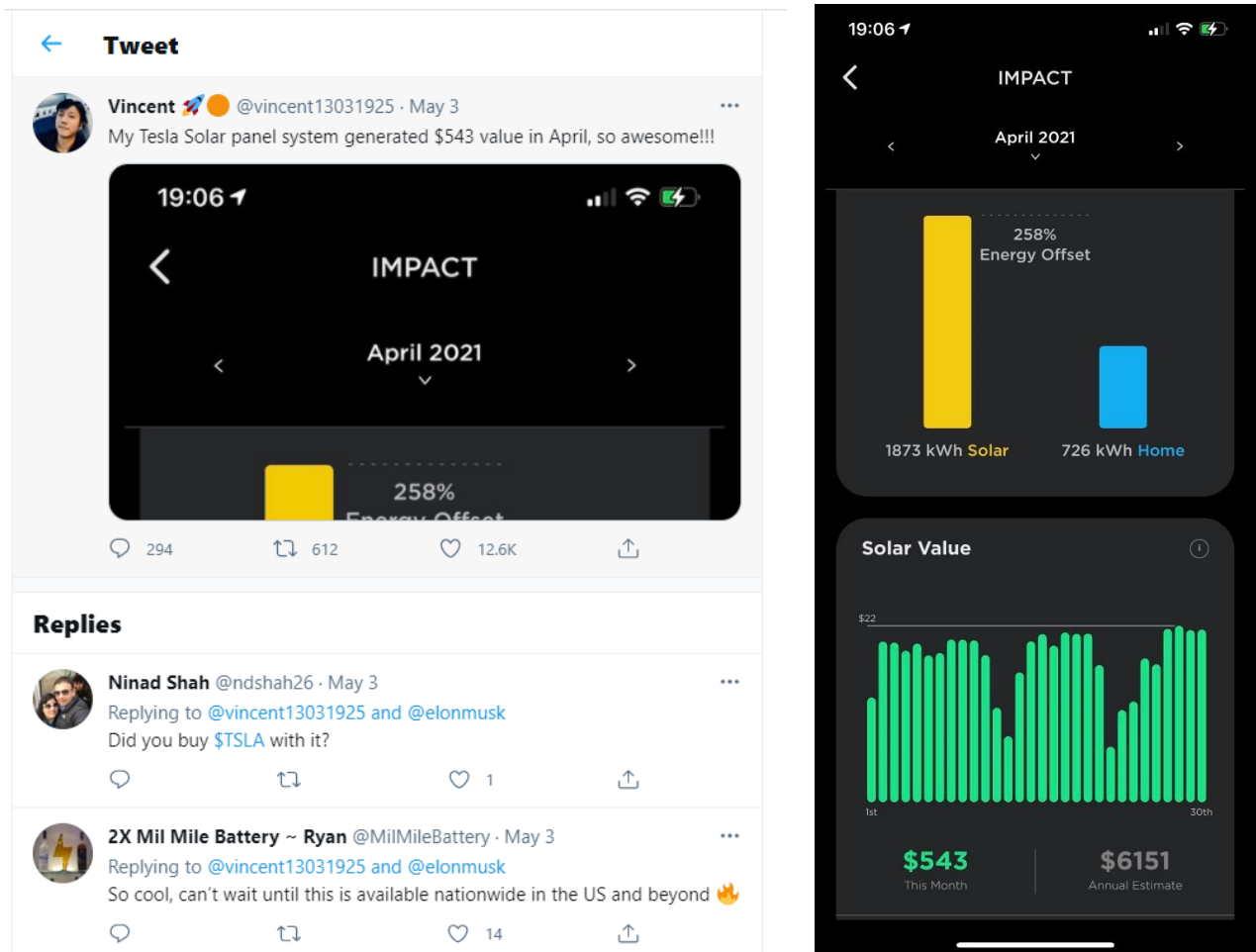


Figure (23): Twitter post of Vincent stating the monthly production and financial outcome from his installed PV. (Vincent, 2021)

An effective FIT policy will flourish the PV market in Bahrain, i.e., installing a 17 kW-PV system on the rooftop of the 1,724 houses will require 65,500 PV panel which worth about BD 9.8 million. This amount may not encourage the government to support or to share this cost because it will make a burden on its budget. However, if the government purchase each kWh @ 30 fils it must bear BD1.3 m, which is much less than BD 9.8. This incentive will attract the customers, although they bear the cost of the PV. Therefore, the government can meet its obligation toward the target, create a competitive market for PV, create green – collar jobs and involve in other Green Economy. This step can be boosted if the

government introduce a Green Loan - in collaboration with the commercial banks- which has lower interest rate than others since it is for a green project.

All in all, the use of buildings for PV applications is a critical area that must be addressed by an appropriate policy process and implementation strategy. The recent PV's global growth has been aided not merely by economies of scale and technical advances, but also by favorable policies such as feed-in tariffs. Germany has surpassed the United States as the world leader in solar PV installed power, thanks to good FIT-driven installations in buildings.

4.3 Conclusion and Recommendations

In conclusion, in order to meet its 5% of renewable energies goals, Kingdom of Bahrain need to use the building sector for PV applications. PV is one of the key technologies for achieving the defined goals as solar energy is the country's most abundant renewable resource. This study main aim was to examine rooftop PV power generation in Bahrain's residential sector which has received little attention up to this time.

Examining the rooftop design of the housing units in Khalifa Town revealed significant restrictions for PV application due to a variety of structural and architectural obstacles that allowed about 35% of the available roof area, depending on the building typology, to be utilized by PV application. As a result, system efficiency and space utilization has been optimized through placing the 5° tilted PV panels on elevated metal structure as shown in Figure (24). Modelling and simulation through PVsyst software show a net annual generation of 3,129 MWh for the 120 housing units, i.e. 44,953 MWh for 1724 housing units which is enough to satisfy about 43% of the overall town's electricity needs.



Figure (24): Cross- sectional view through one of the town's block.

Economically, the study has concluded that comparatively low kWh tariff in Bahrain will not encourage the installation of solar electricity photovoltaic systems on rooftops. The pay-back period (PBP) was found

to be too long which is 83.5 years compared to 9.6 years for 29 fils tariff. Thus, installing PV systems on a rooftop would be appealing only if the client received financial assistance or a low-interest loan, and the government purchased the provided solar energy from the rooftop at a considerable cost between 75 fils to 86.3 fils (Feed-In- Tariff). This will inspire home builders to make roofs more suitable for PV applications, allowing for maximum roof use with no obstacles.

Moreover, the results of this study show that using PV in buildings will greatly boost their environmental efficiency, with annual greenhouse gas emissions in Khalifa Town lowered by up to 34,794 tons of CO₂, which is equivalent to a reduction of around 21% of the town's CO₂ emissions.

In the future, an extended study could be achieved by studying the rooftops of the apartment buildings as well as other facilities existing in the Khalifa Town.

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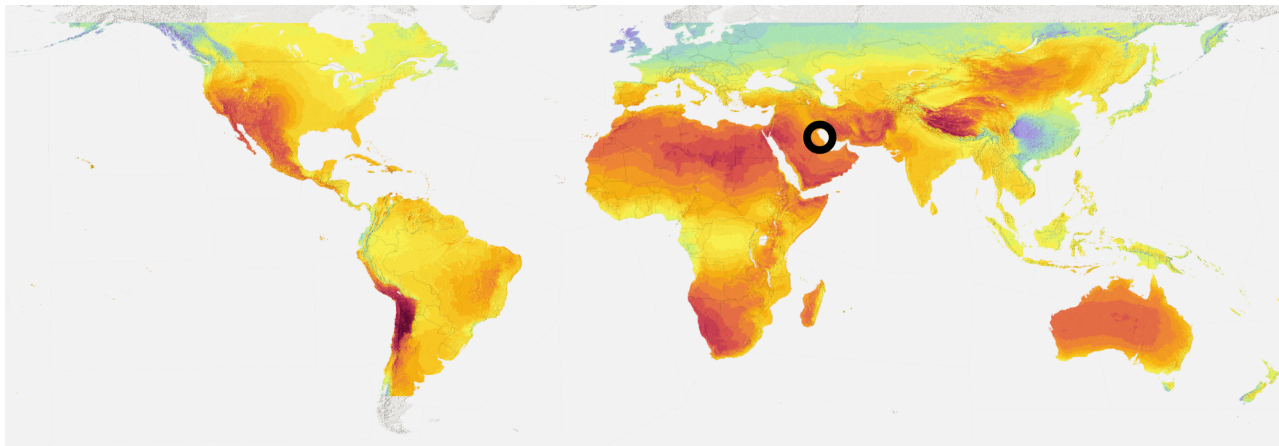
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Appendices

Appendix 1	Solargis Prospect of Southern Governorate "Khalifa Town": Preliminary Assessment of Solar and Meteorological Data.
Appendix 2	Specification of PV module "Jinko-Solar" used in the study.
Appendix 3	PVsyst Simulation Report for the Various Villa Types: 1. A1 Villa Type A. Orientation 1 & 2 B. Orientation 3 & 4 C. Orientation 5 & 6 2. B1 Villa Type A. Orientation 1 & 2 B. Orientation 3 & 4 C. Orientation 5 D. Orientation 6 3. A2 Villa Type A. Orientation 1 & 1 B. Orientation 3 & 4 C. Orientation 5 & 6 4. B2 Villa Type A. Orientation 1 & 3 B. Orientation 2 & 4 5. C2 Villa Type A. Orientation 1 B. Orientation 2 C. Orientation 3 & 4

Appendix 1:

Solargis Prospect of Southern Governorate "Khalifa Town":
Preliminary Assessment of Solar and Meteorological Data.



Preliminary assessment of site solar irradiance

Project: Southern Governorate (Khalifa Town) (Bahrain)

Geographical coordinates	26.036483°,050.614529° (26°02'11", 050°36'52")
Report number	P-sg2 23727-2021-04-13-2033
Report generated	2021-04-13
Generated by	Solargis
Customer	Kingdom University (Bahrain)

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1 Overview

Table 1.1: Yearly average

Global horizontal irradiation	GHI	2016.1 kWh/m ²
Direct normal irradiation	DNI	1549.6 kWh/m ²
Diffuse horizontal irradiation	DIF	955.8 kWh/m ²
Air temperature	TEMP	26.1 °C

2 Project info

Project name	Southern Governorate (Khalifa Town)
Address	unnamed road, Southern Governorate, Bahrain
Geographical coordinates	26.036483°,050.614529° (26°02'11", 050°36'52")
Time zone	UTC+03, Asia/Bahrain [AST]
Elevation	17 m
Land cover	Sparse vegetation (<15%)
Population density	334 inh./km ²
Terrain azimuth	quasi flat
Terrain slope	2°
Location on the map	https://apps.solargis.com/prospect/map? c=26.036483,50.614529,10&s=26.036483,50.614529

Figure 2.1: Project location

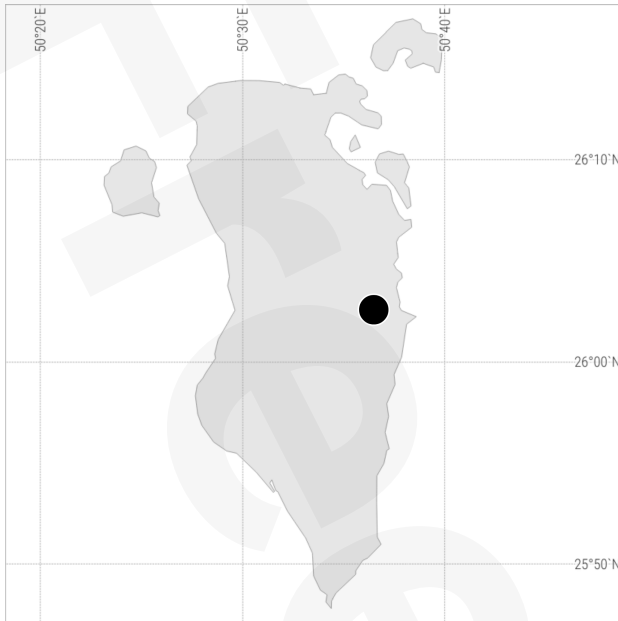


Figure 2.2: Detailed map view



Figure 2.3: Project horizon and sunpath

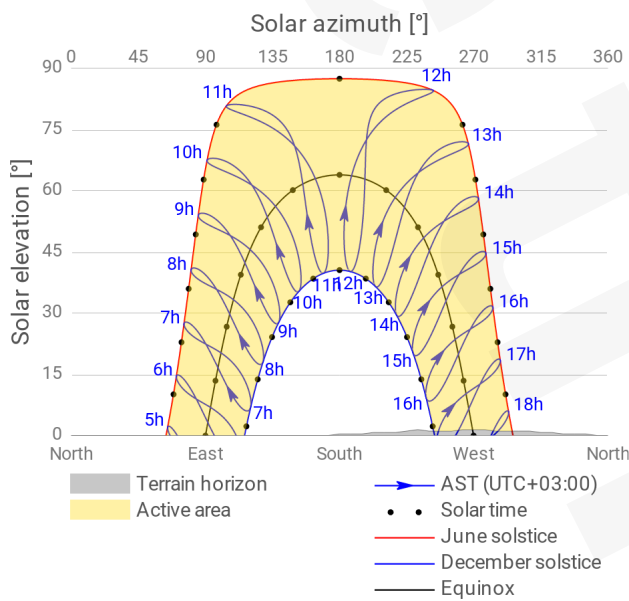
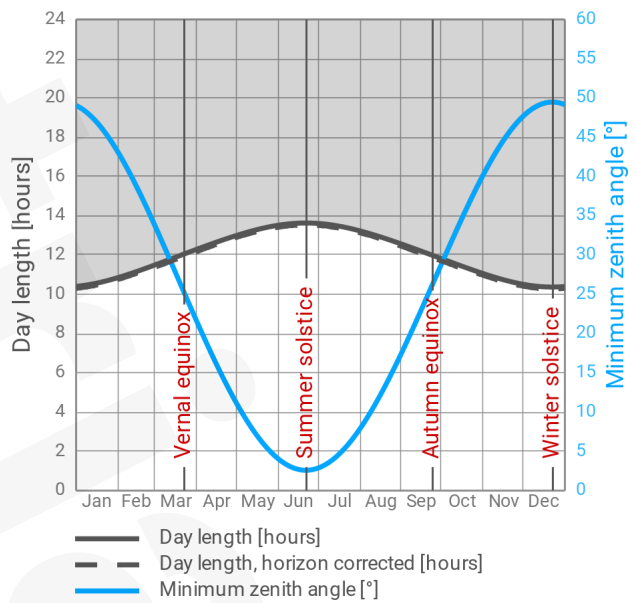


Figure 2.4: Day length and solar zenith angle



3 Solar and meteo: Monthly statistics

The most important project-specific meteorological parameter that determines solar electricity production is solar radiation, which fuels a PV power system. Power production is also influenced by air temperature. Other meteorological parameters also affect the performance, availability and ageing of a PV system.

Table 3.1: Solar radiation and meteorological parameters

Month	GHI kWh/m ²	DNI kWh/m ²	DIF kWh/m ²	D2G	GTI _{opta} kWh/m ²	TEMP °C	WS m/s	CDD degree days	HDD degree days
Jan	113.0	108.6	55.3	0.490	146.6	17.1	5.4	24	8
Feb	123.2	104.4	60.5	0.491	149.0	17.8	5.6	29	6
Mar	163.0	119.2	80.2	0.492	180.4	20.5	5.1	106	0
Apr	177.5	113.1	92.0	0.518	180.5	24.4	4.7	222	0
May	215.7	146.3	101.7	0.472	205.2	28.9	4.6	371	0
Jun	224.4	165.9	97.4	0.434	205.7	31.9	5.1	436	0
Jul	218.2	142.8	106.4	0.487	204.3	33.3	4.7	501	0
Aug	209.0	145.4	98.1	0.470	207.2	33.8	3.9	510	0
Sep	186.9	147.9	81.3	0.435	201.5	32.5	4.1	443	0
Oct	161.2	141.6	72.2	0.448	190.9	29.5	4.1	368	0
Nov	116.7	107.6	57.4	0.492	148.2	24.4	5.2	213	0
Dec	107.3	106.7	53.4	0.497	142.4	19.4	5.3	82	0
Yearly	2016.1	1549.6	955.8	0.474	2161.7	26.1	4.8	3303	14

Optimum tilt/azimuth for GTI_{opta} 25° / 180°

Table 3.2: Other meteorological parameters

Month	ALB	RH %	PWAT kg/m ²	PREC mm
Jan	0.39	66	17	19
Feb	0.38	67	17	15
Mar	0.36	63	18	17
Apr	0.34	59	20	7
May	0.34	54	20	1
Jun	0.35	53	17	0
Jul	0.35	55	23	0
Aug	0.36	58	26	0
Sep	0.38	58	21	0
Oct	0.39	59	21	0
Nov	0.39	62	23	7
Dec	0.40	66	19	13
Yearly	0.37	60	20	79

Figure 3.1: Global + diffuse horizontal irradiation

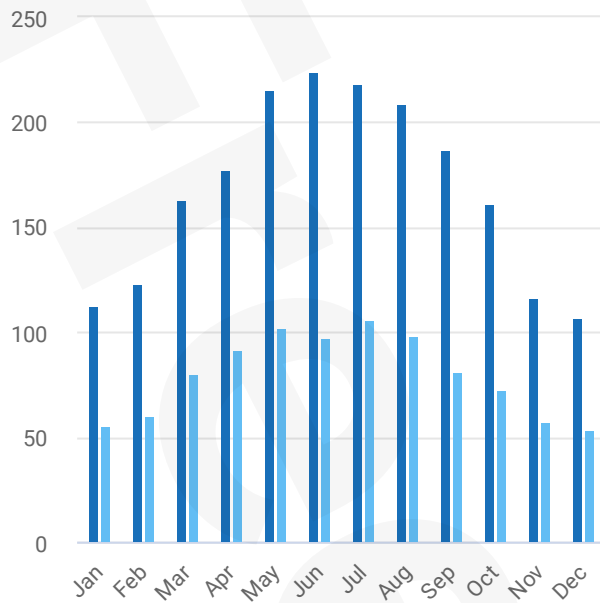


Figure 3.2: Direct normal irradiation

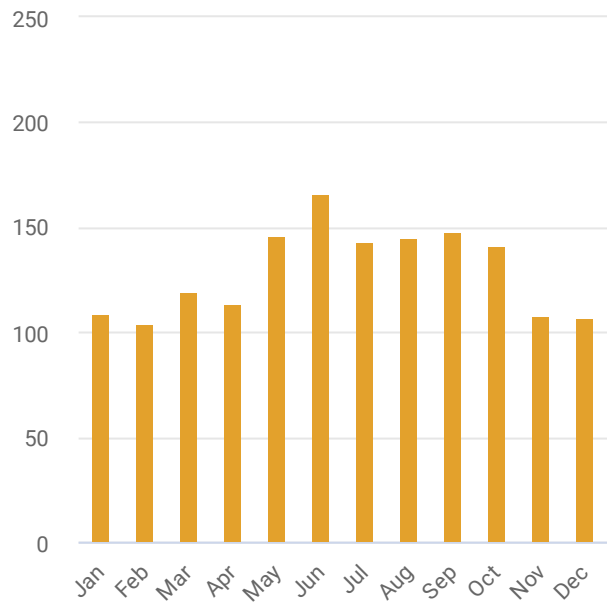


Figure 3.3: Ratio of diffuse to global irradiation

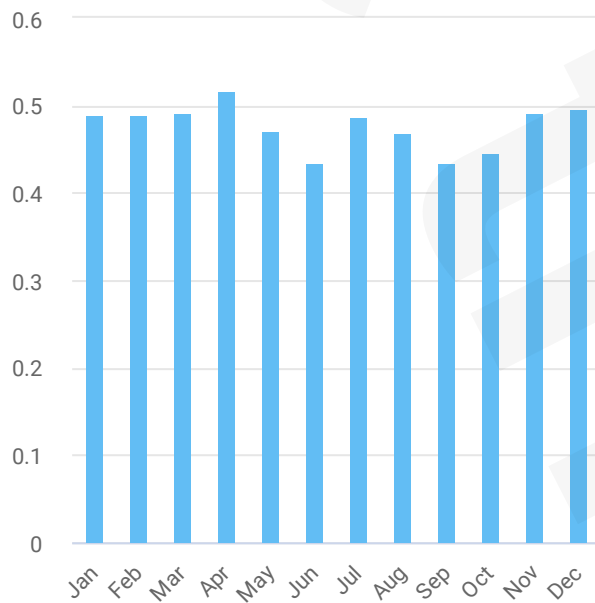


Figure 3.4: Global tilted irradiation at optimum angle

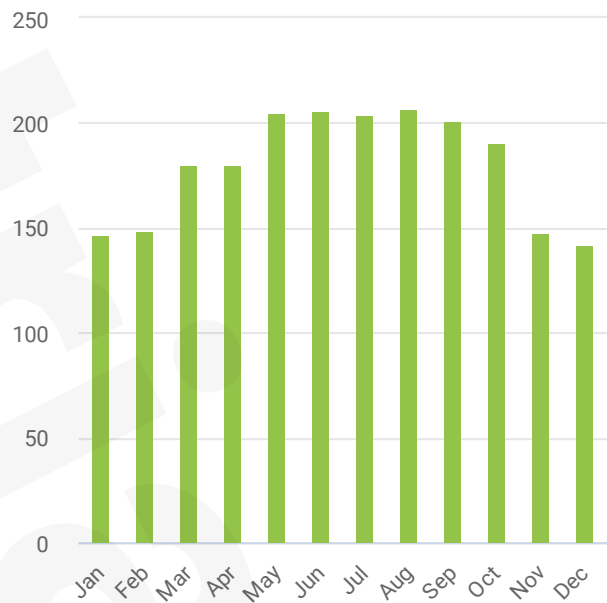


Figure 3.5: Air temperature

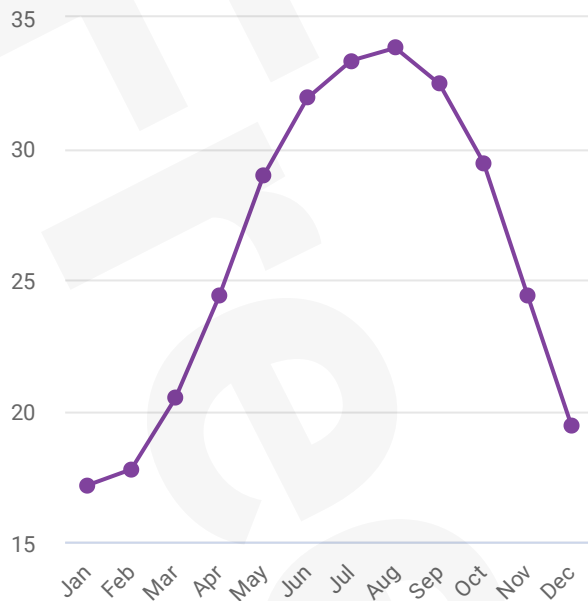


Figure 3.6: Surface albedo

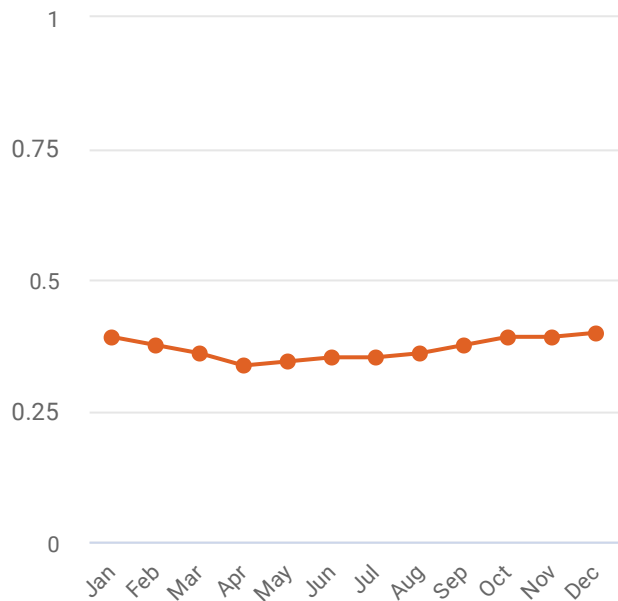


Figure 3.7: Wind speed

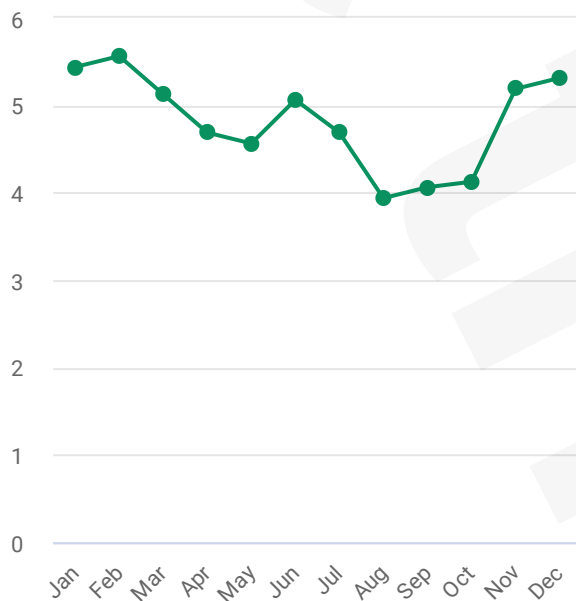


Figure 3.8: Relative humidity

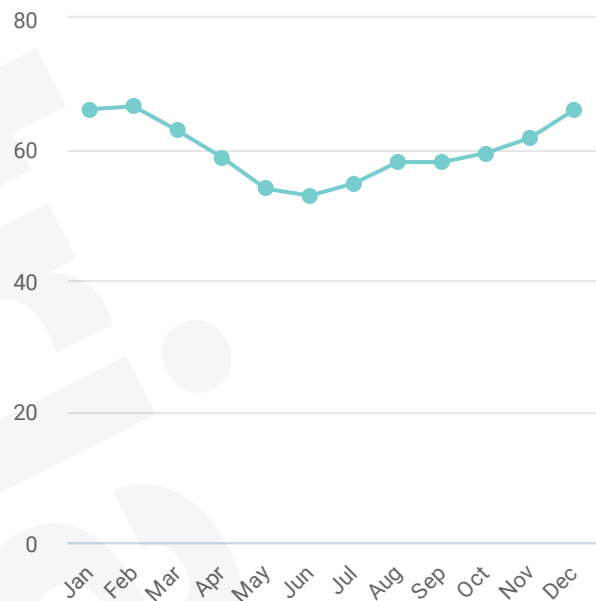


Figure 3.9: Precipitation (rainfall)

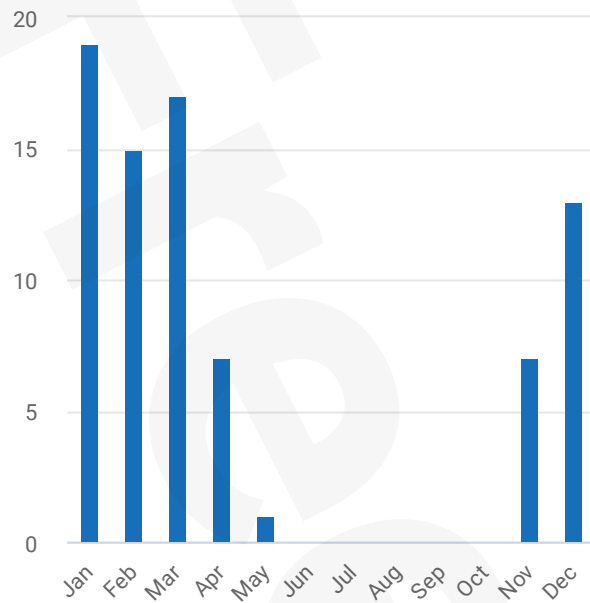


Figure 3.10: Precipitable water

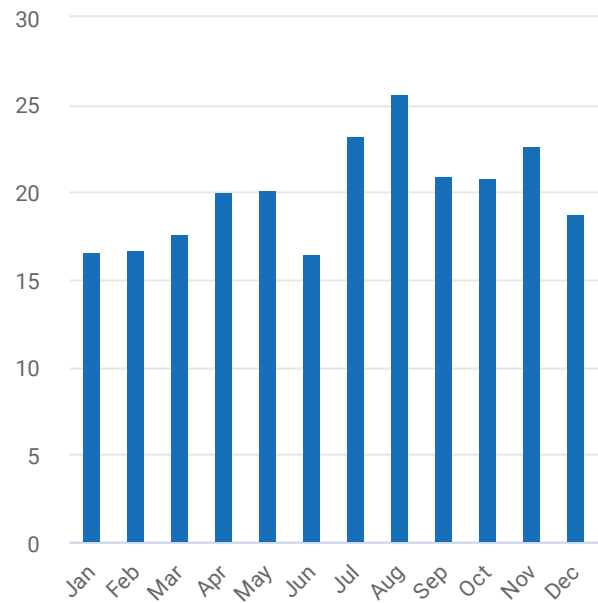


Figure 3.11: Snow days



Figure 3.12: Cooling degree days

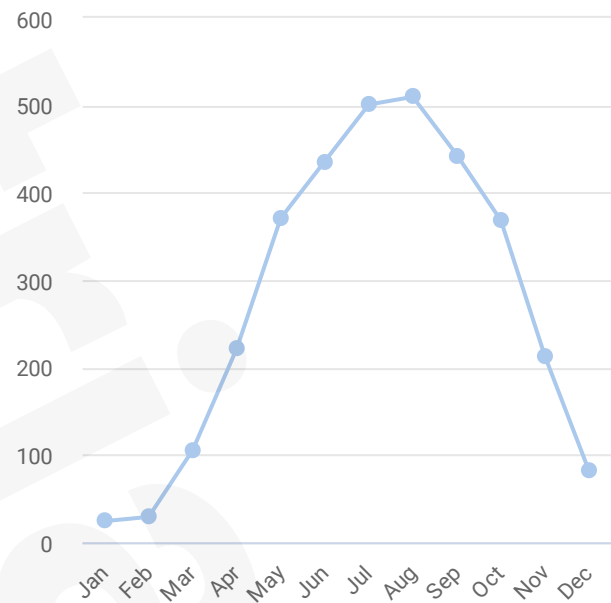
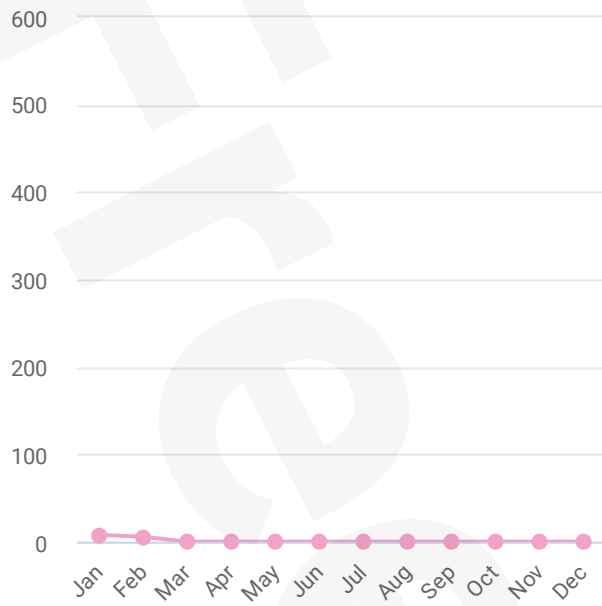


Figure 3.13: Heating degree days



4 Solar and meteo: Daily statistics

Solar radiation profiles below are calculated as an average of all hourly data for each month. The profiles give an indication of changing patterns of GHI per day, separately for each month. These patterns are driven by local geography, astronomy and climate of the site.

Figure 4.1: GHI, DNI, DIF - daily averages

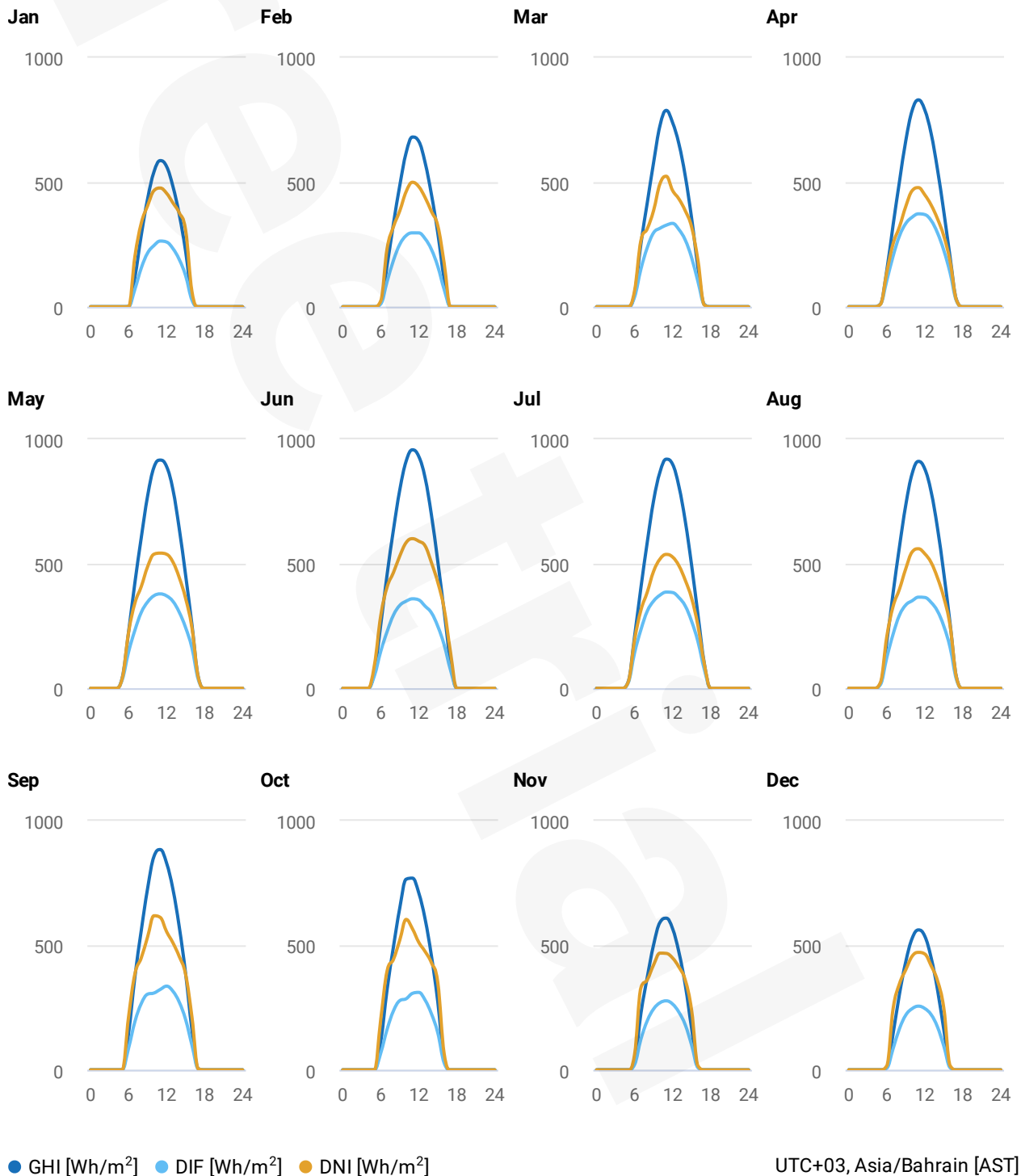


Table 4.1: Global horizontal irradiation - hourly averages [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	0	0	-	-	-	-	-	-
5 - 6	-	-	0	11	42	69	27	18	0	0	-	-
6 - 7	1	14	54	146	226	256	208	185	147	113	32	8
7 - 8	118	166	253	329	424	457	404	383	373	323	227	146
8 - 9	287	333	417	502	604	636	586	568	559	494	371	304
9 - 10	433	487	579	667	772	797	754	736	728	650	502	434
10 - 11	541	618	726	788	887	912	868	862	856	765	592	528
11 - 12	587	682	788	831	916	958	920	911	885	770	609	562
12 - 13	563	664	739	790	891	931	900	881	830	710	567	537
13 - 14	483	578	654	696	798	845	810	789	725	605	472	450
14 - 15	370	450	525	552	641	695	671	644	574	456	340	322
15 - 16	223	295	355	382	454	509	494	461	387	273	166	161
16 - 17	38	112	159	198	256	309	296	258	161	42	11	11
17 - 18	-	0	9	28	45	108	100	44	5	-	-	-
18 - 19	-	-	-	-	0	1	1	0	-	-	-	-
19 - 20	-	-	-	-	-	-	-	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	3644	4401	5258	5918	6957	7481	7038	6742	6230	5201	3889	3463

Table 4.2: Direct normal irradiation - hourly averages [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	-	-	-	-	-	-	-	-
5 - 6	-	-	-	10	40	93	25	23	0	0	-	-
6 - 7	0	24	64	138	224	292	194	207	213	204	62	16
7 - 8	202	234	266	253	342	407	314	329	385	397	330	246
8 - 9	335	321	313	321	408	465	386	398	449	443	361	346
9 - 10	405	385	386	403	488	531	470	480	533	521	421	402
10 - 11	466	462	493	466	538	585	519	547	619	604	468	456
11 - 12	477	500	524	478	543	601	538	560	612	566	467	472
12 - 13	456	482	467	449	538	591	527	540	555	512	449	465
13 - 14	417	438	433	408	507	572	492	505	510	475	412	418
14 - 15	377	382	385	353	444	504	434	444	455	429	360	358
15 - 16	308	325	320	284	361	425	361	364	383	350	239	248
16 - 17	61	175	186	181	243	319	251	250	212	65	16	17
17 - 18	-	-	7	26	44	145	98	43	4	-	-	-
18 - 19	-	-	-	-	-	0	0	-	-	-	-	-
19 - 20	-	-	-	-	-	-	-	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	3504	3728	3845	3771	4721	5530	4608	4691	4930	4566	3586	3443

5 Acronyms and glossary

Table 5.1: Acronyms and glossary

Acronym	Full name	Unit	Explanation
GHI	Global horizontal irradiation	kWh/m ²	Average annual, monthly or daily sum of global horizontal irradiation
DNI	Direct normal irradiation	kWh/m ²	Average yearly, monthly or daily sum of direct normal irradiation
DIF	Diffuse horizontal irradiation	kWh/m ²	Average yearly, monthly or daily sum of diffuse horizontal irradiation
D2G	Ratio of diffuse to global irradiation		Ratio of diffuse horizontal irradiation and global horizontal irradiation (DIF/GHI)
GTI opta	Global tilted irradiation at optimum angle	kWh/m ²	Average annual, monthly or daily sum of global tilted irradiation for PV modules fix-mounted at optimum angle
OPTA	Optimum tilt of PV modules	°	Optimum tilt of fix-mounted PV modules facing towards Equator set for maximizing GTI input
GHI season	GHI seasonality		Ratio of maximum and minimum monthly averages of global horizontal irradiation (GHI_month_max/GHI_month_min)
DNI season	DNI seasonality		Ratio of maximum and minimum monthly averages of direct normal irradiation (DNI_month_max/DNI_month_min)
ALB	Surface albedo		Fraction of solar irradiance reflected by surface. Ratio of upwelling to downwelling (GHI) radiative fluxes at the surface
GTI theoretical	Global tilted irradiation (theoretical)	kWh/m ²	Average annual, monthly or daily sum of global tilted irradiation without consideration of terrain shading
TEMP	Air temperature	°C	Average yearly, monthly and daily air temperature at 2 m above ground
WS	Wind speed	m/s	Average yearly, monthly and daily wind speed at 10 m above ground
RH	Relative humidity	%	Average yearly or monthly relative humidity at 2 m above ground
PWAT	Precipitable water	kg/m ²	Precipitable water is the depth of water vapour in a column of the atmosphere, if all the water in that column were precipitated as rain. It indicates the amount of moisture above ground
PREC	Precipitation (rainfall)	mm	Average yearly and monthly sums of precipitation
SNOWD	Snow days	days	Snow days are calculated as days with snow water depth equivalent to or higher than 5 mm

Acronym	Full name	Unit	Explanation
CDD	Cooling degree days	degree days	Quantifies energy demand needed to cool a building. "Cooling degree days" are a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base daily average temperature (18°C). Yearly and monthly values are aggregated from daily values
HDD	Heating degree days	degree days	Quantifies energy demand needed to heat a building. "Heating degree days" are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific base daily average temperature (18°C). Yearly and monthly values are aggregated from daily values

6 Metadata

This report is based on high-resolution solar and meteorological database developed and operated by Solargis. The data parameters presented in this report are computed by Solargis models and algorithms. The data used as inputs to the models come from different sources. The data characteristics are explained below.

Time representation: 1999 to 2018 (20 calendar years)
 Time step: Monthly and yearly long-term statistics
 The estimations assume a year having 365 days
 Solargis database version 2.5.0

Group of data	Source of data inputs	Organization	Solargis method
GHI, DNI, DIF, GTI, D2G	Meteosat MFG and MSG satellites (IODC) Aerosols from MERRA-2 and MACC-II/CAMS models Water vapour from CSFR and GFS models ELE	EUMETSAT NASA, ECMWF NOAA CGIAR CSI	Solar model
TEMP	ERA-5 model	ECMWF	Data processing
RH, WS, WD	MERRA-2 and CDFv2 models	NASA, NOAA	Data processing
SNOWD	CFSR and CFSv2 models	NOAA	Data processing
PREC	GPCC database	DWD	Data processing
PWAT	CFSR and CFSv2 models	NOAA	Data processing
ALB	MODIS and ERA-5 databases	NASA, ECMWF	Data merging, cleaning, processing
LANDC	Land cover CCI, v2.0.7	ESA CCI	Post-processing
POPUL	Gridded Population of the World, version 4 (GPWv4)	CIESIN	Data processing
ELE, SLO, AZI	SRTM	CGIAR CSI	Data merging, cleaning, processing
PVOUT, OPTA	GTI, TEMP, ELE	Solargis	PV simulation model
HDD, CDD	TEMP	Solargis	Data processing

Documentation

Data uncertainty <https://solargis.com/docs/accuracy-and-comparisons/combined-uncertainty/>

Methodology <https://solargis.com/docs/methodology/solar-radiation-modeling/>

PV energy simulation <https://solargis.com/docs/methodology/pv-energy-modeling/>

7 Disclaimer and legal information

Considering the uncertainty of data and calculations, Solargis s.r.o. does not guarantee the accuracy of estimates. The maximum possible has been done for the assessment of weather parameters and preliminary assessment of the photovoltaic electricity production based on the best available data, software and knowledge. Solargis s.r.o. shall not be liable for any direct, incidental, consequential, indirect or punitive damages arising or alleged to have arisen out of use of the provided report.

This report shows solar power estimation in the start-up phase and over the entire lifetime of a PV system. The estimates are accurate enough for preliminary project assessment. For large projects planning and financing, more information is needed: 1. Statistical distribution and uncertainty of solar radiation 2. Detailed specification of a PV system 3. Inter-annual variability and P90 uncertainty of PV production 4. Lifetime energy production considering performance degradation of PV components.

More information about full PV yield assessment can be found at:
<https://solargis.com/products/pv-yield-assessment-study/overview/>

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Validation of authenticity

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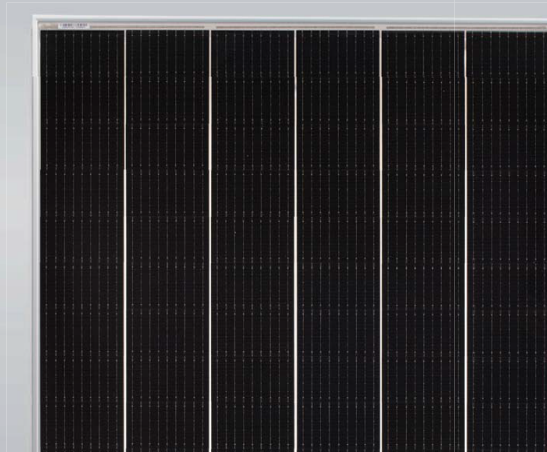
Appendix 2:

Specification of PV module "Jinko-Solar" used in the study.

Tiger Mono-facial 450-470 Watt

Tiling Ribbon (TR) Technology

Positive power tolerance of 0~+3%



KEY FEATURES



TR technology + Half Cell

TR technology with Half cell aims to eliminate the cell gap to increase module efficiency (mono-facial up to 20.93%)



9BB instead of 5BB

9BB technology decreases the distance between bus bars and finger grid line which is benefit to power increase.



Higher lifetime Power Yield

2.5% first year degradation,
0.6% linear degradation



Best Warranty

12 year product warranty,
25 year linear power warranty



Avoid debris, cracks and broken gate risk effectively

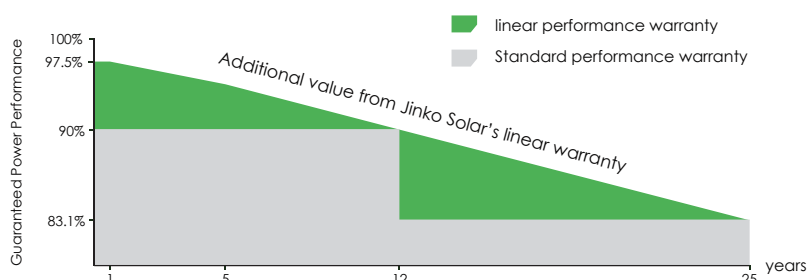
9BB technology using circular ribbon that could avoid debris, cracks and broken gate risk effectively



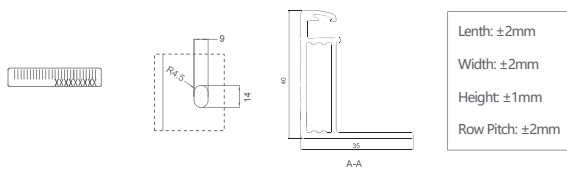
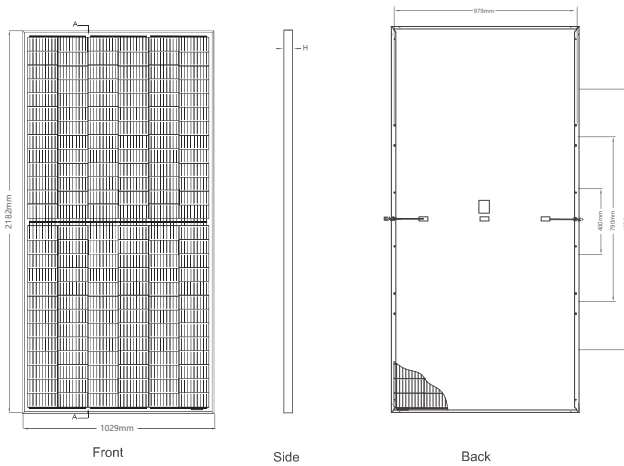
- ISO9001:2015, ISO14001:2015, OHSAS18001 certified factory
- IEC61215, IEC61730 certified product

LINEAR PERFORMANCE WARRANTY

12 Year Product Warranty • 25 Year Linear Power Warranty
0.6% Annual Degradation Over 25 years



Engineering Drawings



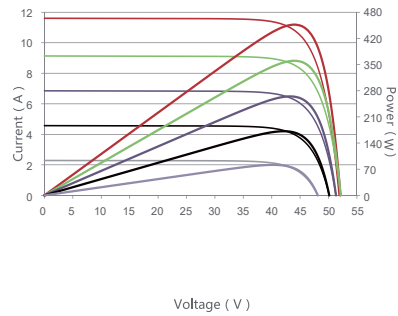
Packaging Configuration

(Two pallets = One stack)

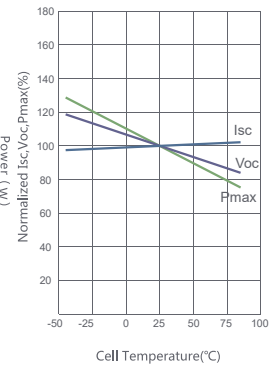
27pcs/pallets, 54pcs/stack, 540pcs/ 40'HQ Container

Electrical Performance & Temperature Dependence

Current-Voltage & Power-Voltage Curves (460W)



Temperature Dependence of Isc, Voc, Pmax



Mechanical Characteristics

Cell Type	P type Mono-crystalline
No. of cells	156 (2×78)
Dimensions	2182×1029×40mm (85.91×40.51×1.57 inch)
Weight	26.1 kg (57.54 lbs)
Front Glass	3.2mm, Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP67 Rated
Output Cables	TUV 1×4.0mm ² (+): 290mm, (-): 145 mm or Customized Length

SPECIFICATIONS

Module Type	JKM450M-7RL3		JKM455M-7RL3		JKM460M-7RL3		JKM465M-7RL3		JKM470M-7RL3	
	JKM450M-7RL3-V		JKM455M-7RL3-V		JKM460M-7RL3-V		JKM465M-7RL3-V		JKM470M-7RL3-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	450Wp	335Wp	455Wp	339Wp	460Wp	342Wp	465Wp	346Wp	470Wp	350Wp
Maximum Power Voltage (Vmp)	42.86V	39.20V	42.97V	39.32V	43.08V	39.43V	43.18V	39.58V	43.28V	39.69V
Maximum Power Current (Imp)	10.50A	8.54A	10.59A	8.61A	10.68A	8.68A	10.77A	8.74A	10.86A	8.81A
Open-circuit Voltage (Voc)	51.50V	48.61V	51.60V	48.70V	51.70V	48.80V	51.92V	49.01V	52.14V	49.21V
Short-circuit Current (Isc)	11.32A	9.14A	11.41A	9.22A	11.50A	9.29A	11.59A	9.36A	11.68A	9.43A
Module Efficiency STC (%)	20.04%		20.26%		20.49%		20.71%		20.93%	
Operating Temperature(°C)	-40°C~+85°C									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	20A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.35%/°C									
Temperature coefficients of Voc	-0.28%/°C									
Temperature coefficients of Isc	0.048%/°C									
Nominal operating cell temperature (NOCT)	45±2°C									

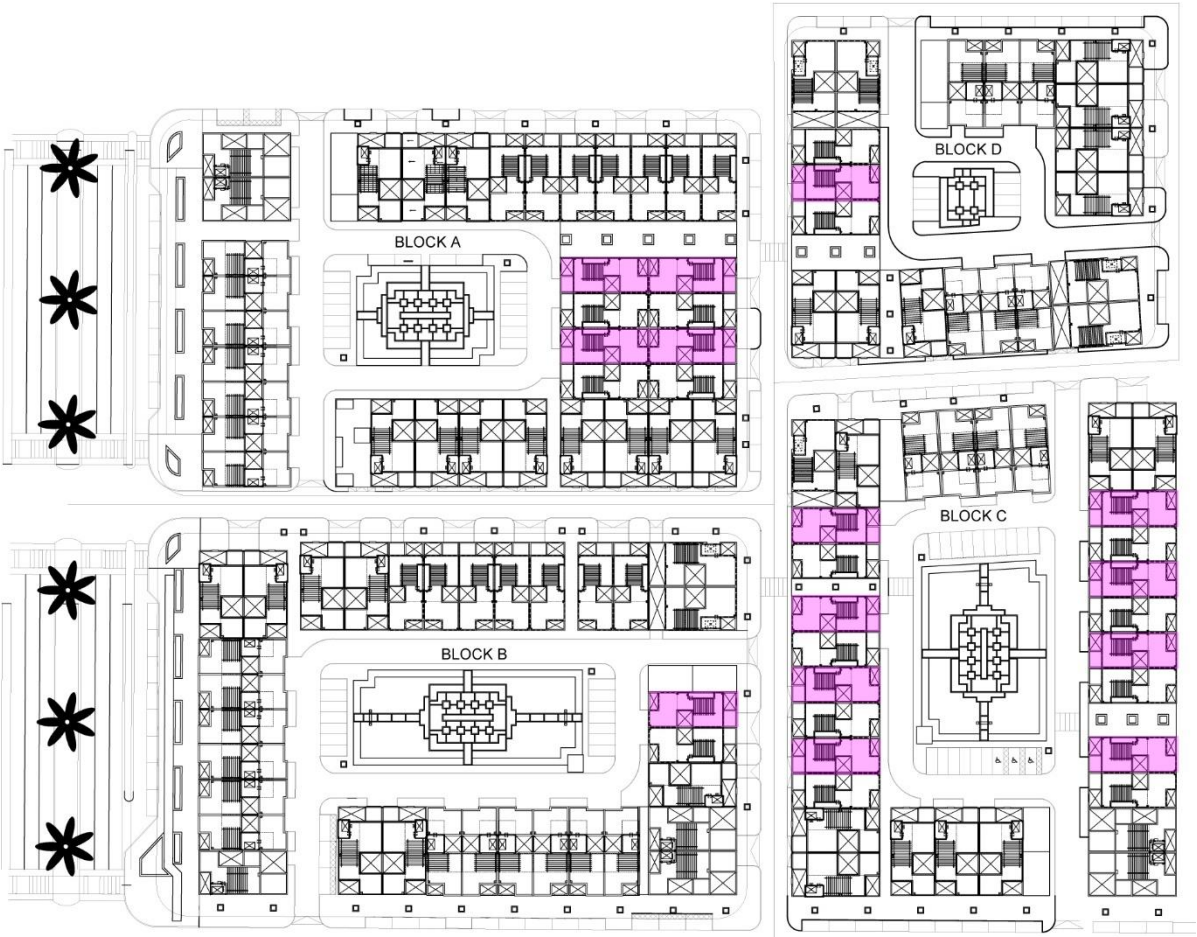
* **STC:** ☀ Irradiance 1000W/m² 📏 Cell Temperature 25°C ☁ AM=1.5
NOCT: ☀ Irradiance 800W/m² 📏 Ambient Temperature 20°C ☁ AM=1.5 🌀 Wind Speed 1m/s
 * Power measurement tolerance: ± 3%

Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

1. A1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
A. Orientation 1 & 2	60.6	21.3



PVSYST V6.88	kawar Energy (Jordan)				30/12/20	Page 1/7
Grid-Connected System: Simulation parameters						
Project :		Villa A1				
Geographical Site		Umm ash Sha'ūm		Country	Bahrain	
Situation		Latitude	26.22° N	Longitude	50.58° E	
Time defined as		Legal Time	Time zone UT+3	Altitude	11 m	
		Albedo	0.20			
Meteo data:		Umm ash Sha'ūm		Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic		
Simulation variant :		New simulation variant				
		Simulation date	30/12/20 18h55			
Simulation parameters		System type	Tables on a building			
Collector Plane Orientation		Tilt	5°	Azimuth	0°	
Sheds configuration		Nb. of sheds	26	Identical arrays		
		Sheds spacing	1.05 m	Collector width	1.03 m	
Shading limit angle		Limit profile angle	75.1°	Ground cov. Ratio (GCR)	98.1 %	
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm	
Horizon		Free Horizon				
Near Shadings		Linear shadings				
User's needs :		Unlimited load (grid)				
PV Arrays Characteristics (2 kinds of array defined)						
PV module		Si-mono	Model	JKM460M-7RL3-V		
Custom parameters definition		Manufacturer		Jinkosolar		
Sub-array "Sub-array #1"						
Number of PV modules		In series	13 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	13	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	5.98 kWp	At operating cond.	5.48 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	499 V	I mpp	11 A	
Sub-array "PV Array"						
Number of PV modules		In series	14 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	14	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	6.44 kWp	At operating cond.	5.91 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	537 V	I mpp	11 A	
Total Arrays global power		Nominal (STC)	12 kWp	Total	27 modules	
		Module area	60.6 m²	Cell area	56.0 m²	
Inverter						
Custom parameters definition		Model	SUN2000MA-10KTL-M0			
Characteristics		Manufacturer	Huawei Technologies			
		Operating Voltage	160-980 V	Unit Nom. Power	10.00 kWac	
Sub-array "Sub-array #1"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.20	
Sub-array "PV Array"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.29	
Total		Nb. of inverters	1	Total Power	10 kWac	
PV Array loss factors						
Array Soiling Losses				Loss Fraction	3.0 %	
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s	

Grid-Connected System: Simulation parameters

Wiring Ohmic Loss	Array#1	751 mOhm	Loss Fraction	1.5 % at STC
	Array#2	809 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Serie Diode Loss			Loss Fraction	2.0 %
LID - Light Induced Degradation			Loss Fraction	-0.8 %
Module Quality Loss			Loss Fraction	1.0 % at MPP
Module Mismatch Losses			Loss Fraction	0.10 %
Strings Mismatch loss				
Incidence effect (IAM): User defined profile				

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

System loss factors				
	Wires: 2x6.0 mm²	39 m	Loss Fraction	1.9 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa A1

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 27

Model SUN2000MA-10KTL-M0

Unlimited load (grid)

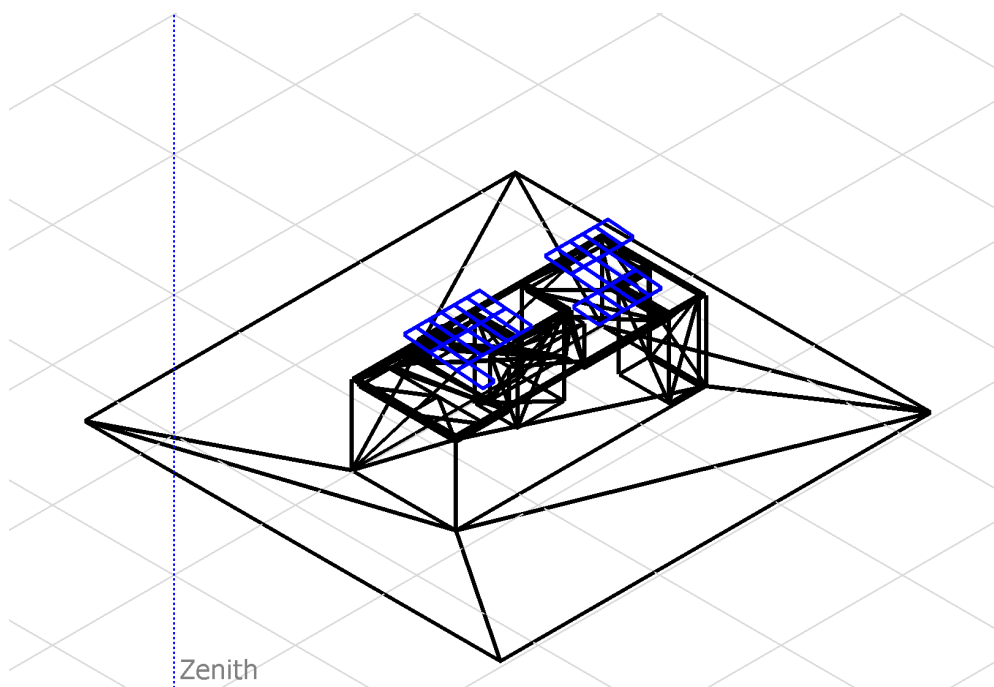
azimuth 0°

Pnom 460 Wp

Pnom total **12.42 kWp**

Pnom 10.00 kW ac

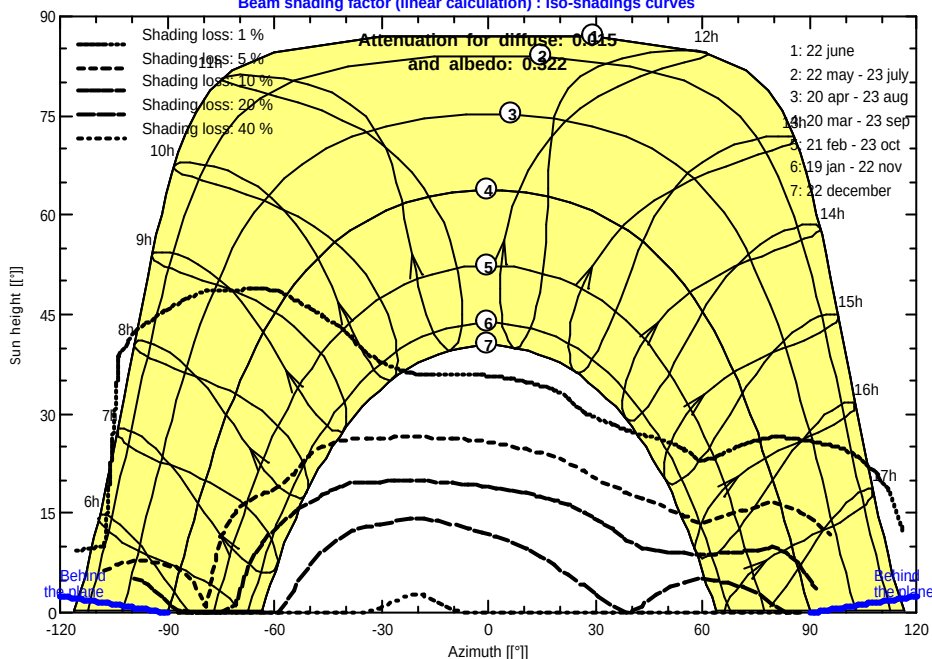
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa A1

Beam shading factor (linear calculation) : Iso-shadings curves



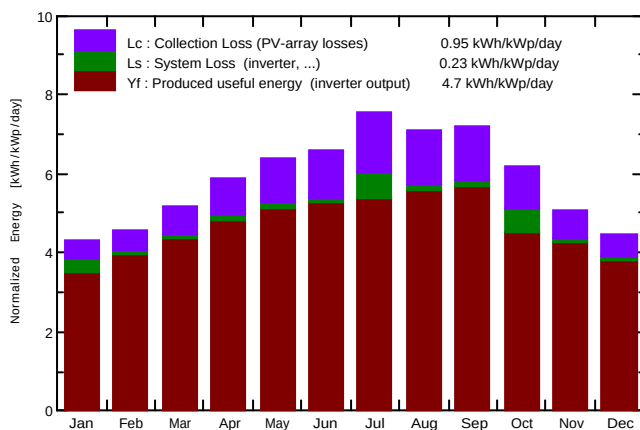
Grid-Connected System: Main results

Project : Villa A1
Simulation variant : New simulation variant

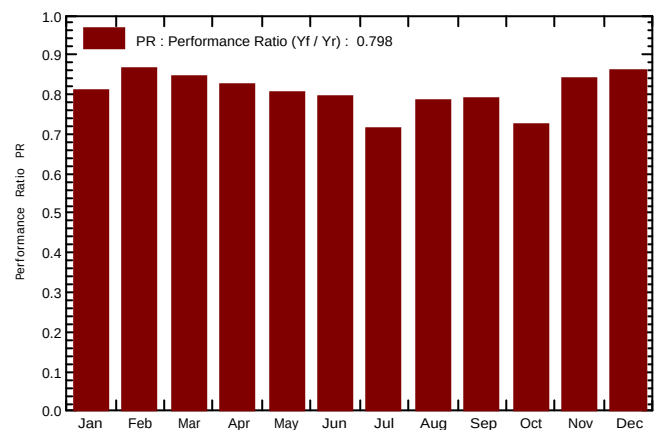
Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	27	Pnom total 12.42 kWp
Inverter	Model	SUN2000MA-10KTL-M0	Pnom 10.00 kW ac
User's needs	Unlimited load (grid)		

Main simulation results			
System Production	Produced Energy	21.30 MWh/year	Specific prod. 1715 kWh/kWp/year
	Performance Ratio PR	79.82 %	

Normalized productions (per installed kWp): Nominal power 12.42 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	127.6	1.489	1.353	0.812
February	121.3	56.57	17.45	128.1	122.2	1.414	1.380	0.867
March	154.6	74.53	21.64	159.9	152.7	1.722	1.679	0.846
April	173.7	83.00	26.31	176.2	168.5	1.850	1.803	0.824
May	198.6	94.05	32.04	198.6	190.0	2.033	1.982	0.804
June	199.0	94.74	34.17	197.8	189.3	2.009	1.959	0.798
July	235.0	78.96	35.63	234.2	224.7	2.333	2.072	0.713
August	218.1	78.31	35.23	220.4	211.3	2.205	2.148	0.785
September	209.8	37.92	32.07	216.5	207.8	2.178	2.121	0.789
October	181.2	34.51	29.31	192.1	184.1	1.979	1.735	0.727
November	140.1	28.92	23.55	152.5	145.7	1.631	1.590	0.840
December	125.0	28.82	18.37	137.9	131.0	1.511	1.474	0.861
Year	2079.7	730.44	26.85	2148.1	2054.9	22.355	21.297	0.798

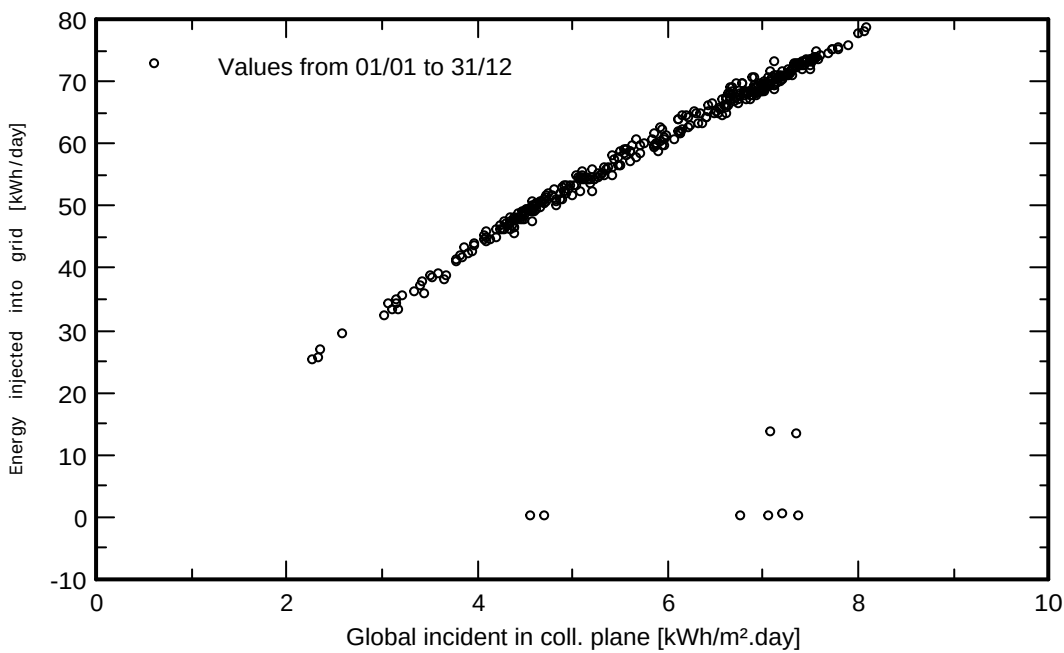
Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

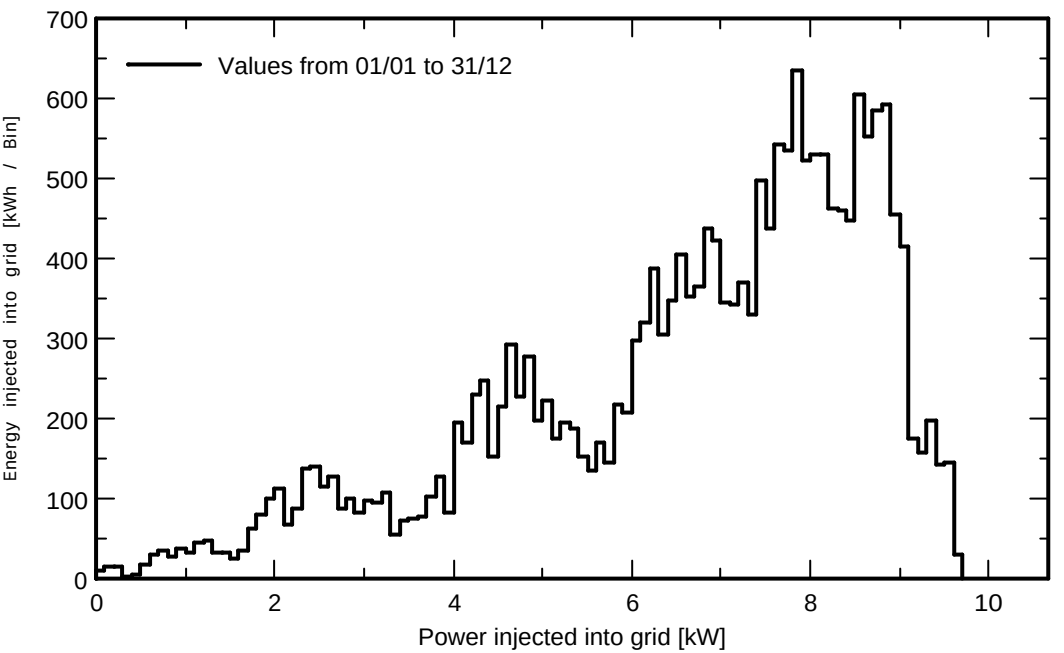
Project : Villa A1
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	27	Pnom total	12.42 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

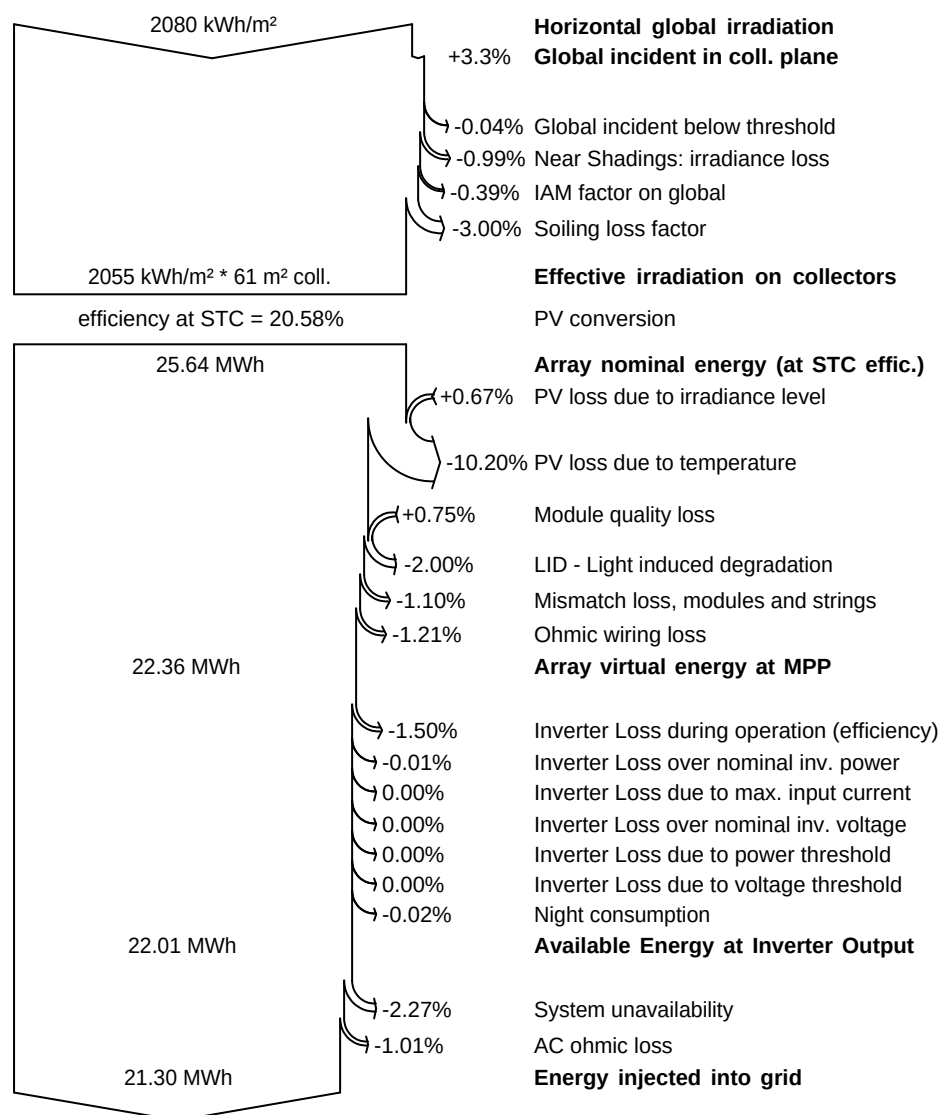


Grid-Connected System: Loss diagram

Project : Villa A1
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	27	Pnom total	12.42 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa A1

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	27	Pnom total	12.42 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

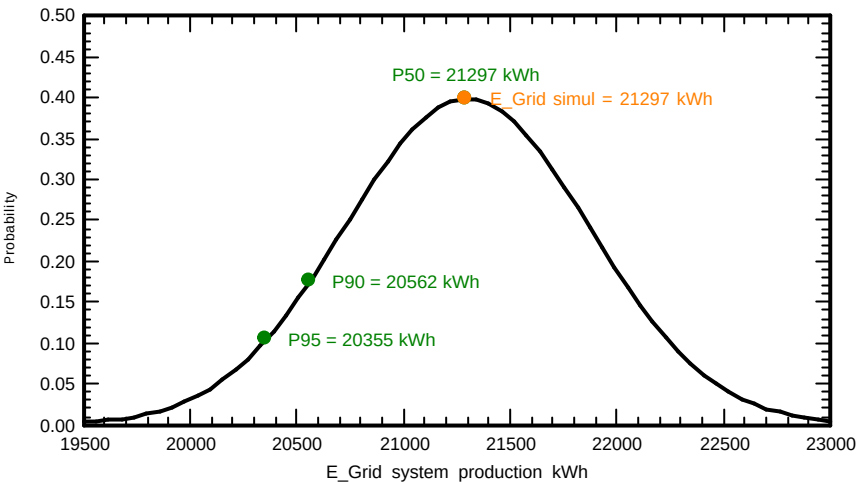
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.57 MWh
	P50	21.30 MWh
	P90	20.56 MWh
	P95	20.35 MWh

Probability distribution

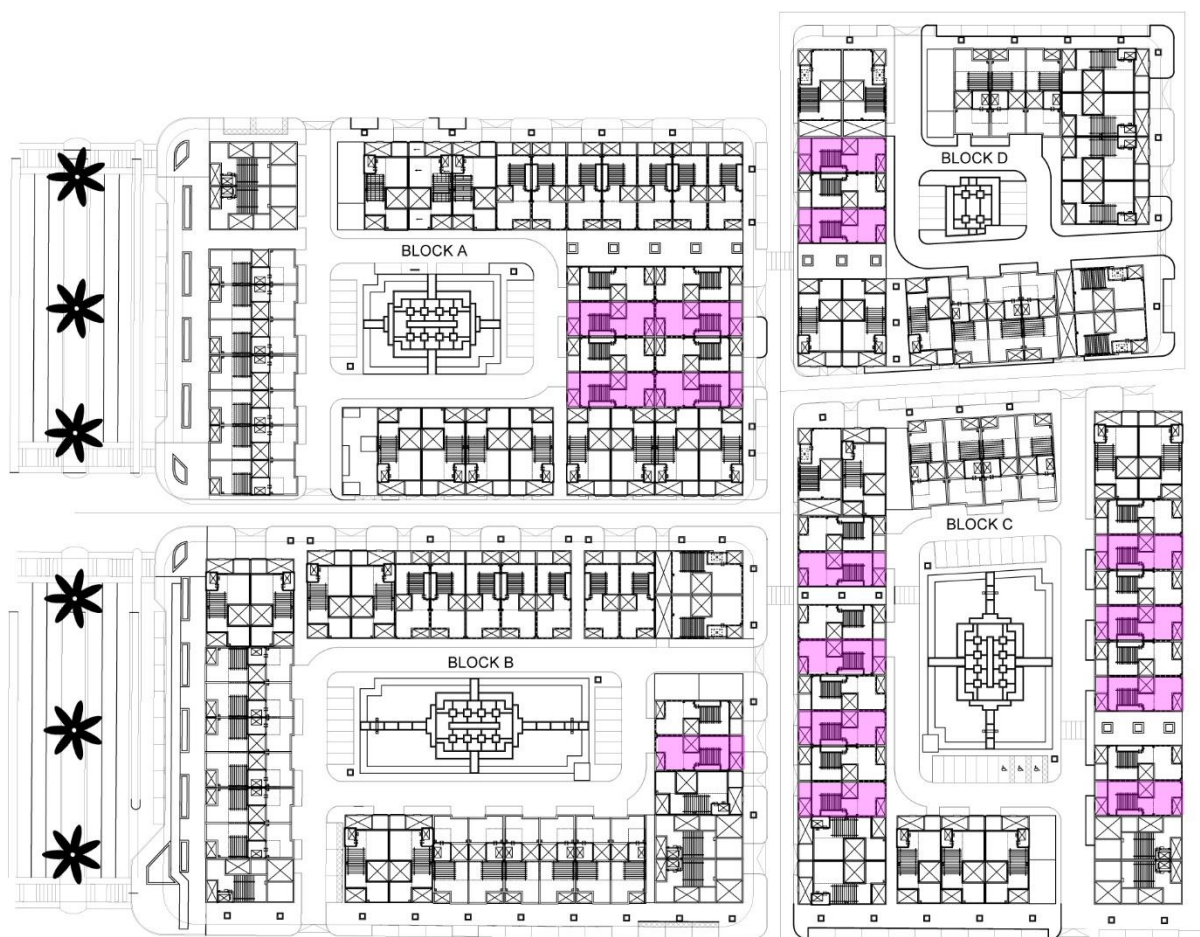


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

1. A1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
B. Orientation 3 & 4	60.6	21.45



PVSYST V6.88	kawar Energy (Jordan)				30/12/20	Page 1/7
Grid-Connected System: Simulation parameters						
Project :		Villa A1				
Geographical Site		Umm ash Sha'ūm			Country	Bahrain
Situation		Latitude	26.22° N	Longitude	50.58° E	
Time defined as		Legal Time	Time zone UT+3	Altitude	11 m	
		Albedo	0.20			
Meteo data:		Umm ash Sha'ūm	Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic			
Simulation variant :		New simulation variant				
		Simulation date	30/12/20 19h20			
Simulation parameters		System type	Tables on a building			
Collector Plane Orientation		Tilt	5°	Azimuth	0°	
Sheds configuration		Nb. of sheds	27	Identical arrays		
		Sheds spacing	1.05 m	Collector width	1.03 m	
Shading limit angle		Limit profile angle	75.1°	Ground cov. Ratio (GCR)	98.1 %	
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm	
Horizon		Free Horizon				
Near Shadings		Linear shadings				
User's needs :		Unlimited load (grid)				
PV Arrays Characteristics (2 kinds of array defined)						
PV module		Si-mono	Model	JKM460M-7RL3-V		
Custom parameters definition		Manufacturer	Jinkosolar			
Sub-array "Sub-array #1"						
Number of PV modules		In series	13 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	13	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	5.98 kWp	At operating cond.	5.48 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	499 V	I mpp	11 A	
Sub-array "PV Array"						
Number of PV modules		In series	14 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	14	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	6.44 kWp	At operating cond.	5.91 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	537 V	I mpp	11 A	
Total Arrays global power		Nominal (STC)	12 kWp	Total	27 modules	
		Module area	60.6 m²	Cell area	56.0 m²	
Inverter						
Custom parameters definition		Model	SUN2000MA-10KTL-M0			
Characteristics		Manufacturer	Huawei Technologies			
		Operating Voltage	160-980 V	Unit Nom. Power	10.00 kWac	
Sub-array "Sub-array #1"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.20	
Sub-array "PV Array"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.29	
Total		Nb. of inverters	1	Total Power	10 kWac	
PV Array loss factors						
Array Soiling Losses				Loss Fraction	3.0 %	
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s	

Grid-Connected System: Simulation parameters

Wiring Ohmic Loss	Array#1	751 mOhm	Loss Fraction	1.5 % at STC
	Array#2	809 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Serie Diode Loss			Loss Fraction	2.0 %
LID - Light Induced Degradation			Loss Fraction	-0.8 %
Module Quality Loss			Loss Fraction	1.0 % at MPP
Module Mismatch Losses			Loss Fraction	0.10 %
Strings Mismatch loss				
Incidence effect (IAM): User defined profile				

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

System loss factors				
	Wires: 2x6.0 mm²	39 m	Loss Fraction	1.9 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa A1

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt

5°

azimuth

0°

Model JKM460M-7RL3-V

Pnom 460 Wp

Nb. of modules 27

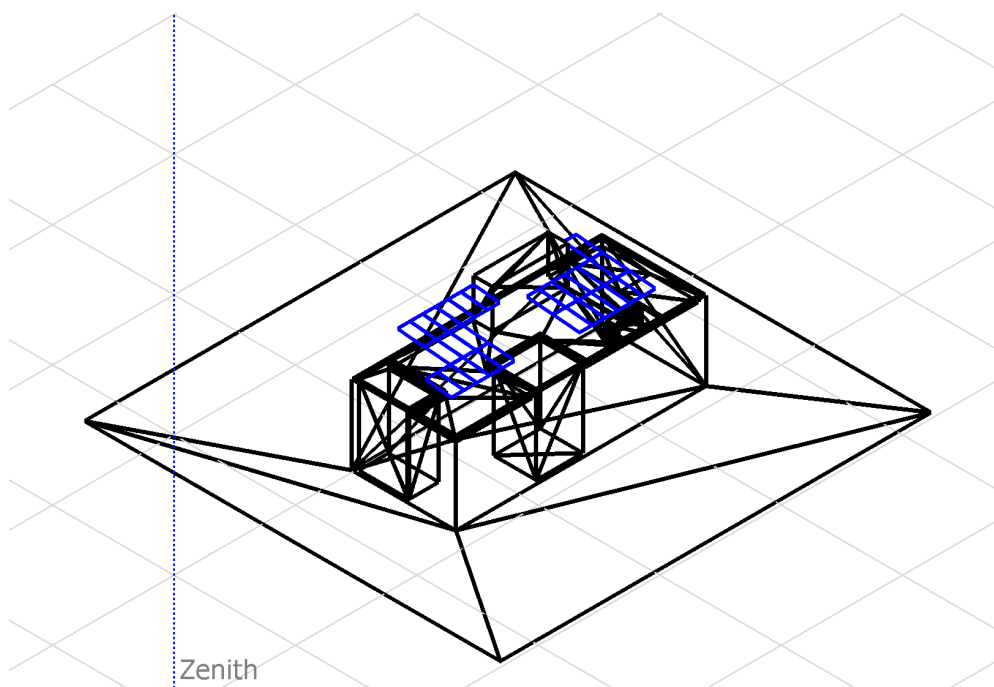
Pnom total **12.42 kWp**

Model SUN2000MA-10KTL-M0

Pnom 10.00 kW ac

Unlimited load (grid)

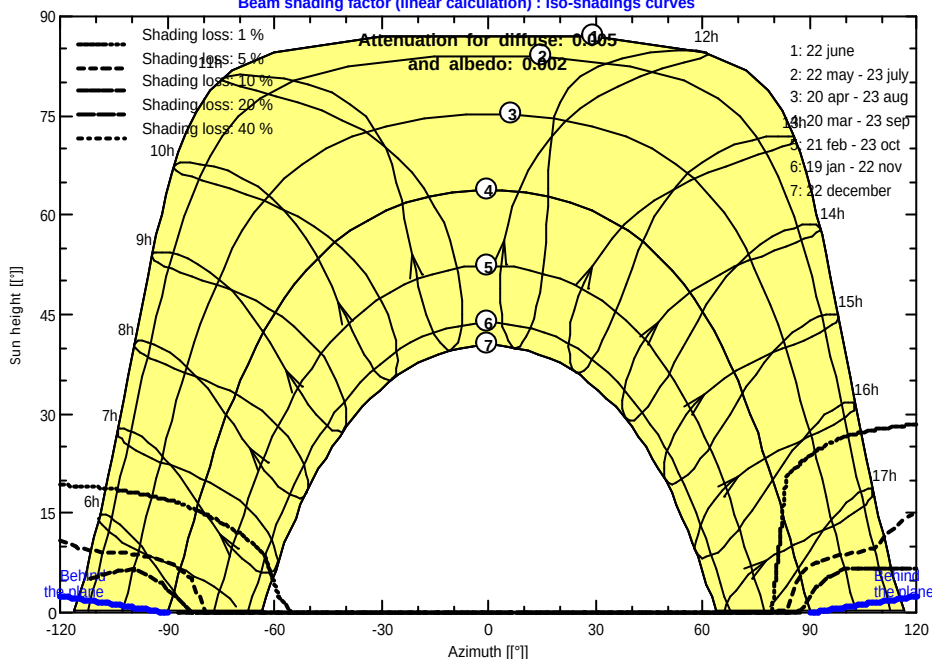
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa A1

Beam shading factor (linear calculation) : Iso-shadings curves



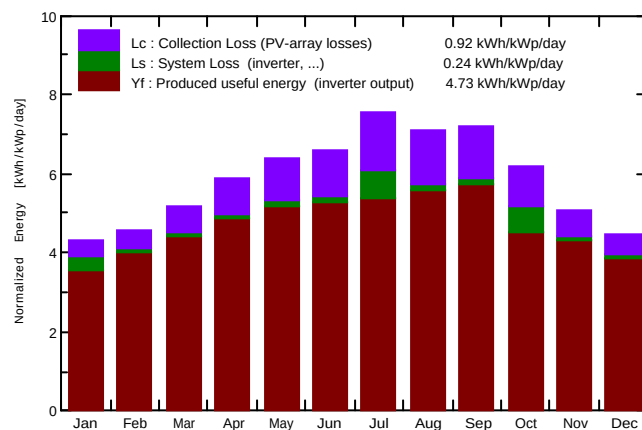
Grid-Connected System: Main results

Project : Villa A1
Simulation variant : New simulation variant

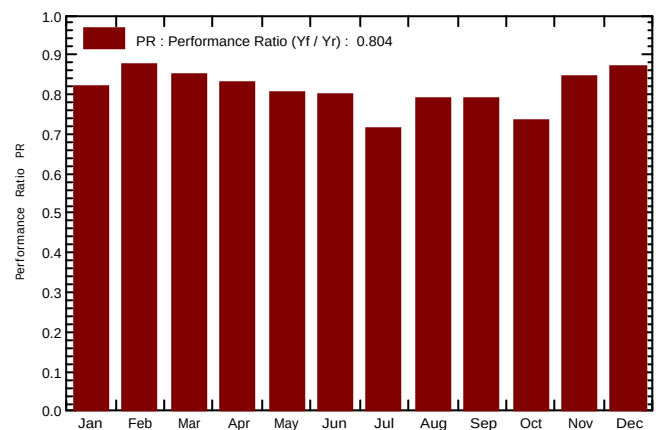
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	27 Pnom total 12.42 kWp
Inverter	Model	SUN2000MA-10KTL-M0 Pnom 10.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results
System Production **Produced Energy 21.45 MWh/year** Specific prod. 1727 kWh/kWp/year
Performance Ratio PR **80.40 %**

Normalized productions (per installed kWp): Nominal power 12.42 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	129.3	1.508	1.370	0.823
February	121.3	56.57	17.45	128.1	123.4	1.427	1.392	0.875
March	154.6	74.53	21.64	159.9	153.9	1.735	1.692	0.852
April	173.7	83.00	26.31	176.2	169.7	1.862	1.815	0.829
May	198.6	94.05	32.04	198.6	191.1	2.044	1.993	0.808
June	199.0	94.74	34.17	197.8	190.3	2.019	1.969	0.802
July	235.0	78.96	35.63	234.2	225.8	2.342	2.080	0.715
August	218.1	78.31	35.23	220.4	212.5	2.216	2.158	0.789
September	209.8	37.92	32.07	216.5	209.0	2.190	2.132	0.793
October	181.2	34.51	29.31	192.1	185.4	1.993	1.748	0.732
November	140.1	28.92	23.55	152.5	147.2	1.648	1.606	0.848
December	125.0	28.82	18.37	137.9	133.0	1.534	1.496	0.874
Year	2079.7	730.44	26.85	2148.1	2070.5	22.517	21.451	0.804

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

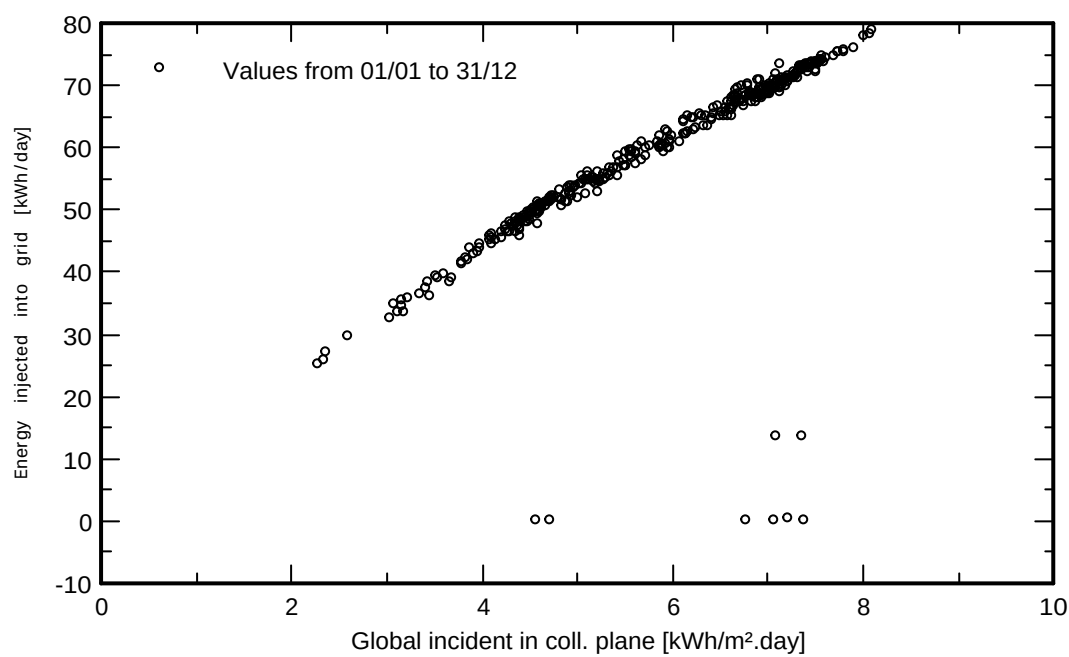
Grid-Connected System: Special graphs

Project : Villa A1

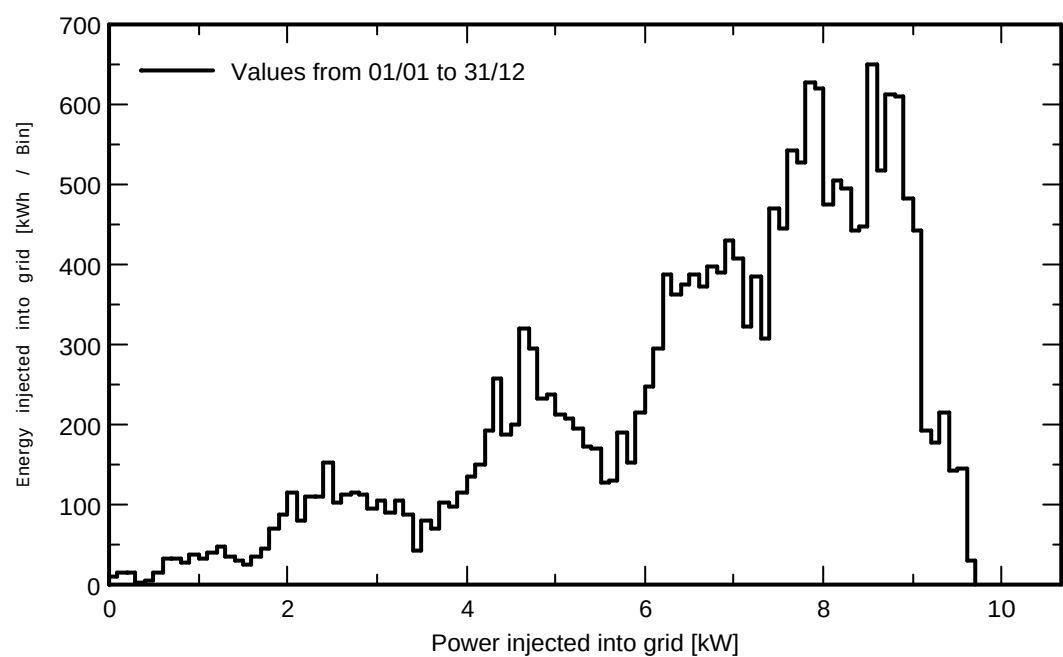
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	27	Pnom total	12.42 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

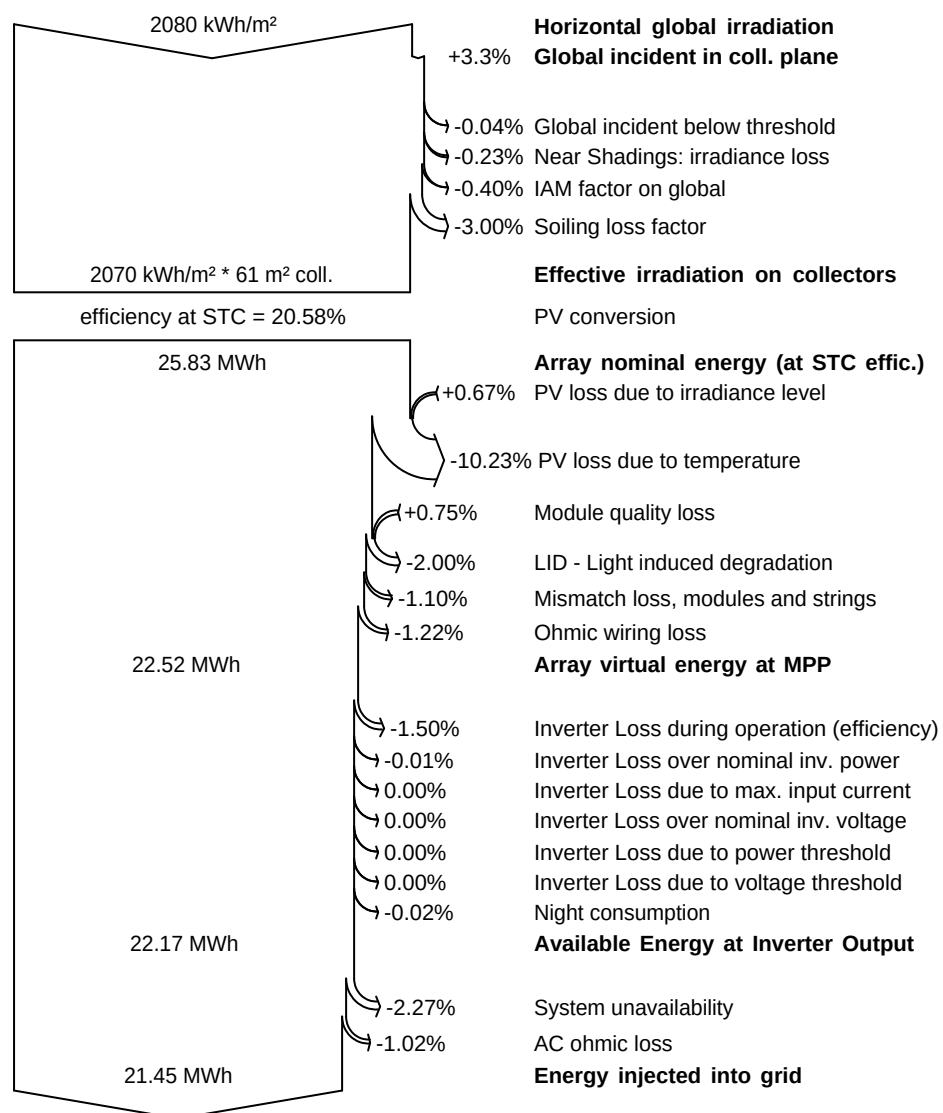


Grid-Connected System: Loss diagram

Project : Villa A1
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	27 Pnom total 12.42 kWp
Inverter	Model	SUN2000MA-10KTL-M0 Pnom 10.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa A1

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	27	Pnom total	12.42 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

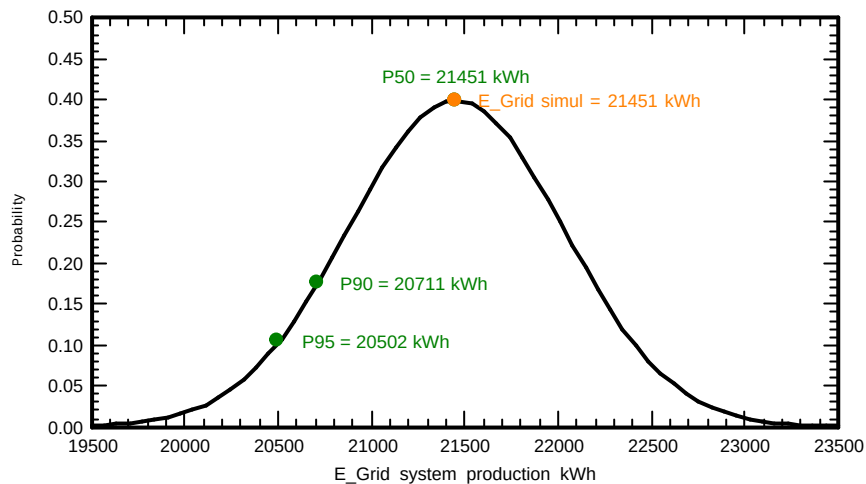
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.58 MWh
	P50	21.45 MWh
	P90	20.71 MWh
	P95	20.50 MWh

Probability distribution

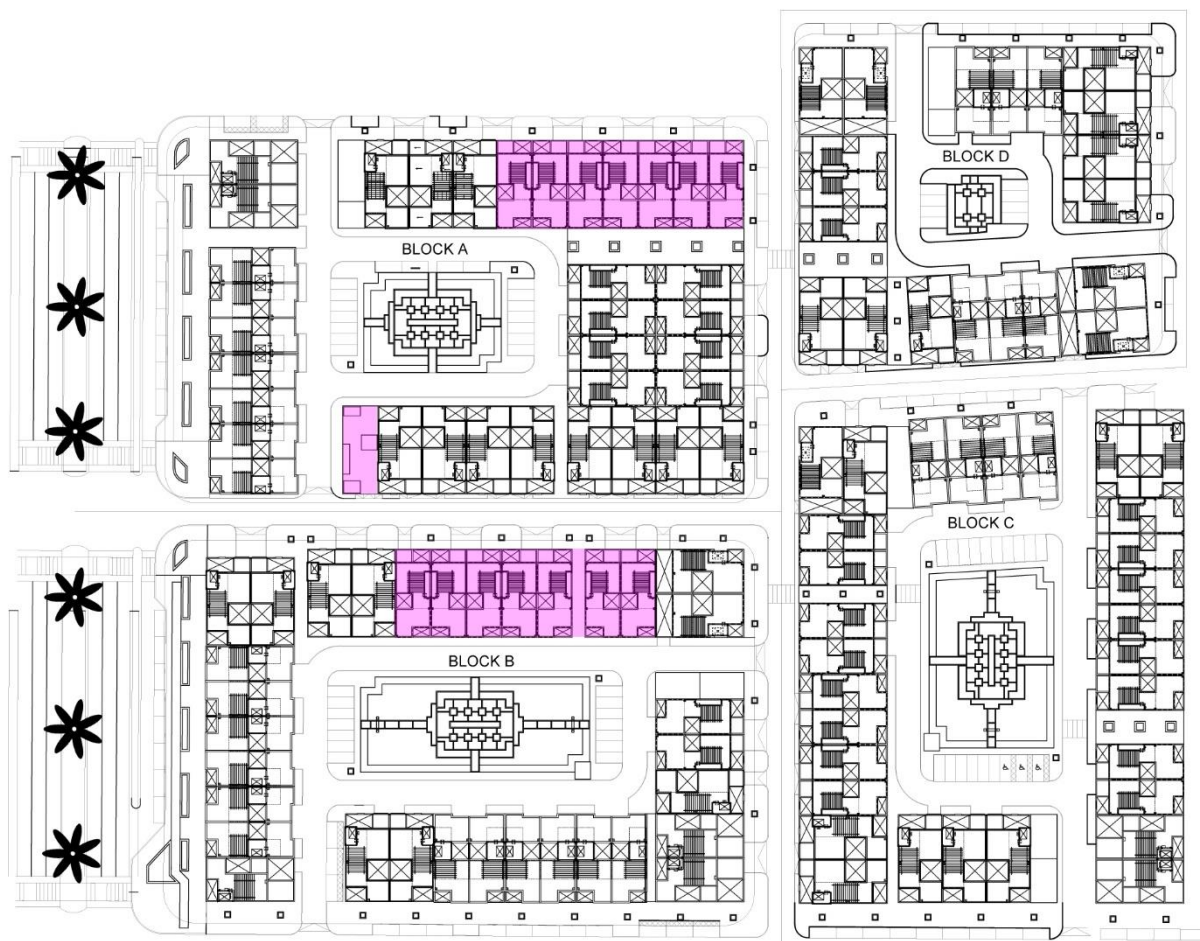


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

1. A1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
C. Orientation 5 & 6	65.1	22.95



PVSYST V6.88	kawar Energy (Jordan)				12/12/20	Page 1/7
Grid-Connected System: Simulation parameters						
Project :		Villa A1				
Geographical Site		Umm ash Sha'ūm		Country	Bahrain	
Situation		Latitude	26.22° N	Longitude	50.58° E	
Time defined as		Legal Time	Time zone UT+3	Altitude	11 m	
		Albedo	0.20			
Meteo data:		Umm ash Sha'ūm		Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic		
Simulation variant :		New simulation variant				
		Simulation date	12/12/20 14h08			
Simulation parameters		System type		Tables on a building		
Collector Plane Orientation		Tilt	5°	Azimuth	0°	
Sheds configuration		Nb. of sheds	29	Identical arrays		
		Sheds spacing	1.05 m	Collector width	1.03 m	
Shading limit angle		Limit profile angle	75.1°	Ground cov. Ratio (GCR)	98.1 %	
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm	
Horizon		Free Horizon				
Near Shadings		Linear shadings				
User's needs :		Unlimited load (grid)				
PV Arrays Characteristics (2 kinds of array defined)						
PV module		Si-mono	Model	JKM460M-7RL3-V		
Custom parameters definition		Manufacturer		Jinkosolar		
Sub-array "Sub-array #1"						
Number of PV modules		In series	15 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	15	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	6.90 kWp	At operating cond.	6.33 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	576 V	I mpp	11 A	
Sub-array "PV Array"						
Number of PV modules		In series	14 modules	In parallel	1 strings	
Total number of PV modules		Nb. modules	14	Unit Nom. Power	460 Wp	
Array global power		Nominal (STC)	6.44 kWp	At operating cond.	5.91 kWp (50°C)	
Array operating characteristics (50°C)		U mpp	537 V	I mpp	11 A	
Total Arrays global power		Nominal (STC)	13 kWp	Total	29 modules	
		Module area	65.1 m²	Cell area	60.2 m²	
Inverter						
Custom parameters definition		Model	SUN2000MA-10KTL-M0			
Characteristics		Manufacturer	Huawei Technologies			
		Operating Voltage	160-980 V	Unit Nom. Power	10.00 kWac	
Sub-array "Sub-array #1"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.38	
Sub-array "PV Array"		Nb. of inverters	1 * MPPT 50 %	Total Power	5.0 kWac	
				Pnom ratio	1.29	
Total		Nb. of inverters	1	Total Power	10 kWac	
PV Array loss factors						
Array Soiling Losses				Loss Fraction	3.0 %	
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s	

Grid-Connected System: Simulation parameters

Wiring Ohmic Loss	Array#1	867 mOhm	Loss Fraction	1.5 % at STC
	Array#2	809 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Serie Diode Loss			Loss Fraction	2.0 %
LID - Light Induced Degradation			Loss Fraction	-0.8 %
Module Quality Loss			Loss Fraction	1.0 % at MPP
Module Mismatch Losses			Loss Fraction	0.10 %
Strings Mismatch loss				
Incidence effect (IAM): User defined profile				

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

System loss factors

Unavailability of the system	Wires: 2x6.0 mm ²	39 m	Loss Fraction	2.0 % at STC
	7.3 days, 3 periods		Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa A1

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 29

Model SUN2000MA-10KTL-M0

Unlimited load (grid)

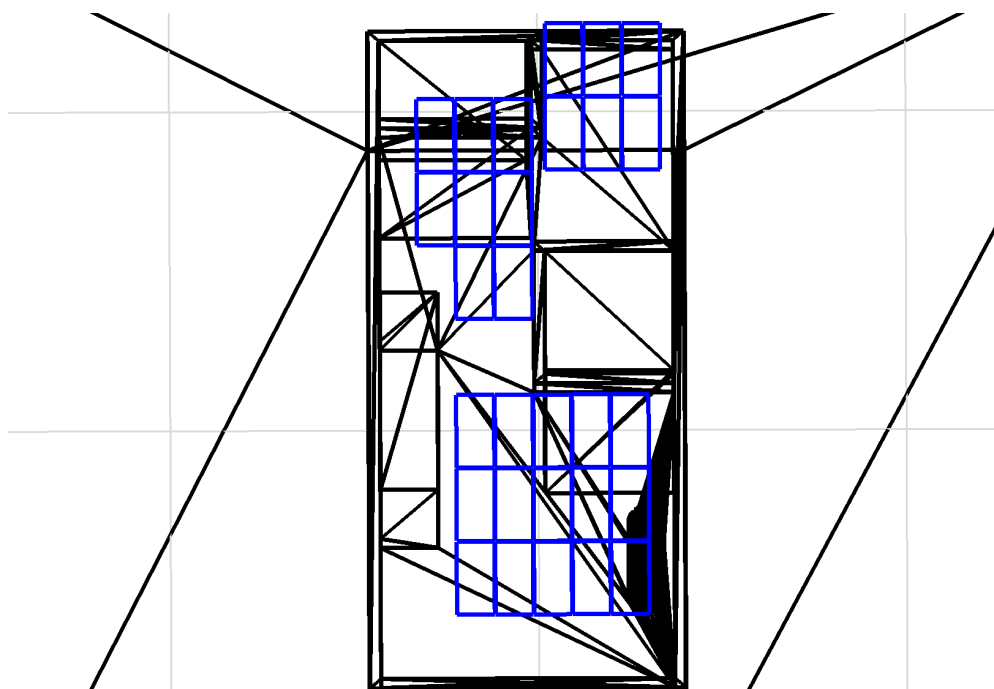
azimuth 0°

Pnom 460 Wp

Pnom total **13.34 kWp**

Pnom 10.00 kW ac

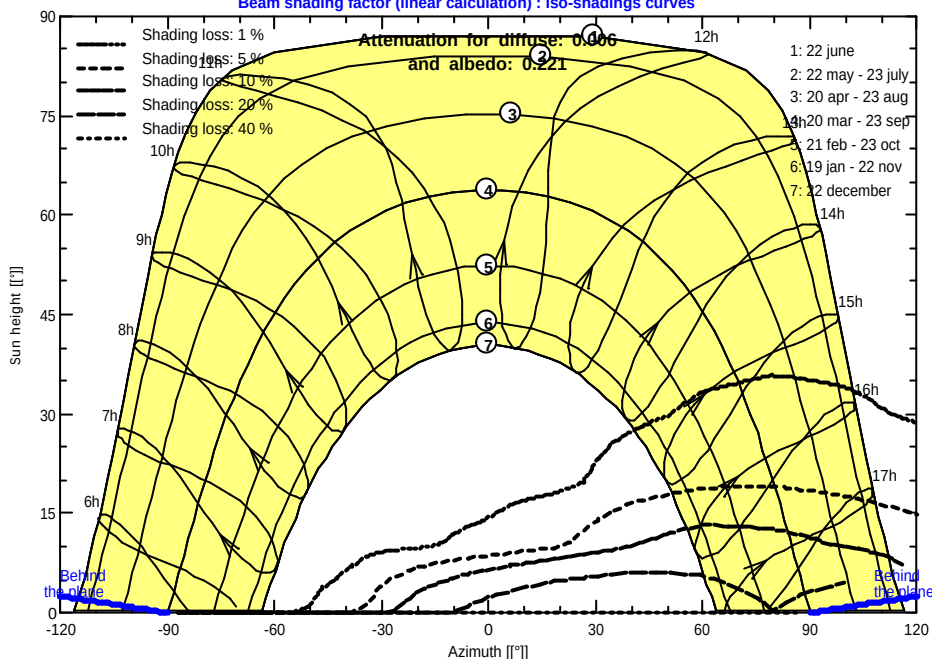
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa A1

Beam shading factor (linear calculation) : Iso-shadings curves



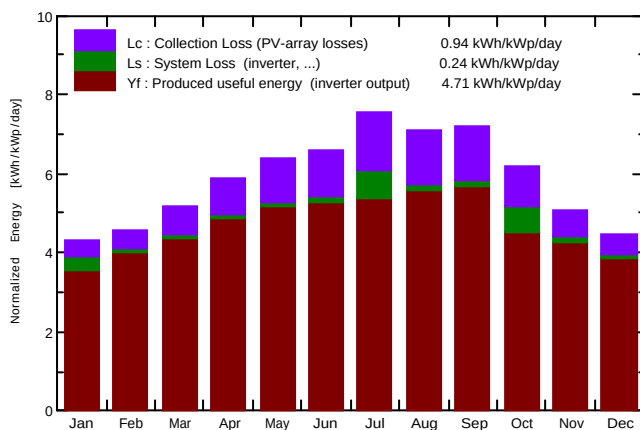
Grid-Connected System: Main results

Project : Villa A1
Simulation variant : New simulation variant

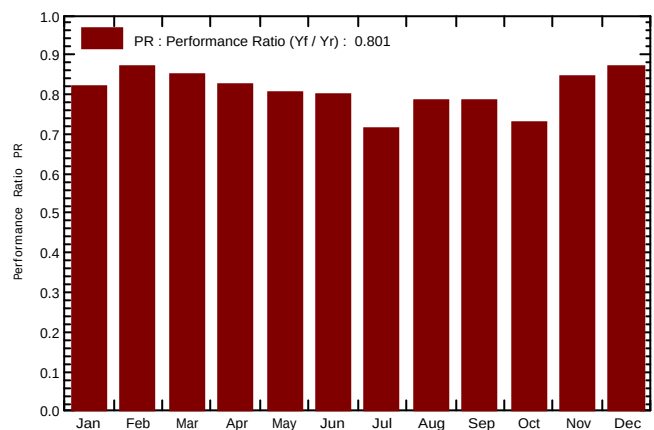
Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	29	Pnom total 13.34 kWp
Inverter	Model	SUN2000MA-10KTL-M0	Pnom 10.00 kW ac
User's needs	Unlimited load (grid)		

Main simulation results			
System Production	Produced Energy	22.95 MWh/year	Specific prod. 1720 kWh/kWp/year
	Performance Ratio PR	80.07 %	

Normalized productions (per installed kWp): Nominal power 13.34 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	128.8	1.614	1.466	0.819
February	121.3	56.57	17.45	128.1	123.0	1.529	1.491	0.872
March	154.6	74.53	21.64	159.9	153.6	1.858	1.811	0.849
April	173.7	83.00	26.31	176.2	169.4	1.995	1.943	0.827
May	198.6	94.05	32.04	198.6	190.9	2.191	2.135	0.806
June	199.0	94.74	34.17	197.8	190.1	2.167	2.112	0.800
July	235.0	78.96	35.63	234.2	225.5	2.508	2.225	0.712
August	218.1	78.31	35.23	220.4	212.2	2.376	2.313	0.787
September	209.8	37.92	32.07	216.5	208.6	2.329	2.266	0.785
October	181.2	34.51	29.31	192.1	184.9	2.131	1.869	0.729
November	140.1	28.92	23.55	152.5	146.6	1.763	1.717	0.844
December	125.0	28.82	18.37	137.9	132.4	1.640	1.599	0.869
Year	2079.7	730.44	26.85	2148.1	2066.1	24.100	22.946	0.801

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

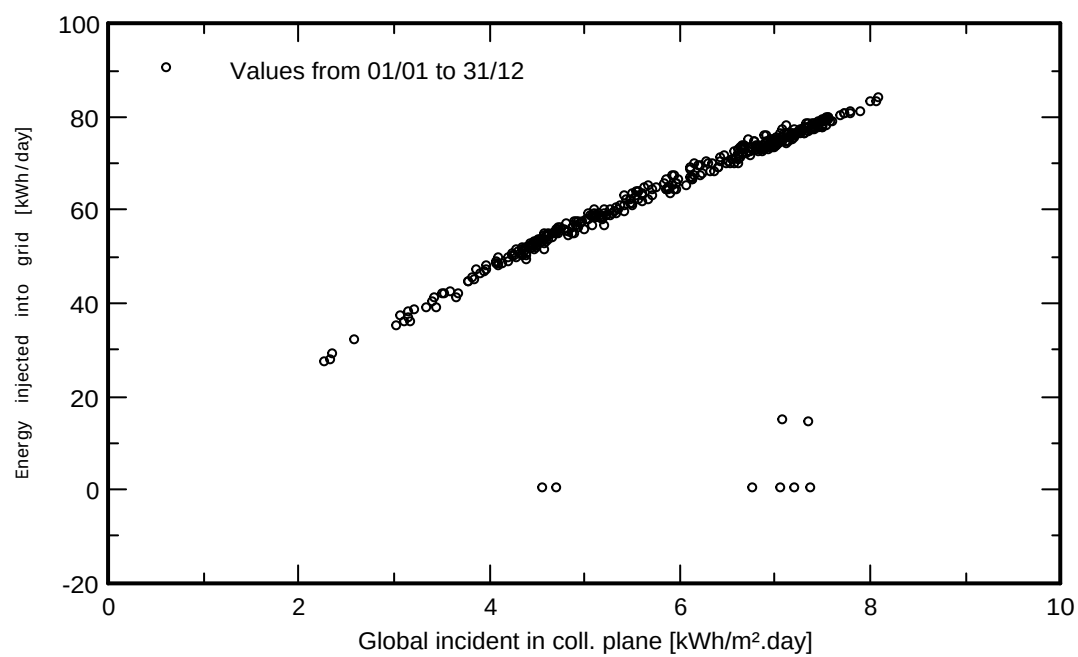
Villa A1

Simulation variant :

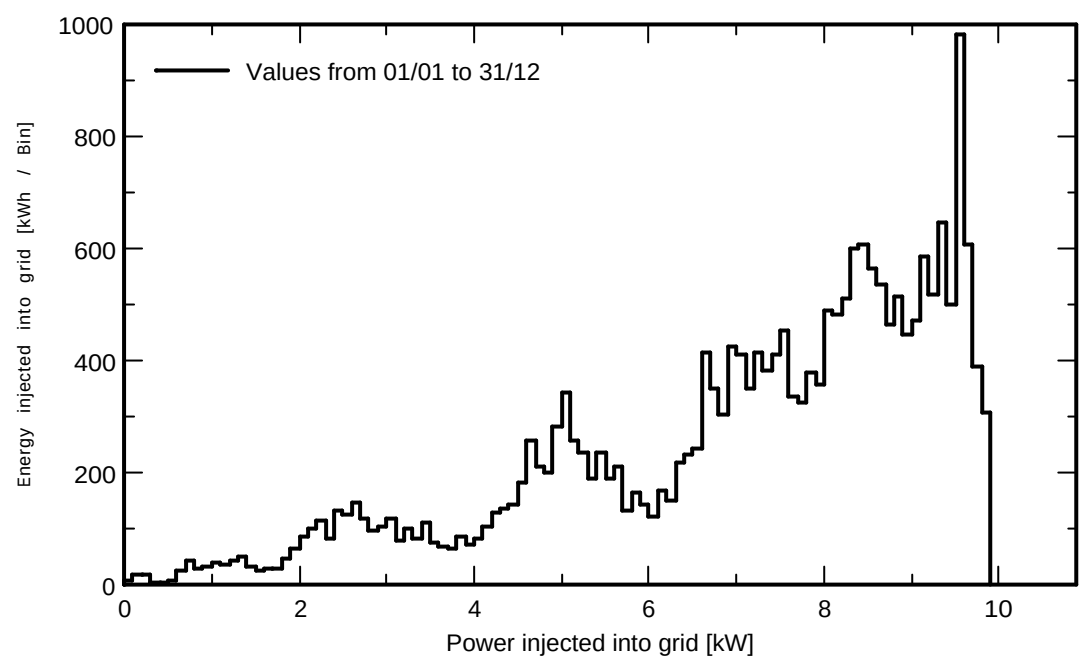
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	29	Pnom total	13.34 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

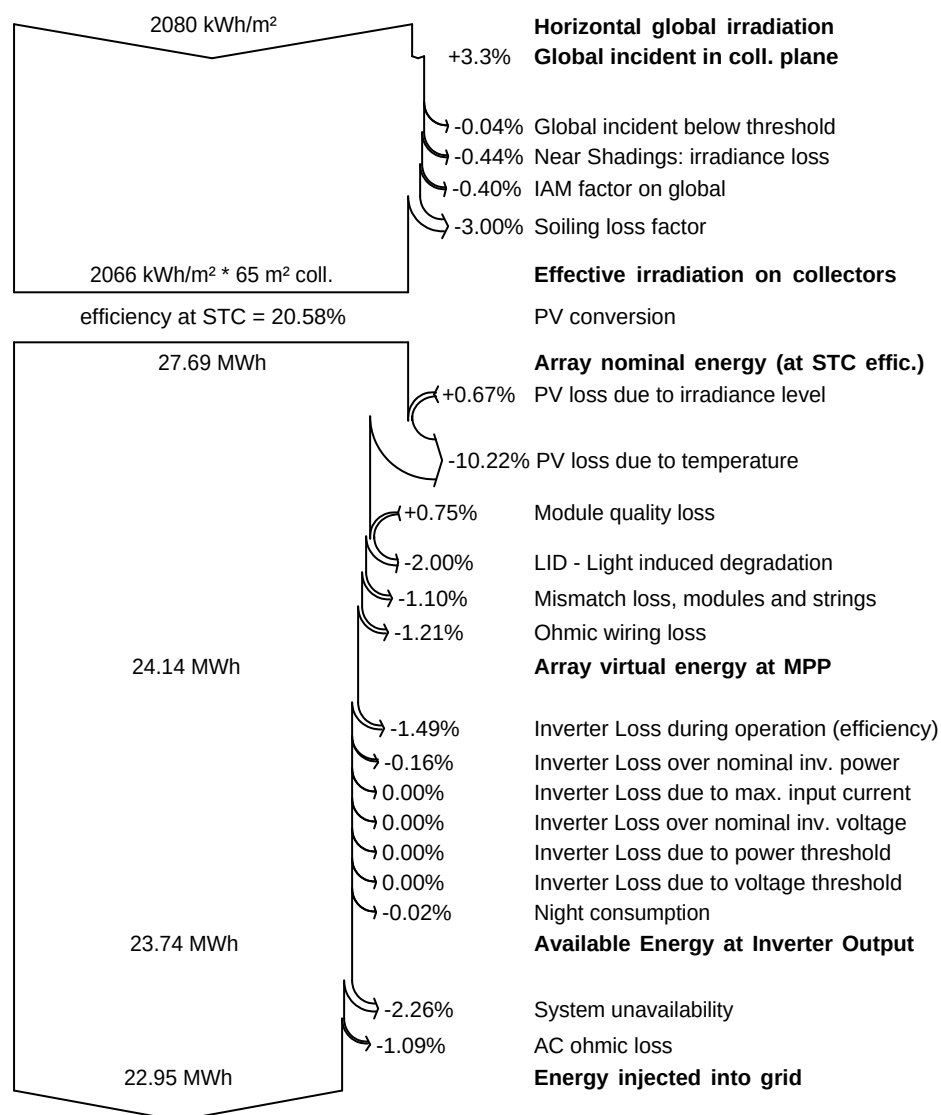


Grid-Connected System: Loss diagram

Project : Villa A1
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	29 Pnom total 13.34 kWp
Inverter	Model	SUN2000MA-10KTL-M0 Pnom 10.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project :
Simulation variant :

Villa A1
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	29	Pnom total	13.34 kWp	
Inverter	Model	SUN2000MA-10KTL-M0	Pnom	10.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

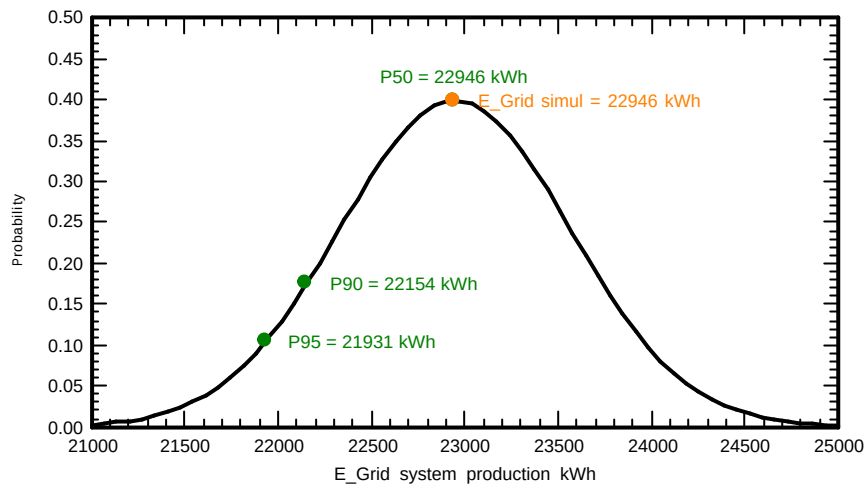
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.62 MWh
	P50	22.95 MWh
	P90	22.15 MWh
	P95	21.93 MWh

Probability distribution

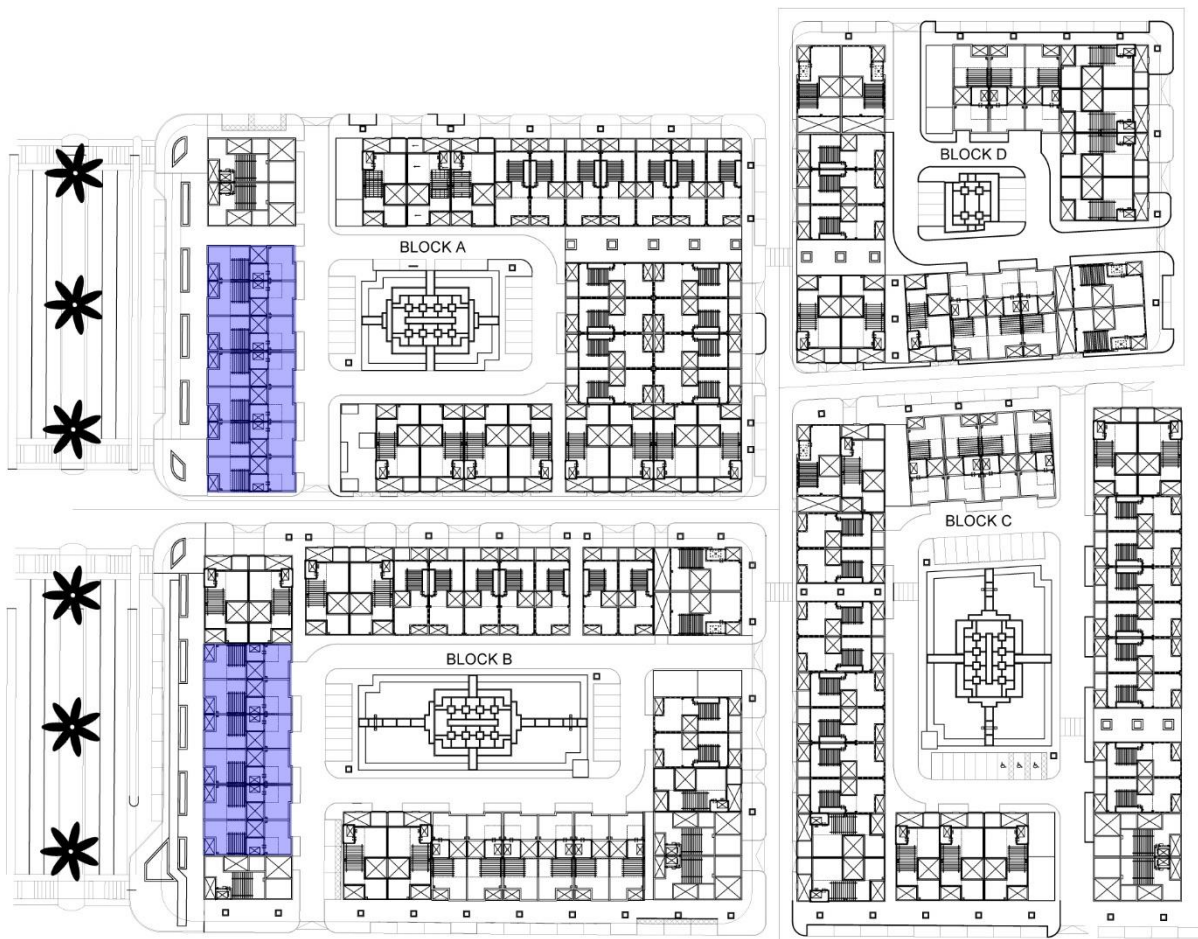


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

2. B1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
A. Orientation 1 & 2	76.3	26.92



PVSYST V6.88	kawar Energy (Jordan)		30/12/20	Page 1/7
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Grid-Connected System: Simulation parameters

Project :

Villa 1B

Geographical Site

Umm ash Sha'um

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'um

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

30/12/20 22h28

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

34

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

74.6°

Ground cov. Ratio (GCR)

98.0 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

17 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

34

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

15.64 kWp

At operating cond.

14.34 kWp (50°C)

Array operating characteristics (50°C)

U mpp

653 V

I mpp

22 A

Total area

Module area

76.3 m²

Cell area

70.5 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.04

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

491 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors			
Wiring Ohmic Loss	Wires: 3x6.0 mm ²	39 m	Loss Fraction 1.2 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

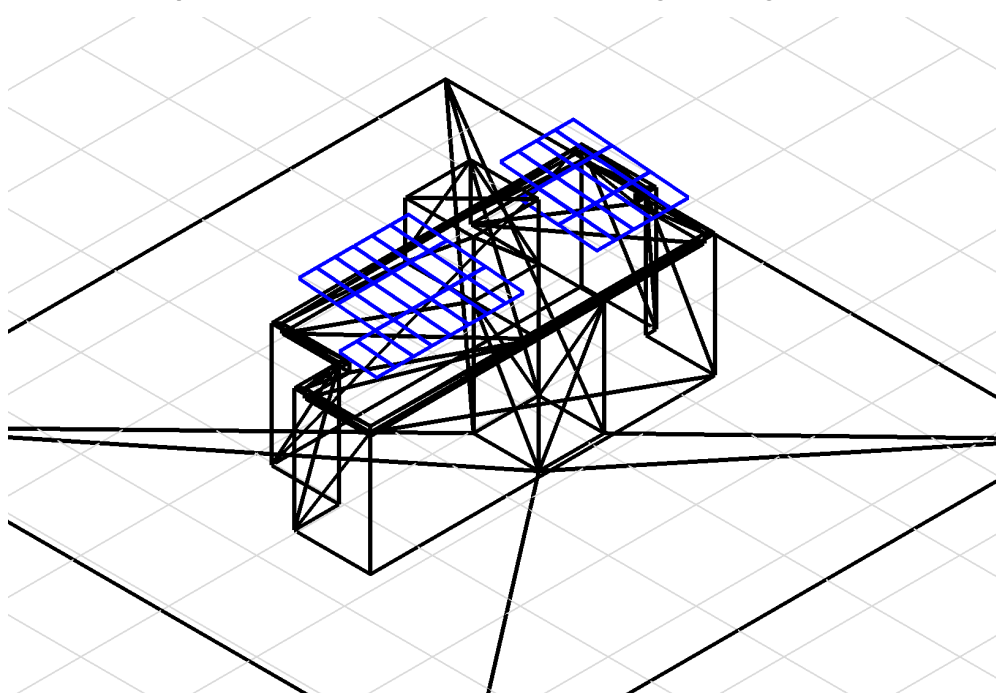
azimuth 0°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

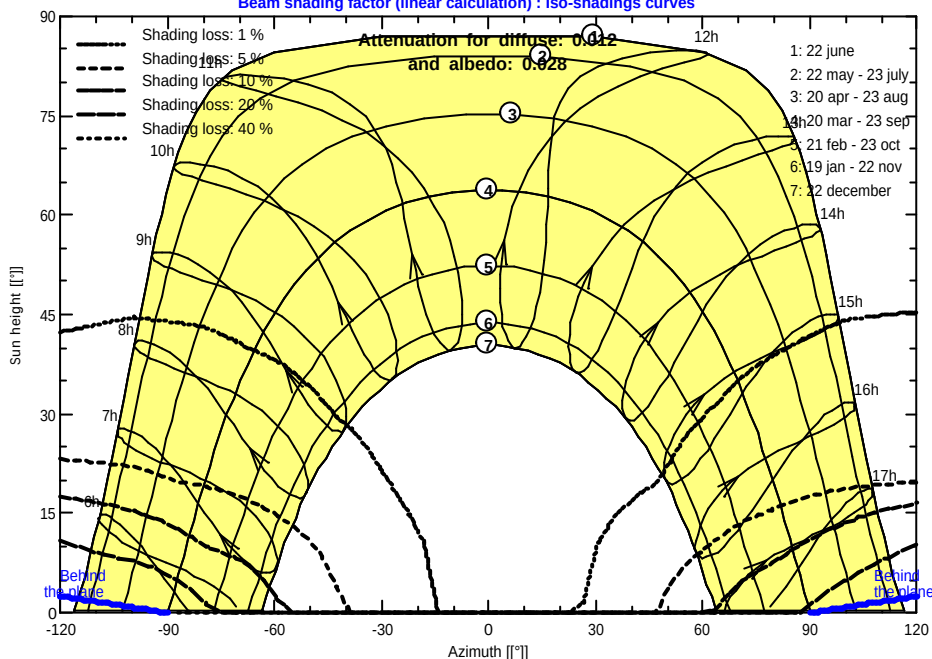
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 1B

Beam shading factor (linear calculation) : Iso-shadings curves



Grid-Connected System: Main results

Project :

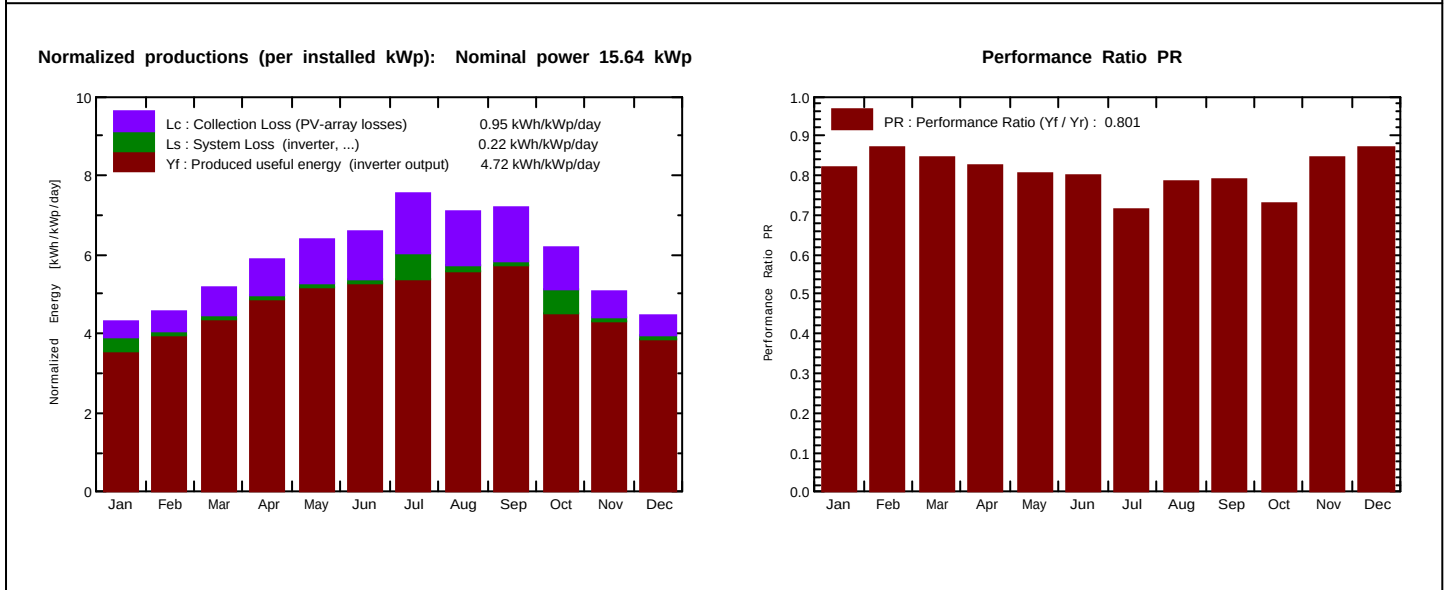
Villa 1B

Simulation variant :

New simulation variant

Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	34	Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom 15.00 kW ac
User's needs	Unlimited load (grid)		

Main simulation results			
System Production	Produced Energy	26.92 MWh/year	Specific prod. 1721 kWh/kWp/year
	Performance Ratio PR	80.14 %	



New simulation variant

Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	128.4	1.886	1.717	0.819
February	121.3	56.57	17.45	128.1	122.5	1.786	1.746	0.871
March	154.6	74.53	21.64	159.9	152.9	2.171	2.122	0.848
April	173.7	83.00	26.31	176.2	168.5	2.330	2.277	0.826
May	198.6	94.05	32.04	198.6	189.8	2.557	2.501	0.805
June	199.0	94.74	34.17	197.8	189.0	2.527	2.472	0.799
July	235.0	78.96	35.63	234.2	224.3	2.932	2.613	0.713
August	218.1	78.31	35.23	220.4	211.1	2.774	2.711	0.787
September	209.8	37.92	32.07	216.5	207.5	2.741	2.678	0.791
October	181.2	34.51	29.31	192.1	184.2	2.494	2.194	0.730
November	140.1	28.92	23.55	152.5	146.2	2.062	2.016	0.845
December	125.0	28.82	18.37	137.9	132.2	1.920	1.876	0.870
Year	2079.7	730.44	26.85	2148.1	2056.5	28.180	26.923	0.801

Legends:

GlobHor

DiffHor

T_Amb

GlobInc

Horizontal global irradiation

Horizontal diffuse irradiation

T amb.

Global incident in coll. plane

GlobEff

EArray

E_Grid

PR

Effective Global, corr. for IAM and shadings

Effective energy at the output of the array

Energy injected into grid

Performance Ratio

Grid-Connected System: Special graphs

Project :

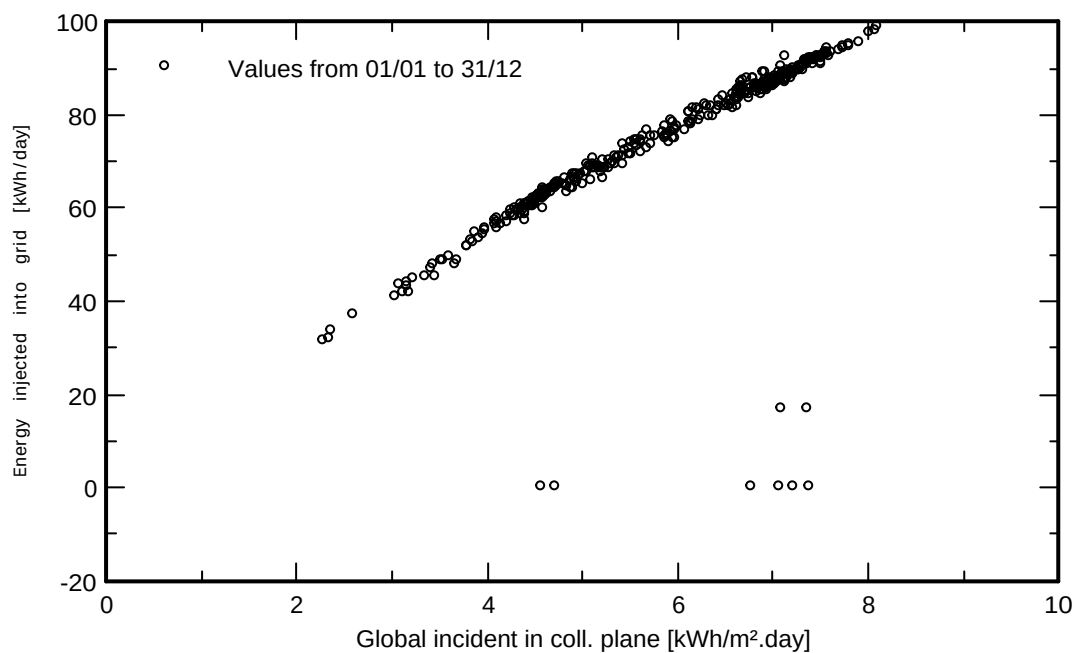
Simulation variant :

Villa 1B

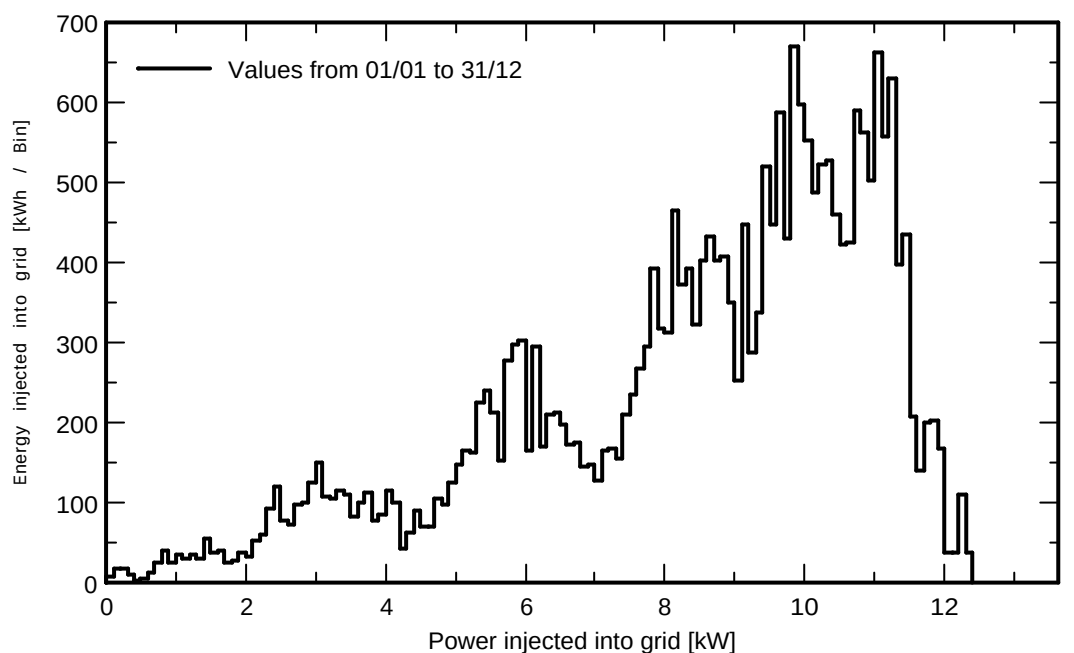
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

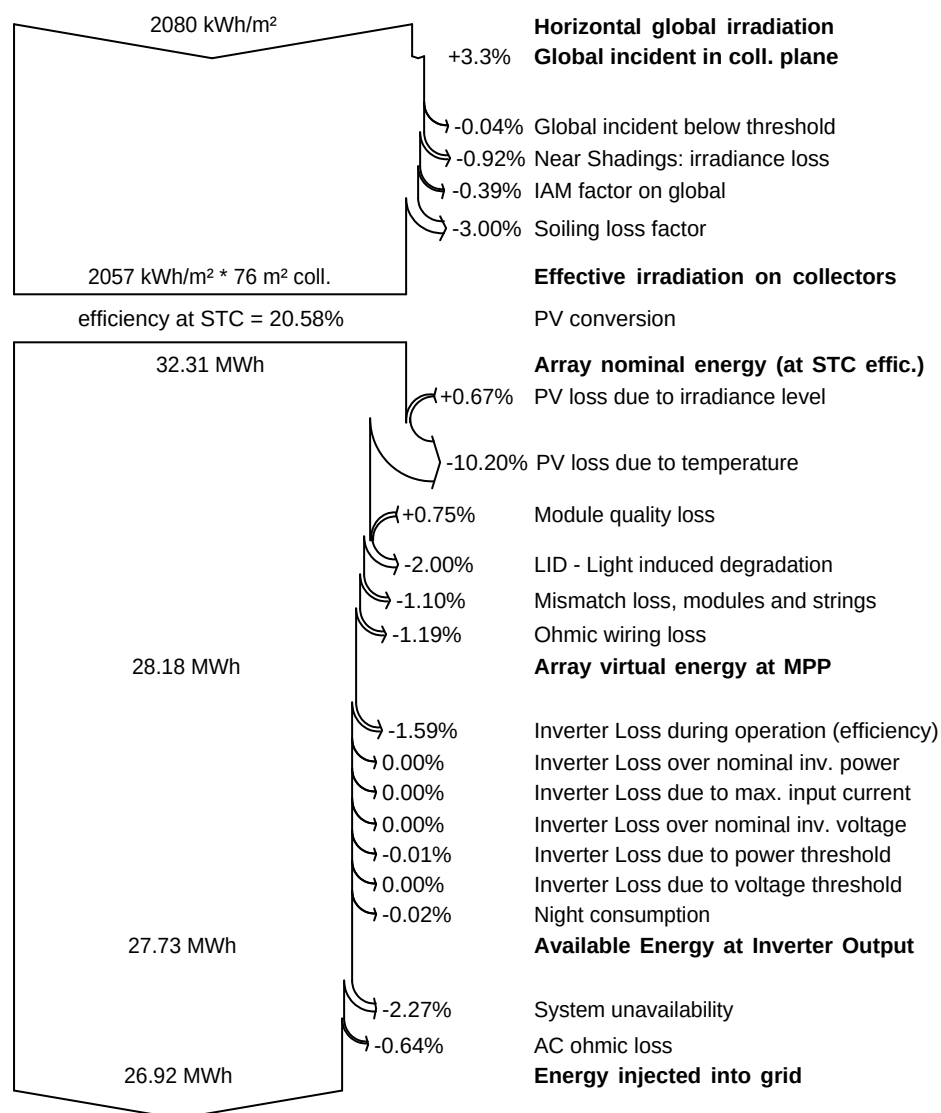


Grid-Connected System: Loss diagram

Project : Villa 1B
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	34 Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

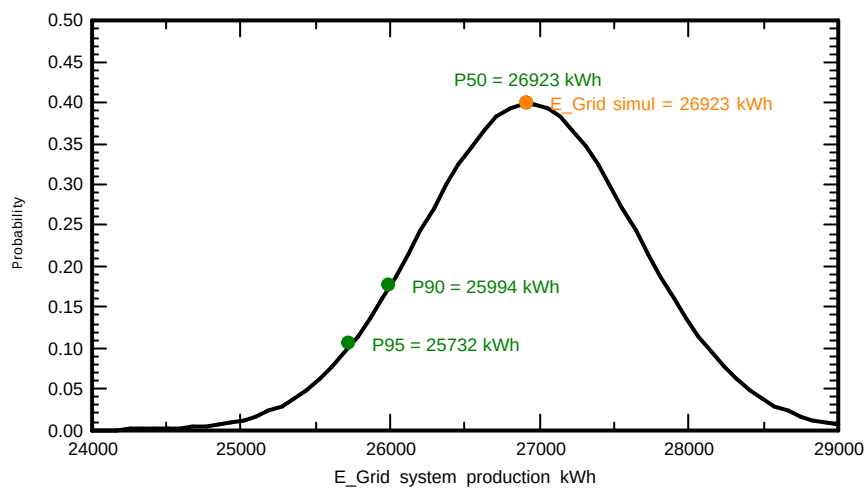
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.72 MWh
	P50	26.92 MWh
	P90	25.99 MWh
	P95	25.73 MWh

Probability distribution

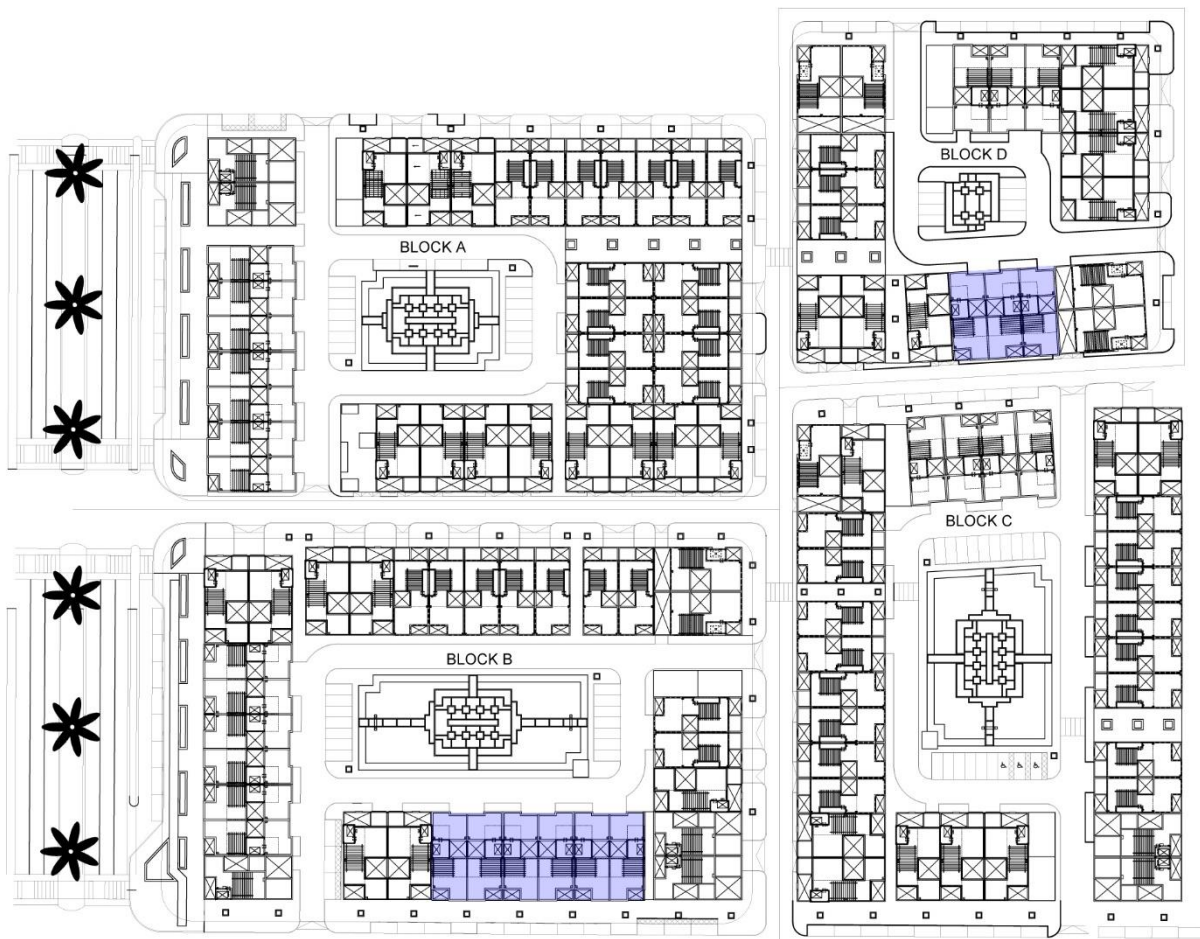


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

2. B1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
B. Orientation 3 & 4	76.3	27.03



PVSYST V6.88	kawar Energy (Jordan)		23/12/20	Page 1/7
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Grid-Connected System: Simulation parameters

Project :

Villa 1B

Geographical Site

Umm ash Sha'um

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'um

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

23/12/20 12h09

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

34

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.1°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

17 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

34

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

15.64 kWp

At operating cond.

14.34 kWp (50°C)

Array operating characteristics (50°C)

U mpp

653 V

I mpp

22 A

Total area

Module area

76.3 m²

Cell area

70.5 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.04

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

491 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 39 m	Loss Fraction	1.2 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

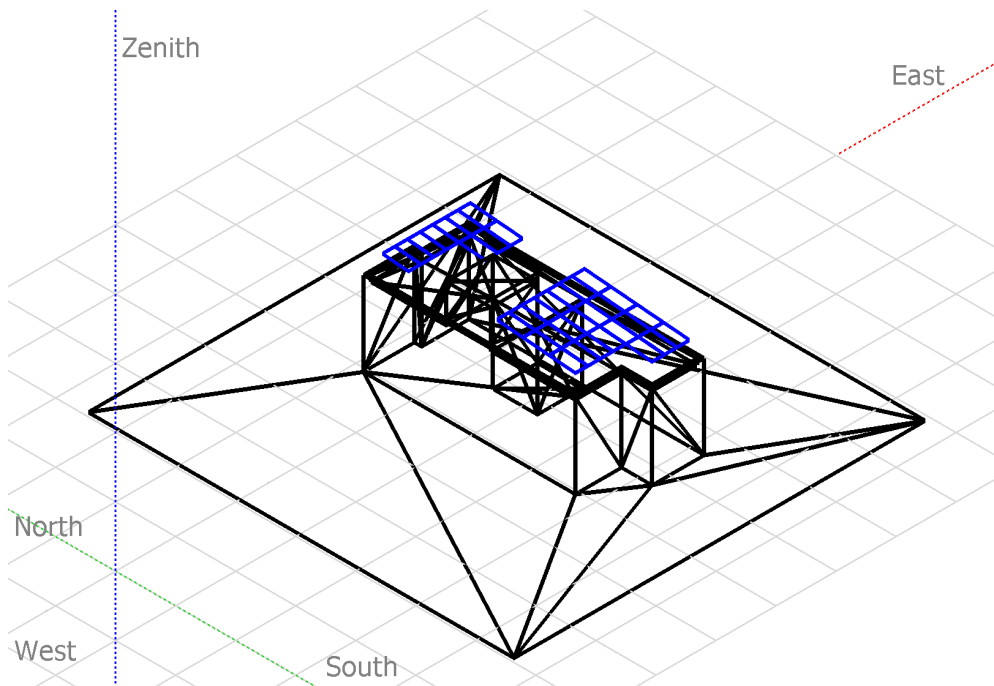
azimuth 0°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

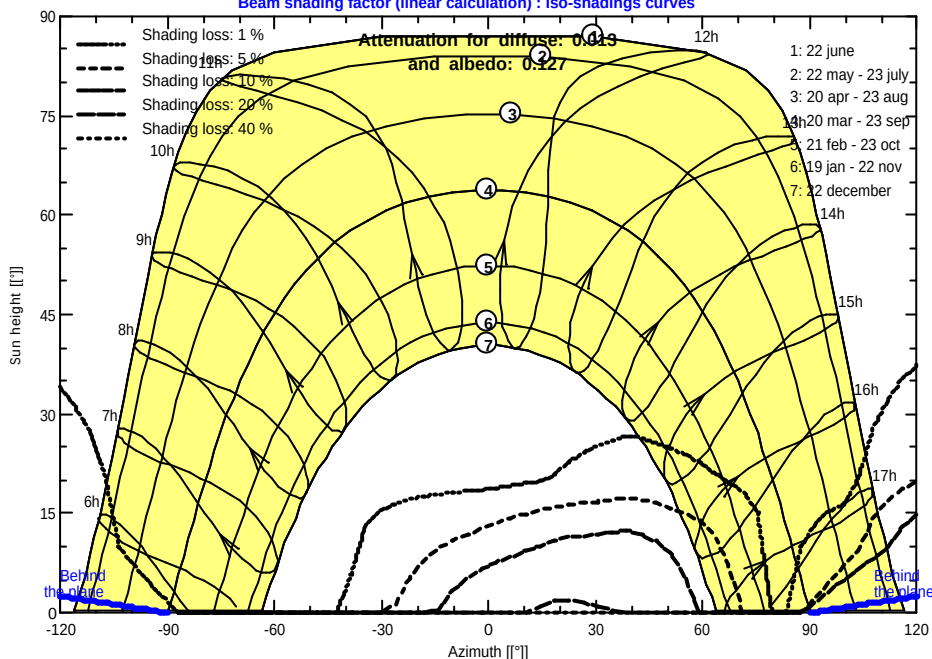
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 1B

Beam shading factor (linear calculation) : Iso-shadings curves



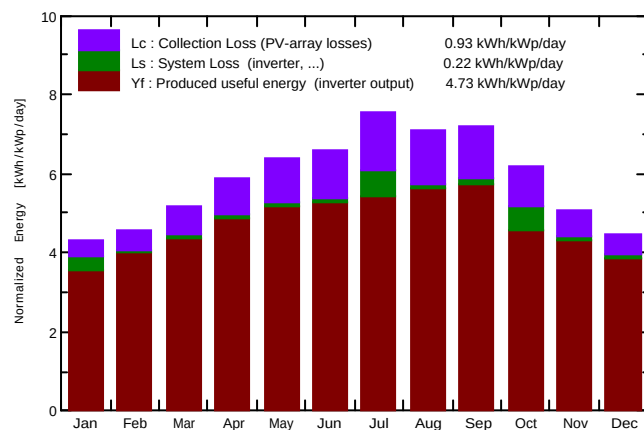
Grid-Connected System: Main results

Project : Villa 1B
Simulation variant : New simulation variant

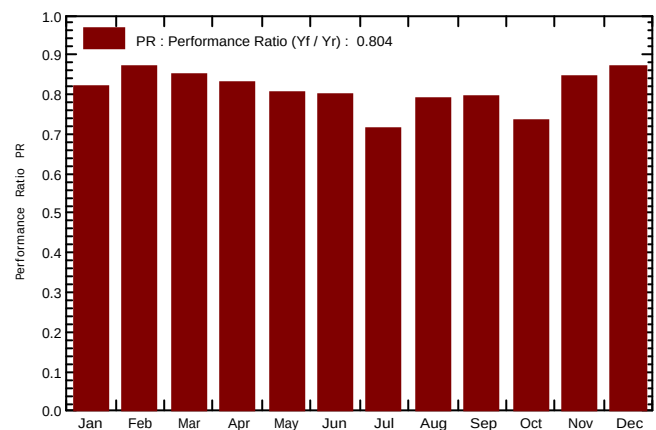
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	34 Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results	Produced Energy	Specific prod.
System Production	27.03 MWh/year	1728 kWh/kWp/year
	Performance Ratio PR	80.45 %

Normalized productions (per installed kWp): Nominal power 15.64 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	128.8	1.892	1.722	0.821
February	121.3	56.57	17.45	128.1	122.9	1.791	1.750	0.874
March	154.6	74.53	21.64	159.9	153.4	2.179	2.129	0.851
April	173.7	83.00	26.31	176.2	169.1	2.338	2.286	0.829
May	198.6	94.05	32.04	198.6	190.5	2.566	2.510	0.808
June	199.0	94.74	34.17	197.8	189.6	2.535	2.479	0.802
July	235.0	78.96	35.63	234.2	225.2	2.944	2.624	0.716
August	218.1	78.31	35.23	220.4	212.0	2.785	2.723	0.790
September	209.8	37.92	32.07	216.5	208.9	2.759	2.696	0.796
October	181.2	34.51	29.31	192.1	185.2	2.508	2.206	0.734
November	140.1	28.92	23.55	152.5	146.7	2.069	2.022	0.848
December	125.0	28.82	18.37	137.9	132.4	1.923	1.880	0.872
Year	2079.7	730.44	26.85	2148.1	2064.5	28.288	27.027	0.804

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

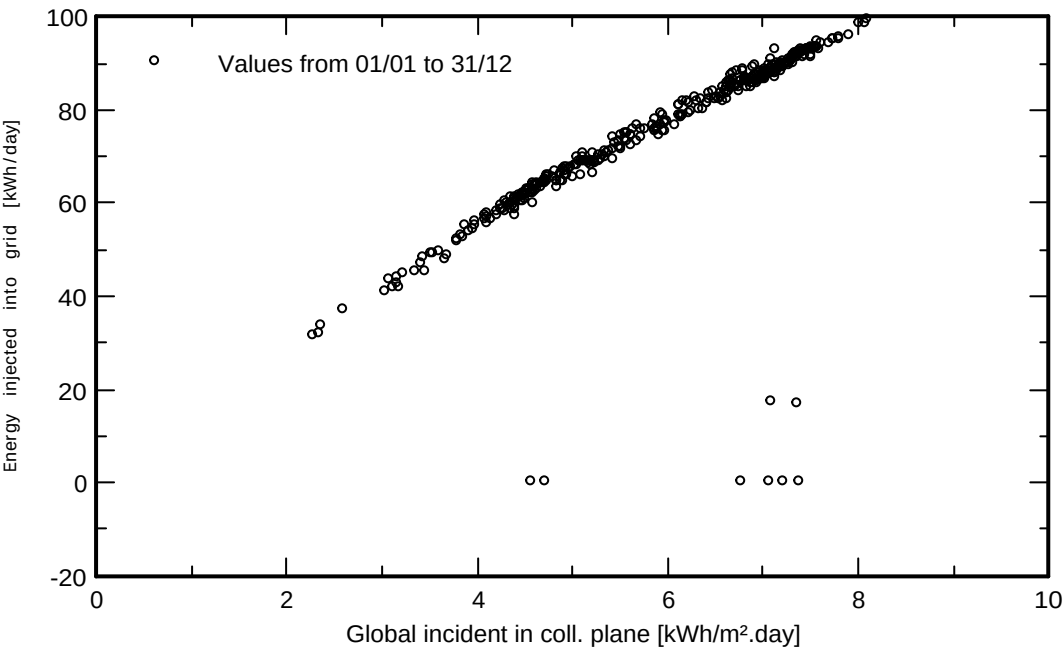
Villa 1B

Simulation variant :

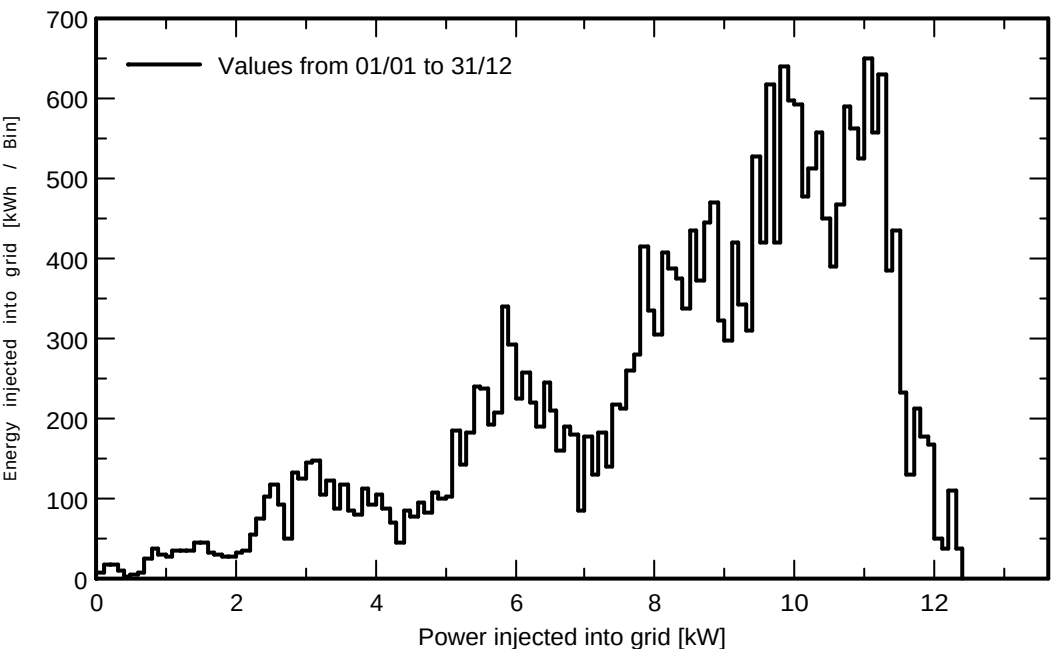
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution



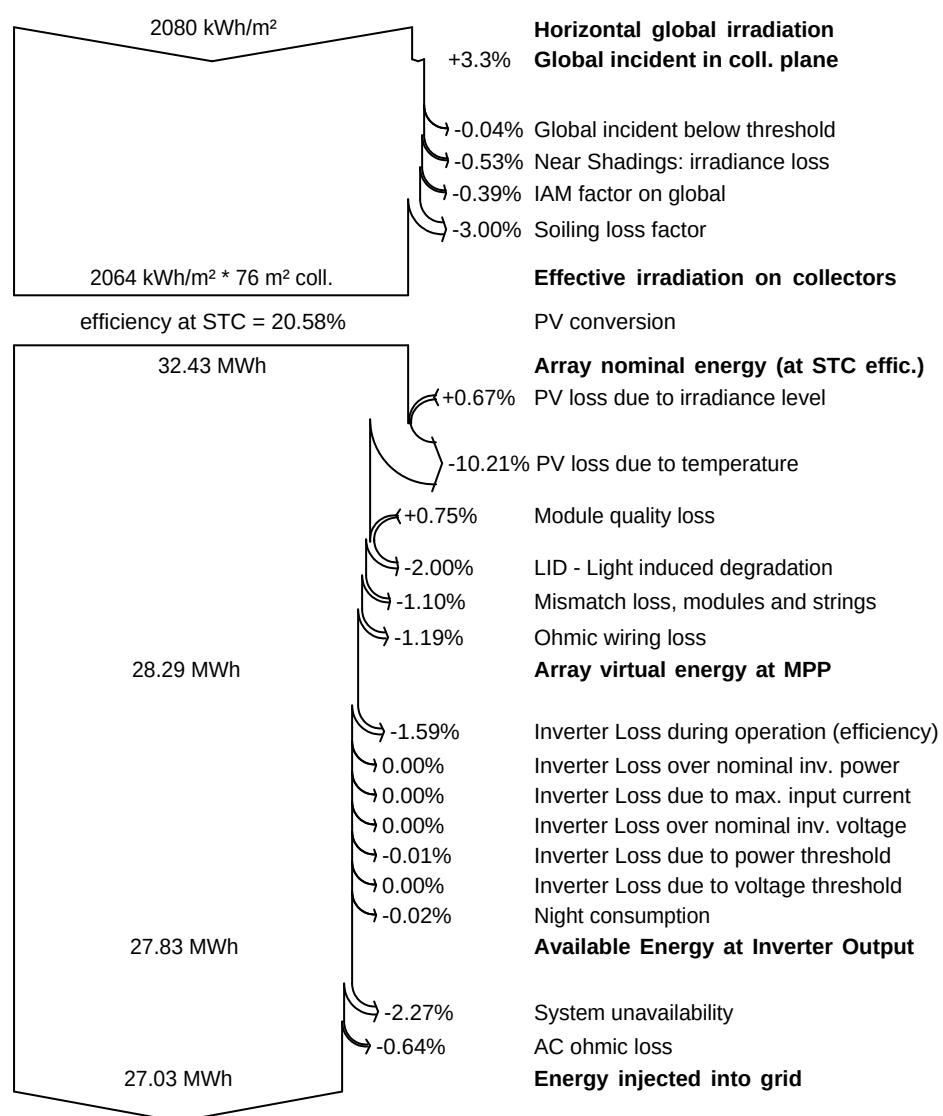
Grid-Connected System: Loss diagram

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project :
Simulation variant :

Villa 1B
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

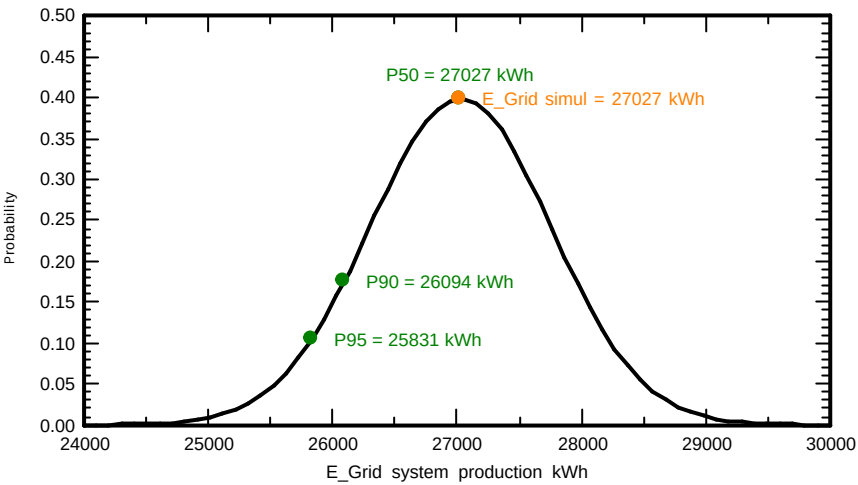
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.73 MWh
	P50	27.03 MWh
	P90	26.09 MWh
	P95	25.83 MWh

Probability distribution

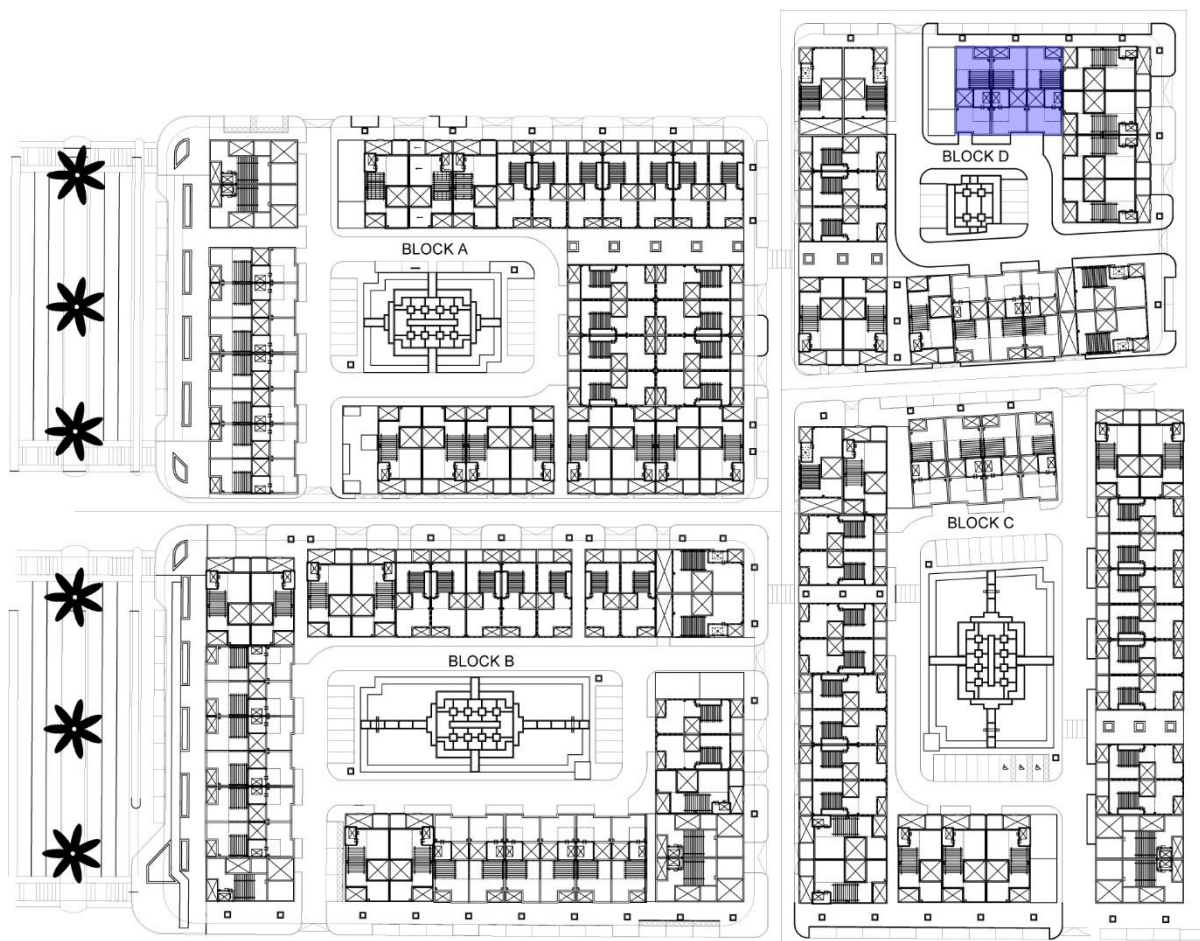


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

2. B1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
C. Orientation 5	76.3	26.19



PVSYST V6.88	kawar Energy (Jordan)				30/12/20	Page 1/7																		
Grid-Connected System: Simulation parameters																								
Project :		Villa 1B																						
Geographical Site		Umm ash Sha'• m		Country	Bahrain																			
Situation		Latitude	26.22° N	Longitude	50.58° E																			
Time defined as		Legal Time	Time zone UT+3	Altitude	11 m																			
		Albedo	0.20																					
Meteo data:		Umm ash Sha'• m	Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic																					
Simulation variant :		New simulation variant																						
		Simulation date	30/12/20 22h13																					
Simulation parameters		System type	Tables on a building																					
Collector Plane Orientation		Tilt	5°	Azimuth	0°																			
Sheds configuration		Nb. of sheds	34	Identical arrays																				
		Sheds spacing	1.05 m	Collector width	1.03 m																			
Shading limit angle		Limit profile angle	75.1°	Ground cov. Ratio (GCR)	98.1 %																			
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm																			
Horizon		Free Horizon																						
Near Shadings		Linear shadings																						
User's needs :		Unlimited load (grid)																						
PV Array Characteristics																								
PV module		Si-mono	Model	JKM460M-7RL3-V																				
Custom parameters definition		Manufacturer	Jinkosolar																					
Number of PV modules		In series	17 modules	In parallel	2 strings																			
Total number of PV modules		Nb. modules	34	Unit Nom. Power	460 Wp																			
Array global power		Nominal (STC)	15.64 kWp	At operating cond.	14.34 kWp (50°C)																			
Array operating characteristics (50°C)		U mpp	653 V	I mpp	22 A																			
Total area		Module area	76.3 m²	Cell area	70.5 m²																			
Inverter																								
Custom parameters definition		Model	SUN2000MA-15KTL-M0 TL																					
Characteristics		Manufacturer	Huawei Technologies																					
		Operating Voltage	160-950 V	Unit Nom. Power	15.0 kWac																			
				Max. power (=>45°C)	16.5 kWac																			
Inverter pack		Nb. of inverters	1 units	Total Power	15.0 kWac																			
				Pnom ratio	1.04																			
PV Array loss factors																								
Array Soiling Losses				Loss Fraction	3.0 %																			
Thermal Loss factor		Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s																			
Wiring Ohmic Loss		Global array res.	491 mOhm	Loss Fraction	1.5 % at STC																			
Serie Diode Loss		Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC																			
LID - Light Induced Degradation				Loss Fraction	2.0 %																			
Module Quality Loss				Loss Fraction	-0.8 %																			
Module Mismatch Losses				Loss Fraction	1.0 % at MPP																			
Strings Mismatch loss				Loss Fraction	0.10 %																			
Incidence effect (IAM): User defined profile																								
<table><tr><td>0°</td><td>30°</td><td>50°</td><td>60°</td><td>70°</td><td>75°</td><td>80°</td><td>85°</td><td>90°</td></tr><tr><td>1.000</td><td>1.000</td><td>1.000</td><td>1.000</td><td>0.982</td><td>0.963</td><td>0.932</td><td>0.857</td><td>0.000</td></tr></table>							0°	30°	50°	60°	70°	75°	80°	85°	90°	1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000
0°	30°	50°	60°	70°	75°	80°	85°	90°																
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000																

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss

Wires: 3x6.0 mm² 39 m

Loss Fraction 1.2 % at STC

Unavailability of the system

7.3 days, 3 periods

Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

System type **Tables on a building**

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt

5°

Model JKM460M-7RL3-V

Nb. of modules

34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

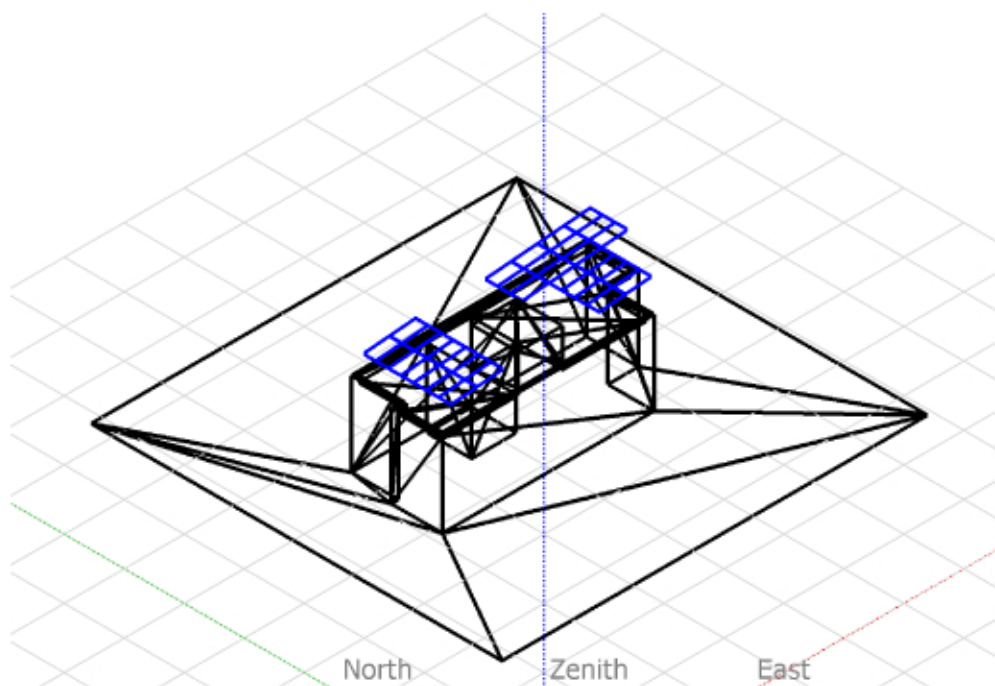
azimuth 0°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

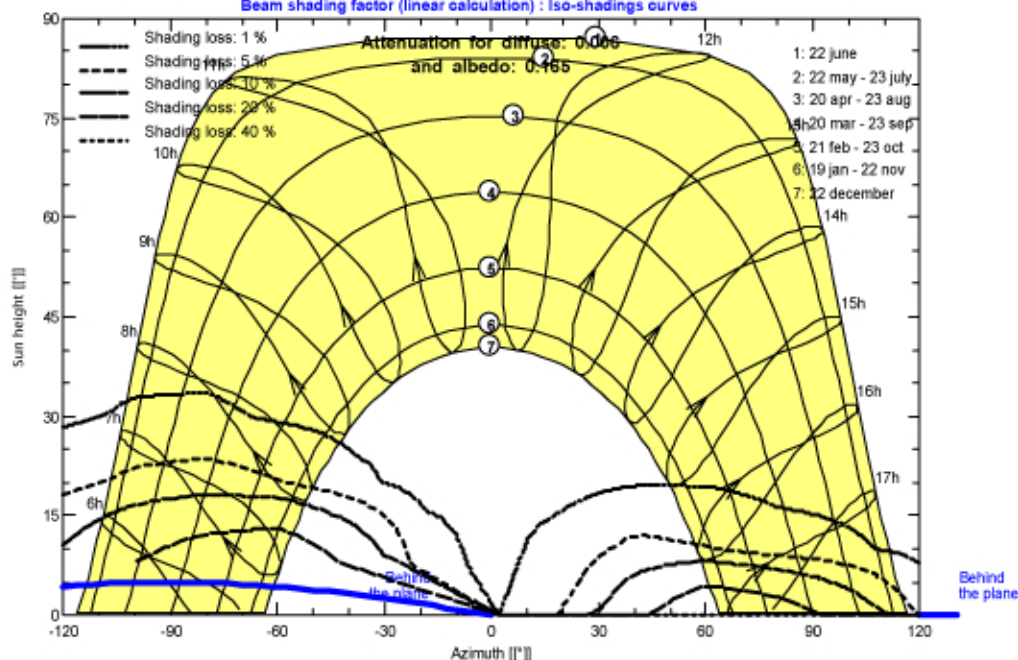
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 1B

Beam shading factor (linear calculation) : Iso-shadings curves



Grid-Connected System: Main results

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

Linear shadings

PV Field Orientation

tilt

5°

azimuth

0°

PV modules

Model

JKM460M-7RL3-V

Pnom

460 Wp

PV Array

Nb. of modules

34

Pnom total

15.64 kWp

Inverter

Model

SUN2000MA-15KTL-M0 TL

Pnom

15.00 kW ac

User's needs

Unlimited load (grid)

Main simulation results

System Production

Produced Energy

26.19 MWh/year

Specific prod.

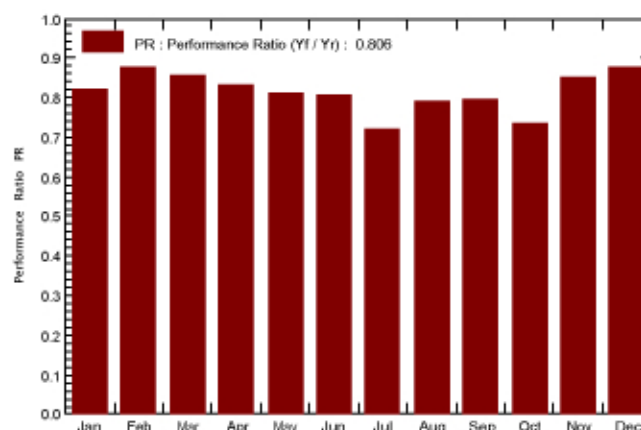
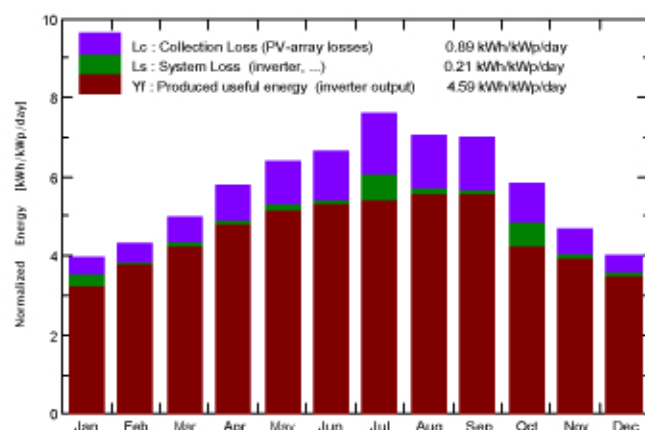
1675 kWh/kWp/year

Performance Ratio PR

80.56 %

Normalized productions (per installed kWp): Nominal power 15.64 kWp

Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	122.8	117.6	1.736	1.579	0.822
February	121.3	56.57	17.45	121.3	116.4	1.703	1.664	0.877
March	154.6	74.53	21.64	154.7	148.6	2.116	2.068	0.855
April	173.7	83.00	26.31	173.2	166.5	2.305	2.253	0.832
May	198.6	94.05	32.04	198.8	191.1	2.575	2.518	0.810
June	199.0	94.74	34.17	198.8	191.2	2.555	2.499	0.804
July	235.0	78.96	35.63	235.1	226.5	2.961	2.638	0.717
August	218.1	78.31	35.23	218.5	210.4	2.768	2.706	0.792
September	209.8	37.92	32.07	209.5	201.7	2.673	2.612	0.797
October	181.2	34.51	29.31	181.0	174.1	2.369	2.080	0.735
November	140.1	28.92	23.55	140.1	134.5	1.908	1.865	0.852
December	125.0	28.82	18.37	125.0	119.7	1.749	1.709	0.874
Year	2079.7	730.44	26.85	2078.7	1998.3	27.417	26.192	0.806

Legends: GlobHor

Horizontal global irradiation

DiffHor

Horizontal diffuse irradiation

T_Amb

T amb.

GlobInc

Global incident in coll. plane

GlobEff

Effective Global, corr. for IAM and shadings

EArray

Effective energy at the output of the array

E_Grid

Energy injected into grid

PR

Performance Ratio

Grid-Connected System: Special graphs

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

Linear shadings

PV Field Orientation

tilt

5°

azimuth

0°

PV modules

Model

JKM460M-7RL3-V

Pnom

460 Wp

PV Array

Nb. of modules

34

Pnom total

15.64 kWp

Inverter

Model

SUN2000MA-15KTL-M0 TL

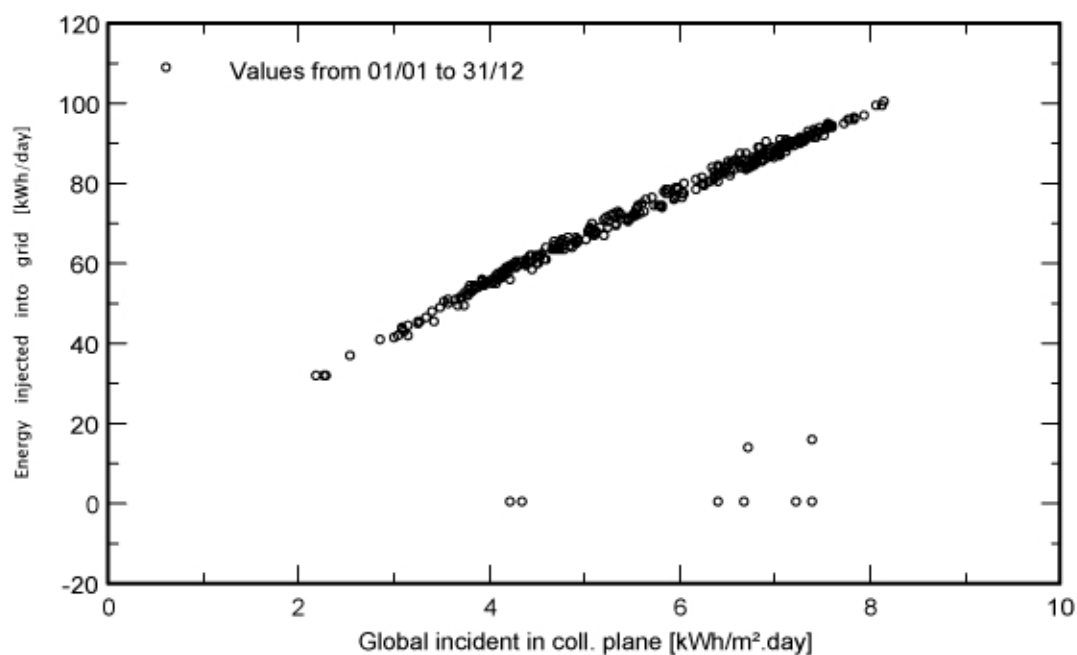
Pnom

15.00 kW ac

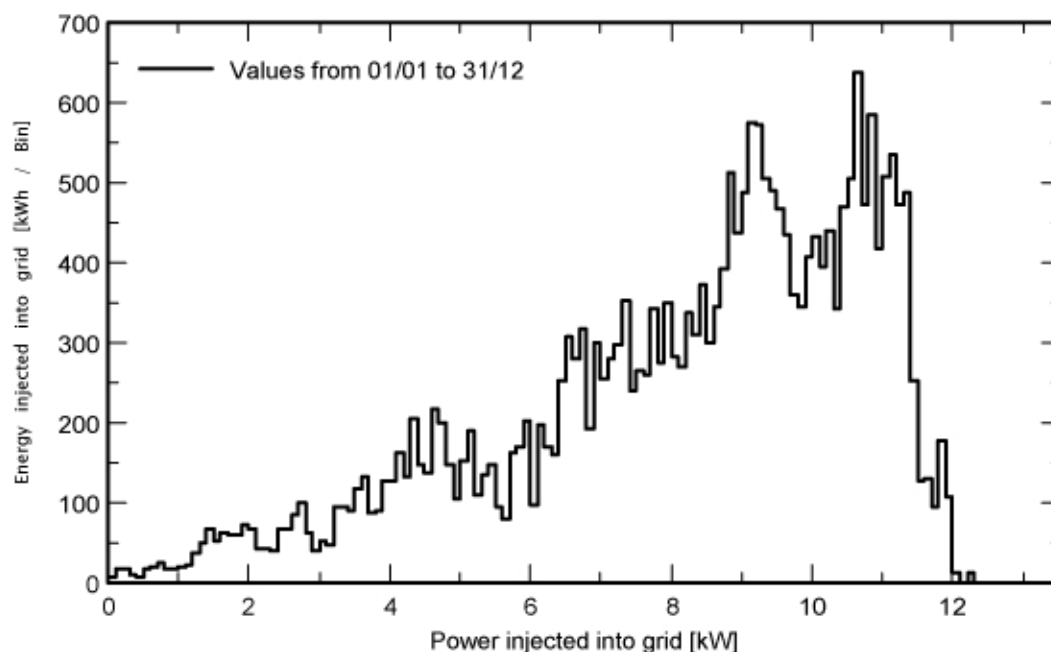
User's needs

Unlimited load (grid)

Daily Input/Output diagram



System Output Power Distribution



Grid-Connected System: Loss diagram

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt

Model JKM460M-7RL3-V

Nb. of modules

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

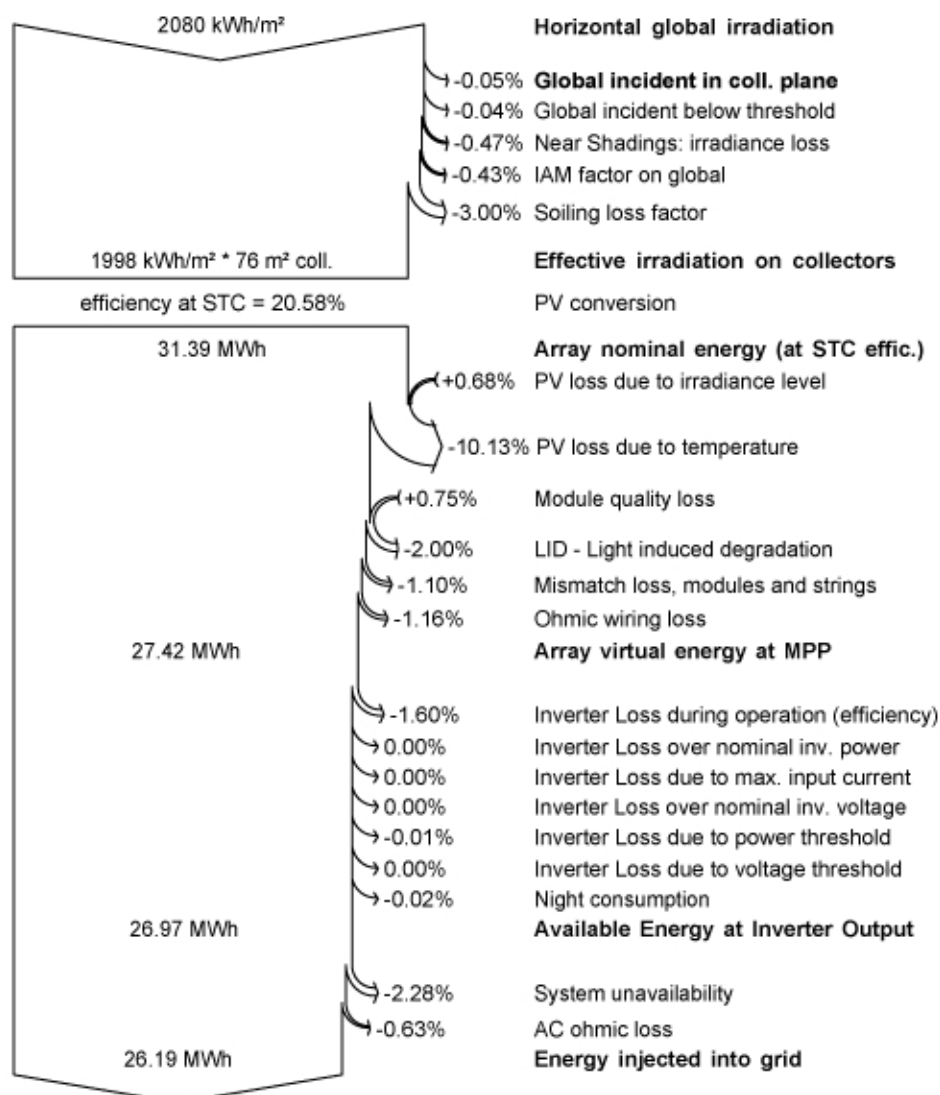
azimuth 0°

Pnom 460 Wp

Pnom total 15.64 kWp

Pnom 15.00 kW ac

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

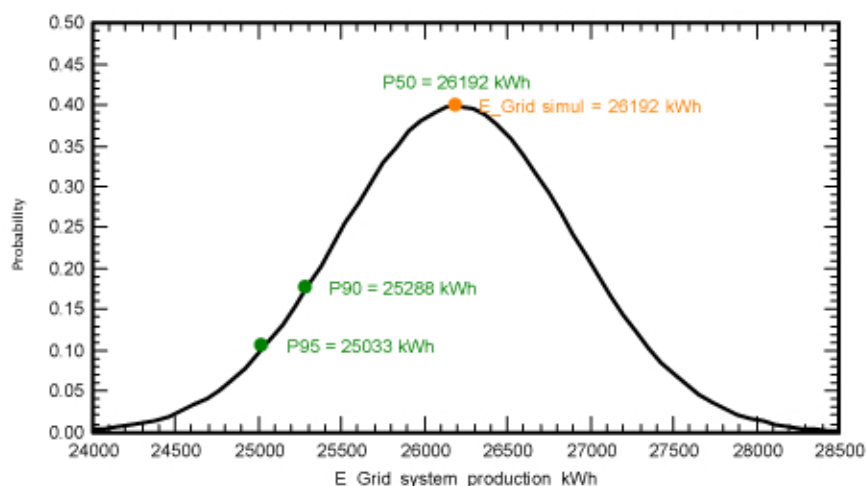
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.71 MWh
	P50	26.19 MWh
	P90	25.29 MWh
	P95	25.03 MWh

Probability distribution

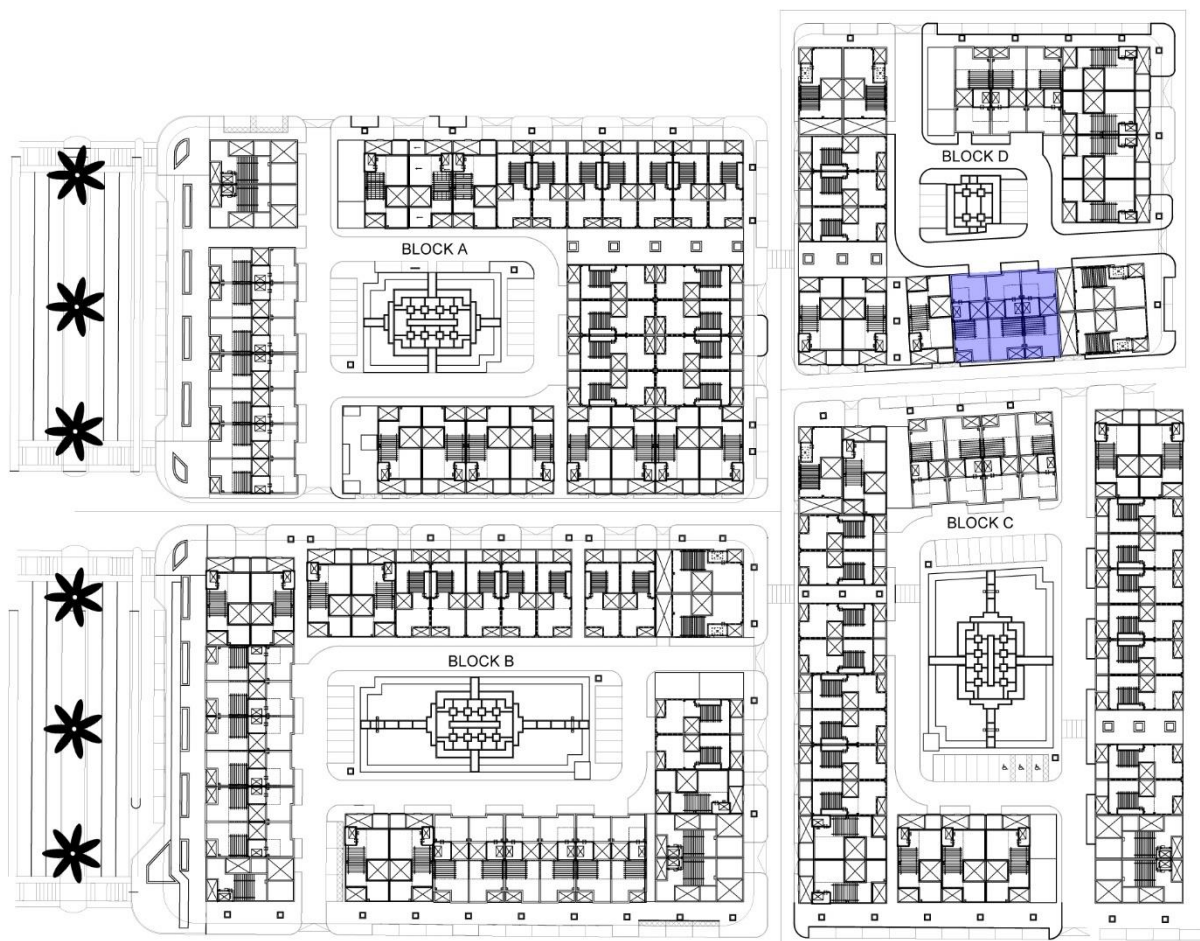


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

2. B1 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
D. Orientation 6	76.3	27.00



PVSYST V6.88	kawar Energy (Jordan)		23/12/20	Page 1/7
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Grid-Connected System: Simulation parameters

Project :

Villa 1B

Geographical Site

Umm ash Sha'um

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'um

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

23/12/20 12h29

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

11°

Sheds configuration

Nb. of sheds

34

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.0°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

17 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

34

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

15.64 kWp

At operating cond.

14.34 kWp (50°C)

Array operating characteristics (50°C)

U mpp

653 V

I mpp

22 A

Total area

Module area

76.3 m²

Cell area

70.5 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.04

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

491 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 39 m	Loss Fraction	1.2 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

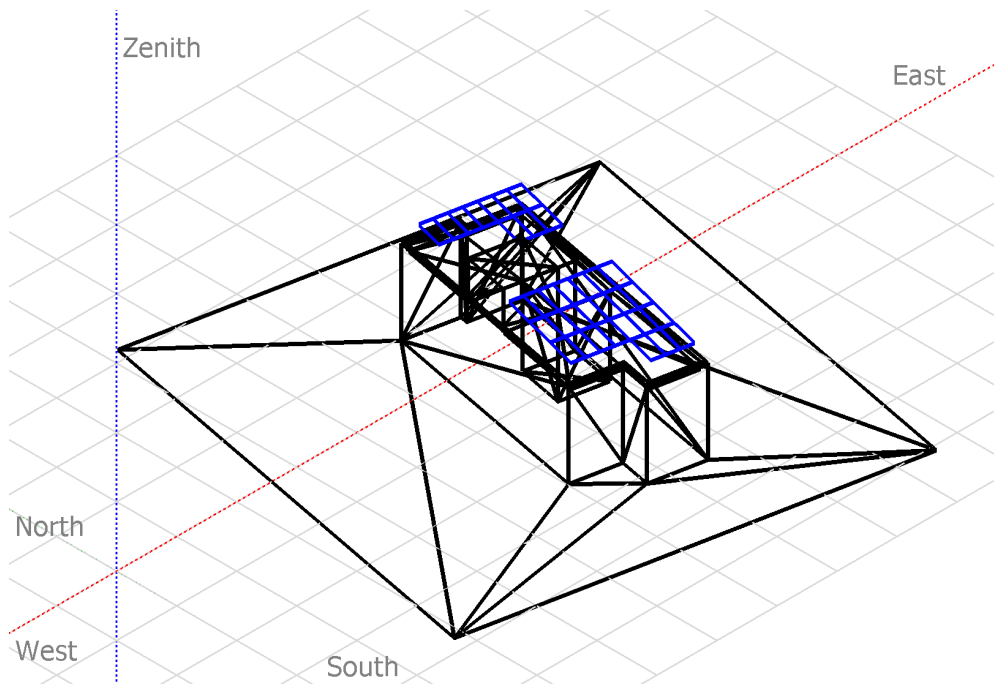
azimuth 11°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

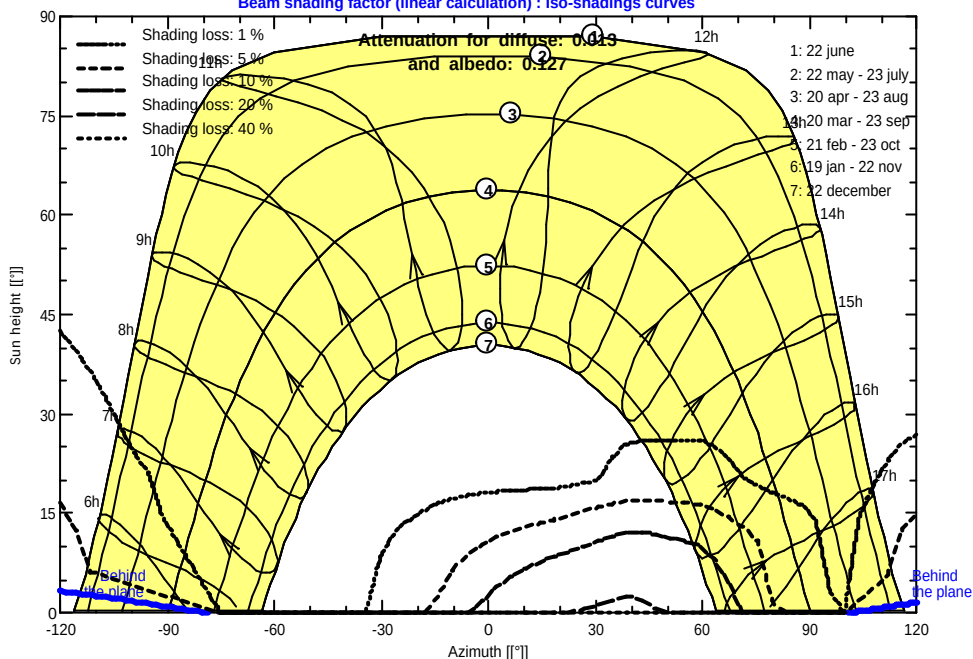
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 1B

Beam shading factor (linear calculation) : Iso-shadings curves



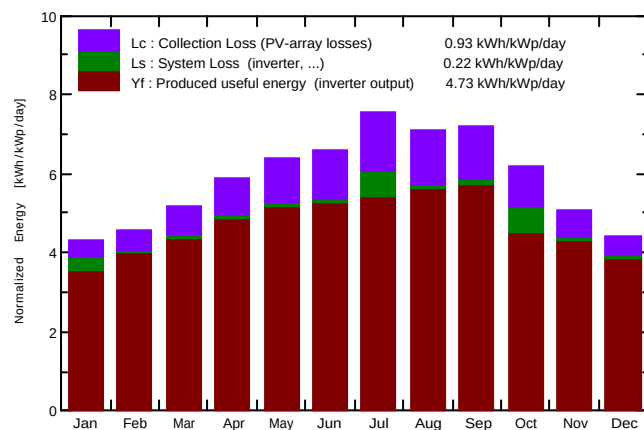
Grid-Connected System: Main results

Project : Villa 1B
Simulation variant : New simulation variant

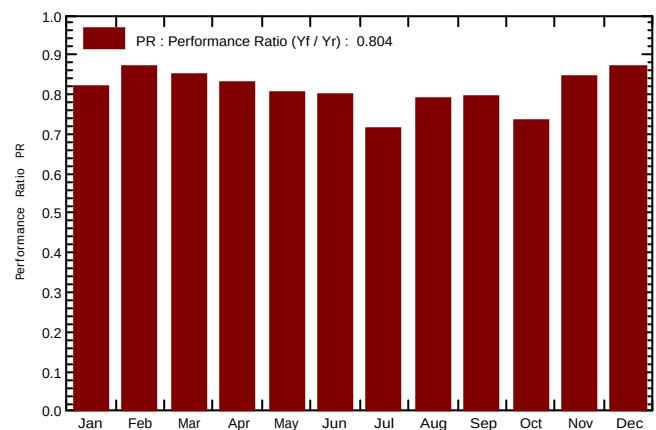
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 11°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	34 Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results
System Production **Produced Energy 27.00 MWh/year** Specific prod. 1726 kWh/kWp/year
Performance Ratio PR 80.41 %

Normalized productions (per installed kWp): Nominal power 15.64 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	133.8	128.4	1.887	1.717	0.821
February	121.3	56.57	17.45	128.0	122.7	1.788	1.748	0.873
March	154.6	74.53	21.64	159.8	153.3	2.177	2.128	0.851
April	173.7	83.00	26.31	176.1	168.9	2.336	2.283	0.829
May	198.6	94.05	32.04	198.6	190.5	2.566	2.510	0.808
June	199.0	94.74	34.17	197.7	189.6	2.535	2.479	0.802
July	235.0	78.96	35.63	234.2	225.2	2.944	2.624	0.716
August	218.1	78.31	35.23	220.4	211.9	2.785	2.722	0.790
September	209.8	37.92	32.07	216.3	208.6	2.755	2.693	0.796
October	181.2	34.51	29.31	191.9	184.9	2.503	2.201	0.733
November	140.1	28.92	23.55	152.2	146.4	2.064	2.018	0.848
December	125.0	28.82	18.37	137.6	132.1	1.919	1.876	0.871
Year	2079.7	730.44	26.85	2146.8	2062.5	28.259	26.999	0.804

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

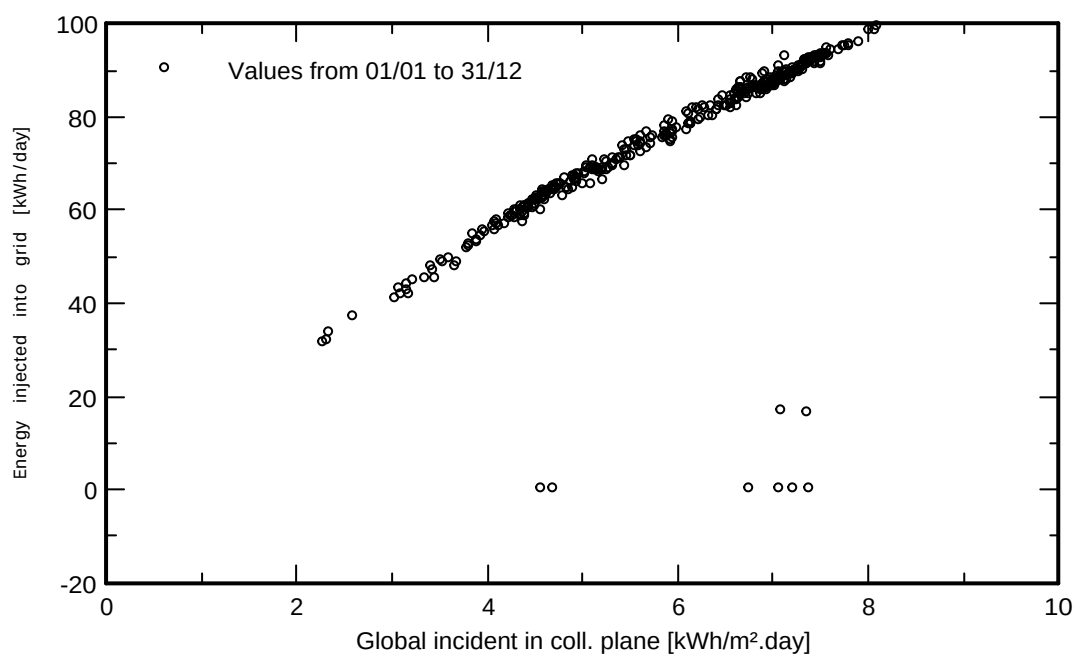
Villa 1B

Simulation variant :

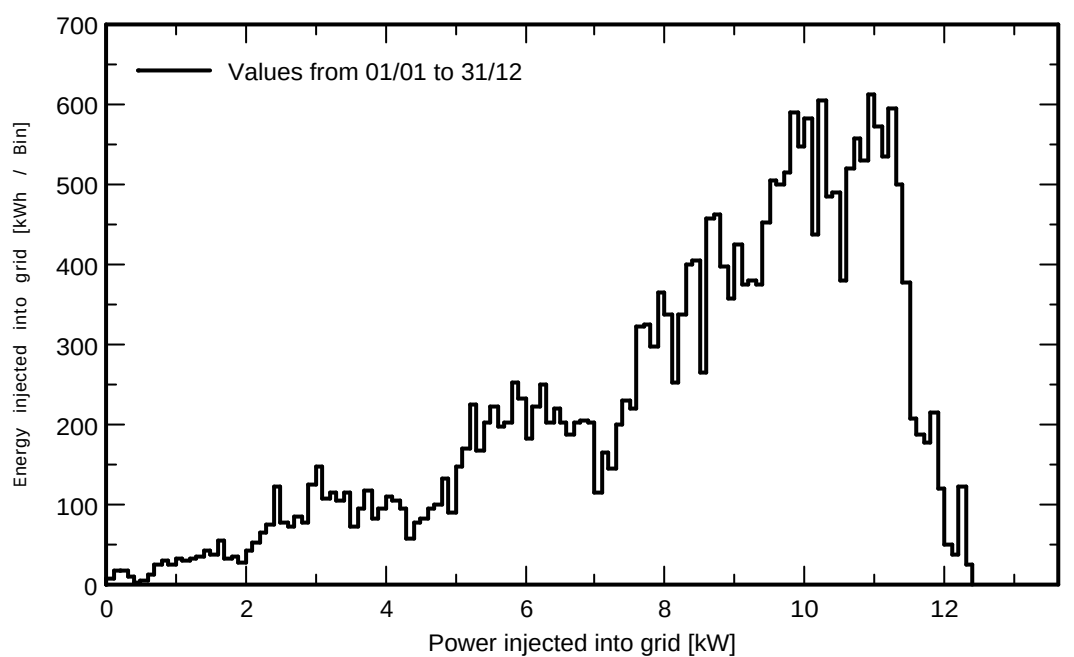
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	11°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution



Grid-Connected System: Loss diagram

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

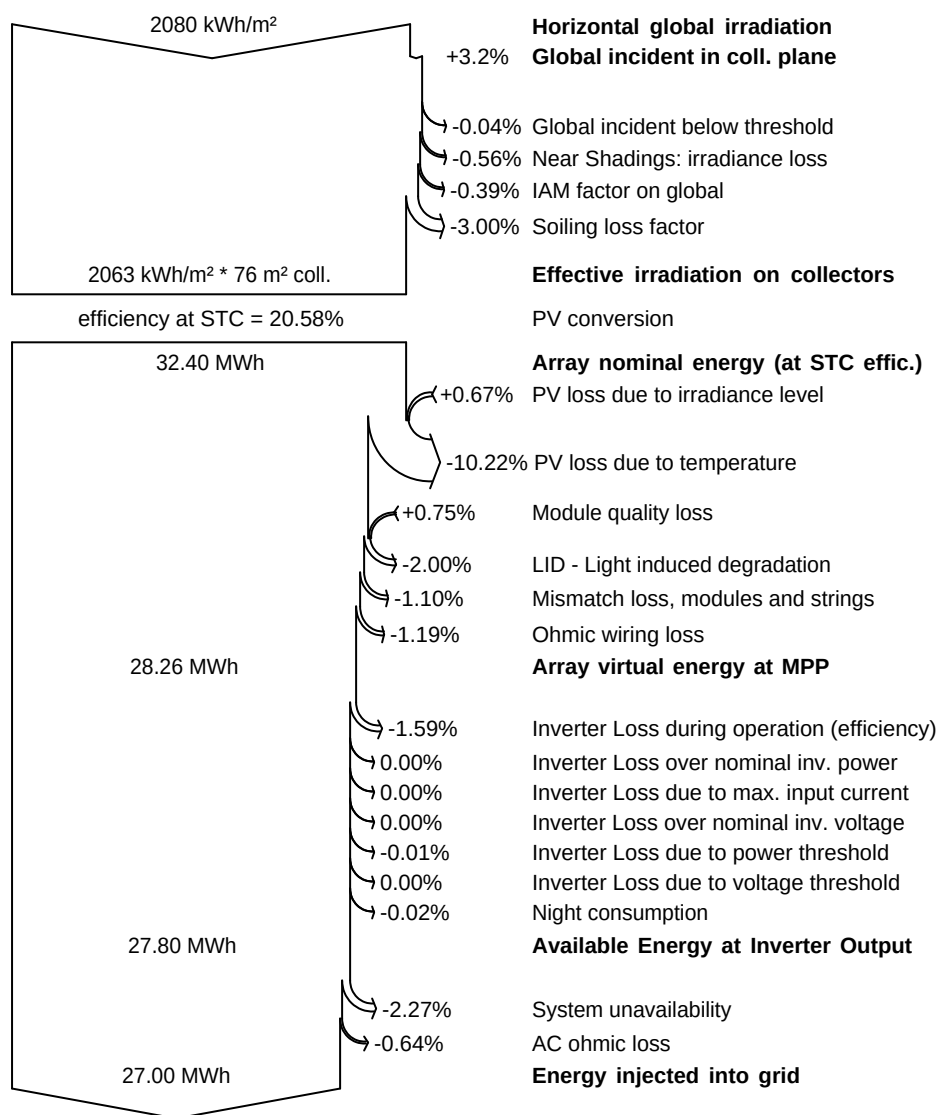
azimuth 11°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 1B

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	11°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

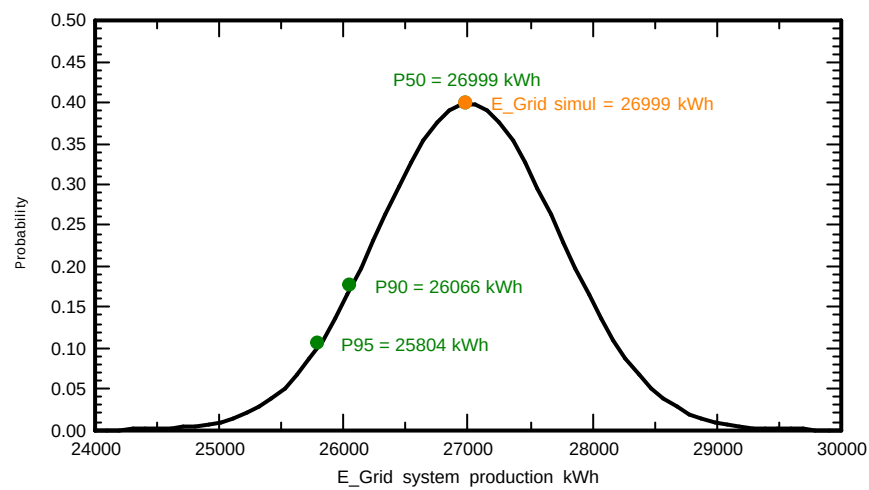
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.73 MWh
	P50	27.00 MWh
	P90	26.07 MWh
	P95	25.80 MWh

Probability distribution

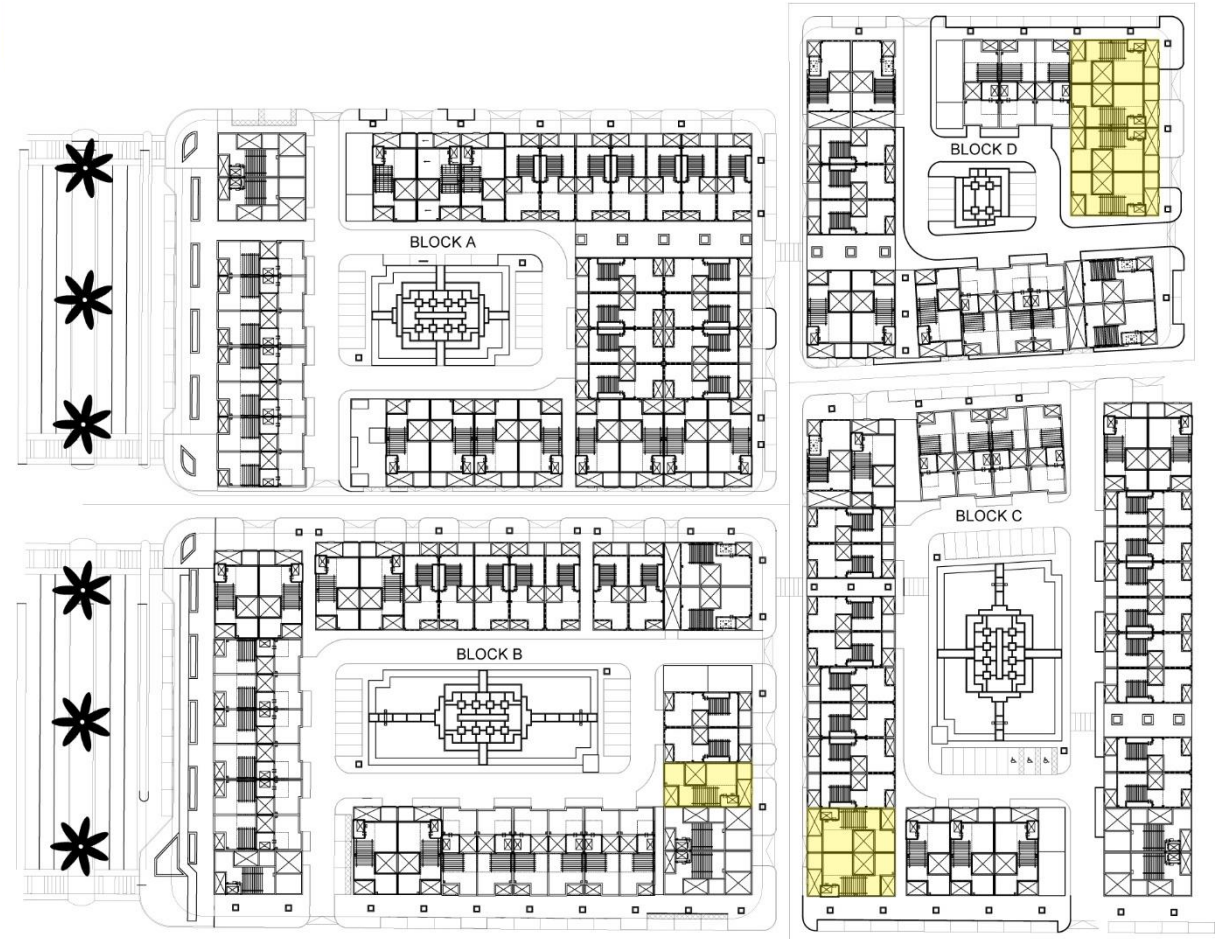


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

3. A2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
A. Orientation 1 & 2	76.3	26.97



PVSYST V6.88	kawar Energy (Jordan)		30/12/20	Page 1/7
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Grid-Connected System: Simulation parameters

Project :

Villa 2A

Geographical Site

Umm ash Sha'um

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'um

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

30/12/20 21h18

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

34

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.1°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

17 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

34

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

15.64 kWp

At operating cond.

14.34 kWp (50°C)

Array operating characteristics (50°C)

U mpp

653 V

I mpp

22 A

Total area

Module area

76.3 m²

Cell area

70.5 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.04

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

491 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors			
Wiring Ohmic Loss	Wires: 3x6.0 mm ²	39 m	Loss Fraction 1.2 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

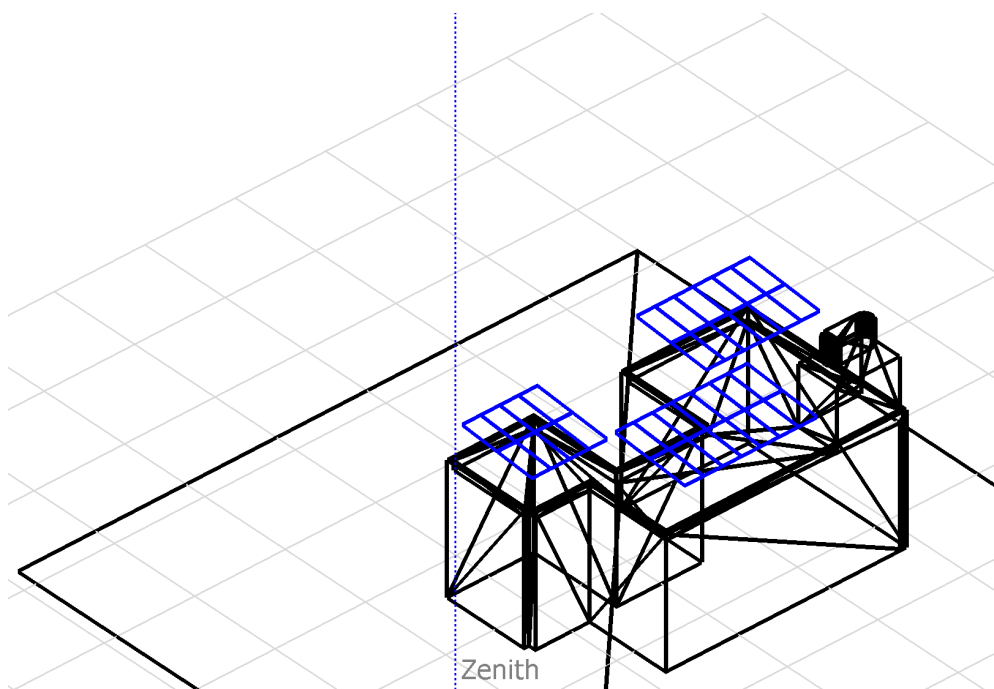
azimuth 0°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

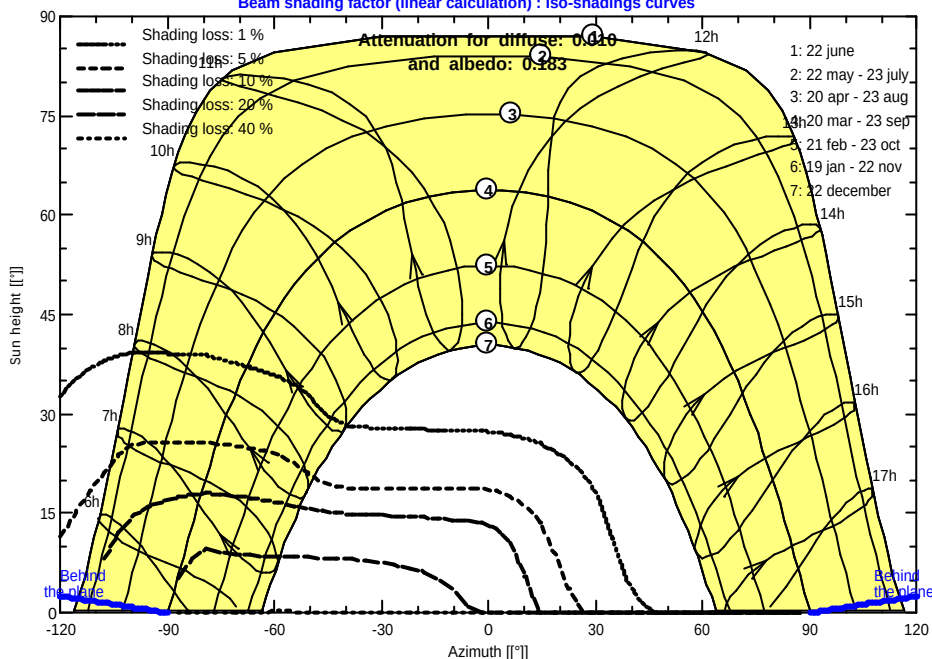
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2A

Beam shading factor (linear calculation) : Iso-shadings curves



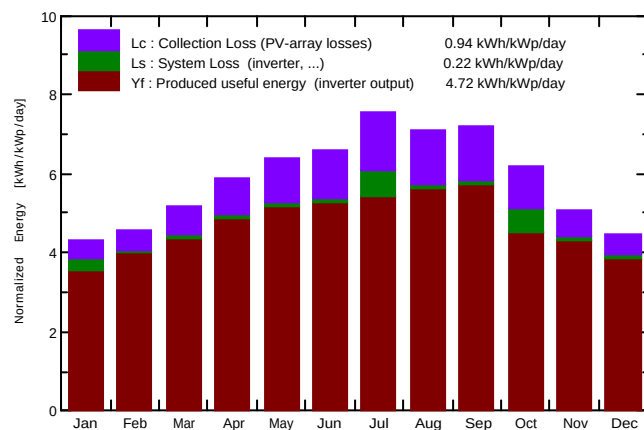
Grid-Connected System: Main results

Project : Villa 2A
Simulation variant : New simulation variant

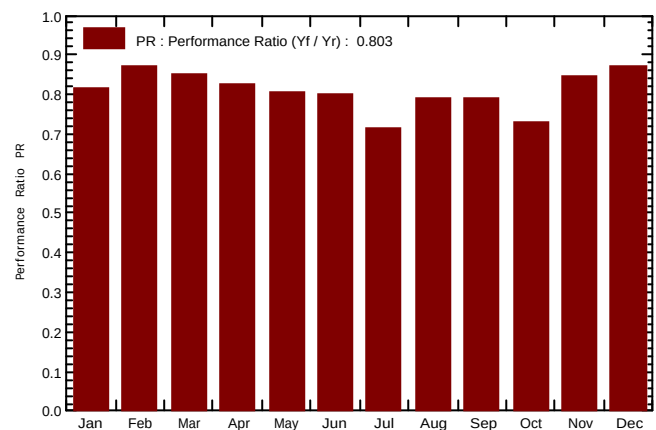
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	34 Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results
System Production **Produced Energy 26.97 MWh/year** Specific prod. 1724 kWh/kWp/year
Performance Ratio PR 80.28 %

Normalized productions (per installed kWp): Nominal power 15.64 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	128.3	1.885	1.716	0.818
February	121.3	56.57	17.45	128.1	122.7	1.787	1.747	0.872
March	154.6	74.53	21.64	159.9	153.2	2.175	2.126	0.850
April	173.7	83.00	26.31	176.2	168.9	2.335	2.282	0.828
May	198.6	94.05	32.04	198.6	190.4	2.565	2.509	0.808
June	199.0	94.74	34.17	197.8	189.7	2.535	2.480	0.802
July	235.0	78.96	35.63	234.2	225.1	2.942	2.622	0.716
August	218.1	78.31	35.23	220.4	211.7	2.782	2.719	0.789
September	209.8	37.92	32.07	216.5	208.0	2.747	2.684	0.793
October	181.2	34.51	29.31	192.1	184.3	2.495	2.195	0.730
November	140.1	28.92	23.55	152.5	146.2	2.062	2.016	0.845
December	125.0	28.82	18.37	137.9	132.1	1.918	1.875	0.869
Year	2079.7	730.44	26.85	2148.1	2060.6	28.229	26.970	0.803

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

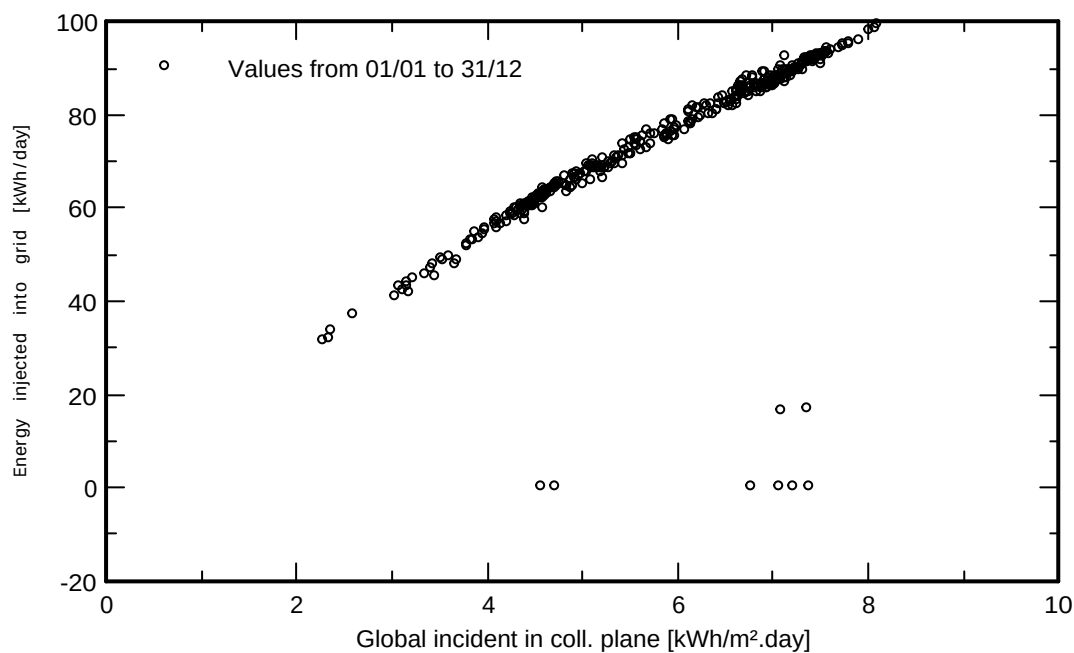
Villa 2A

Simulation variant :

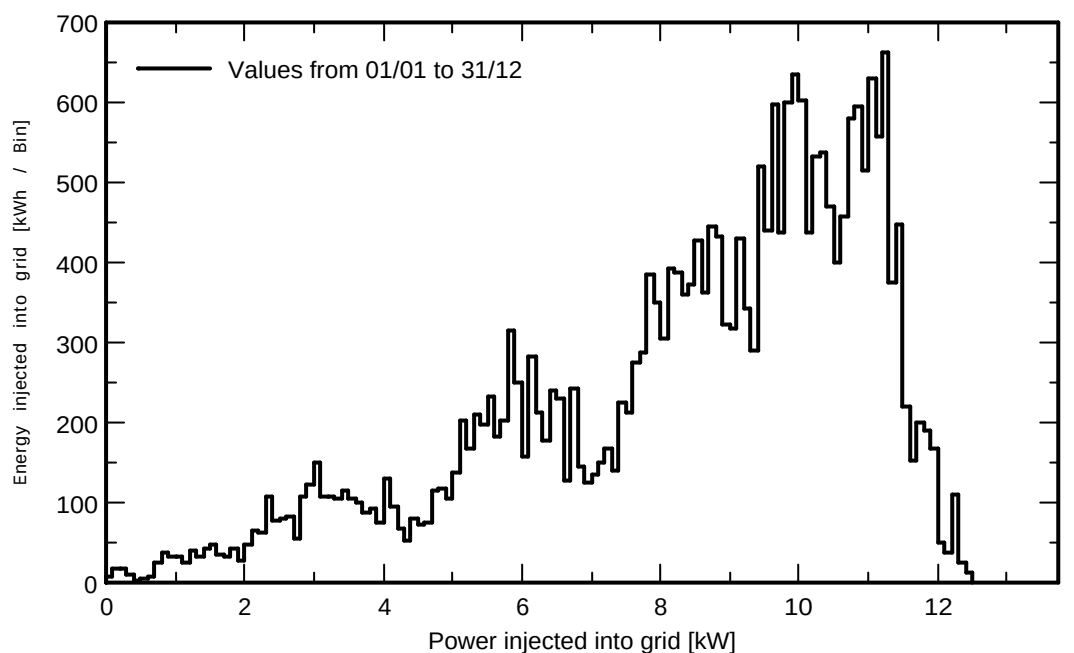
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

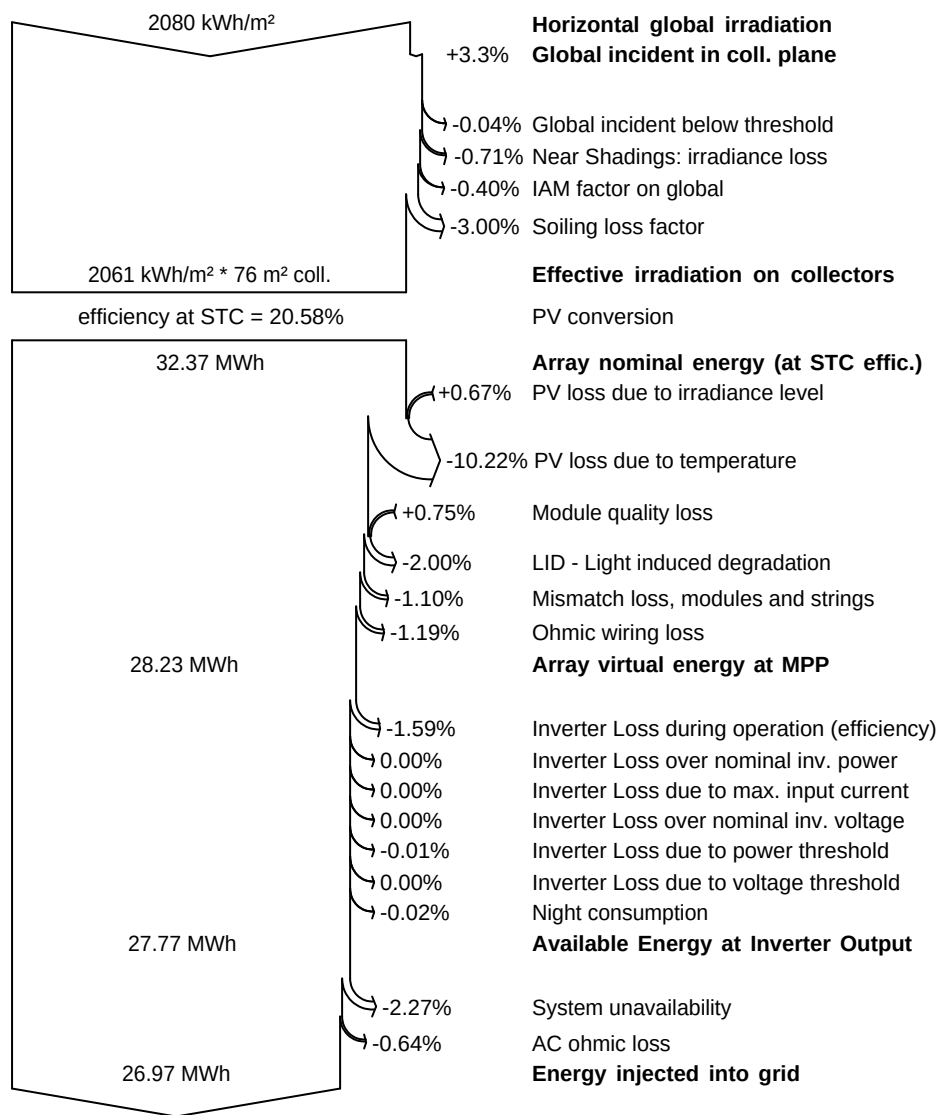


Grid-Connected System: Loss diagram

Project : Villa 2A
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	34	Pnom total	15.64 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

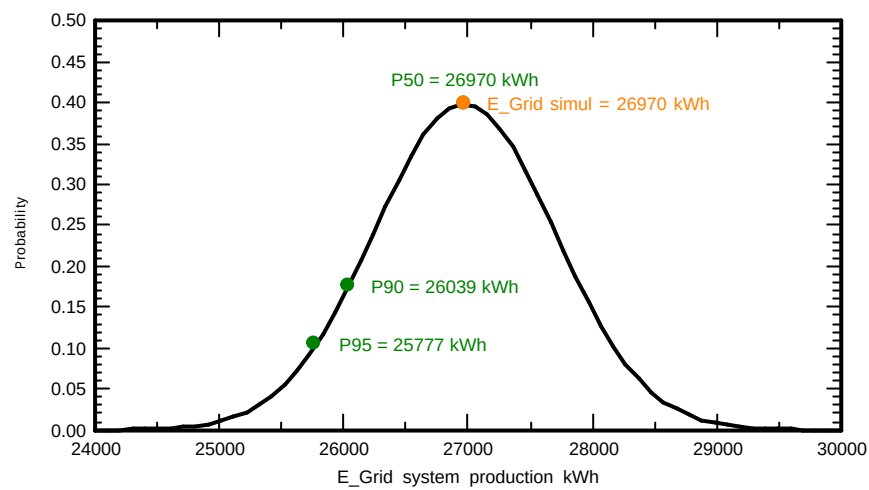
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.73 MWh
	P50	26.97 MWh
	P90	26.04 MWh
	P95	25.78 MWh

Probability distribution

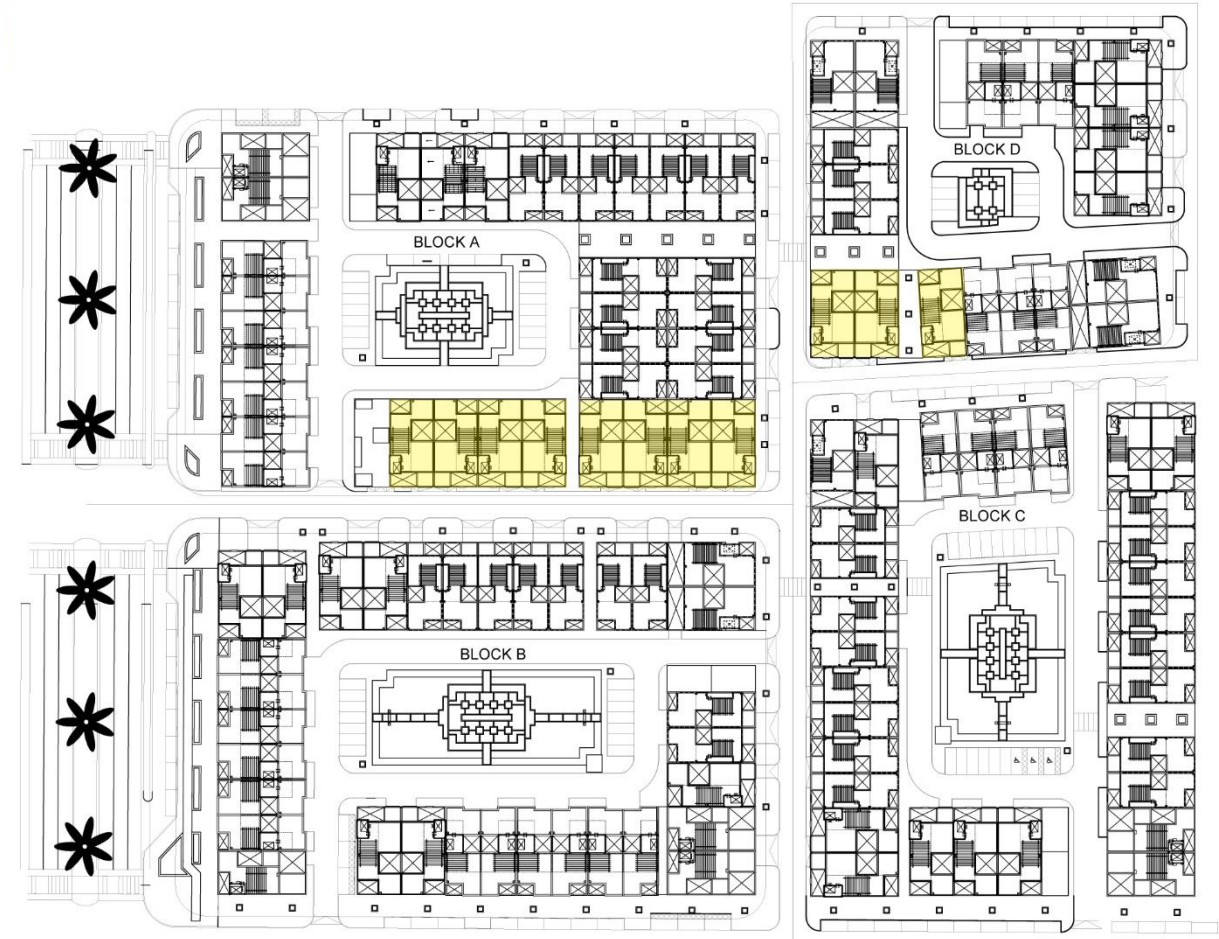


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

3. A2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
B. Orientation 3 & 4	80.8	28.19



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Grid-Connected System: Simulation parameters

Project :

Villa 2A

Geographical Site

Umm ash Sha'ūm

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'ūm

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

23/12/20 14h47

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

36

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.1°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

18 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

36

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

16.56 kWp

At operating cond.

15.19 kWp (50°C)

Array operating characteristics (50°C)

U mpp

691 V

I mpp

22 A

Total area

Module area

80.8 m²

Cell area

74.7 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.10

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

520 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 39 m	Loss Fraction	1.2 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 36

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

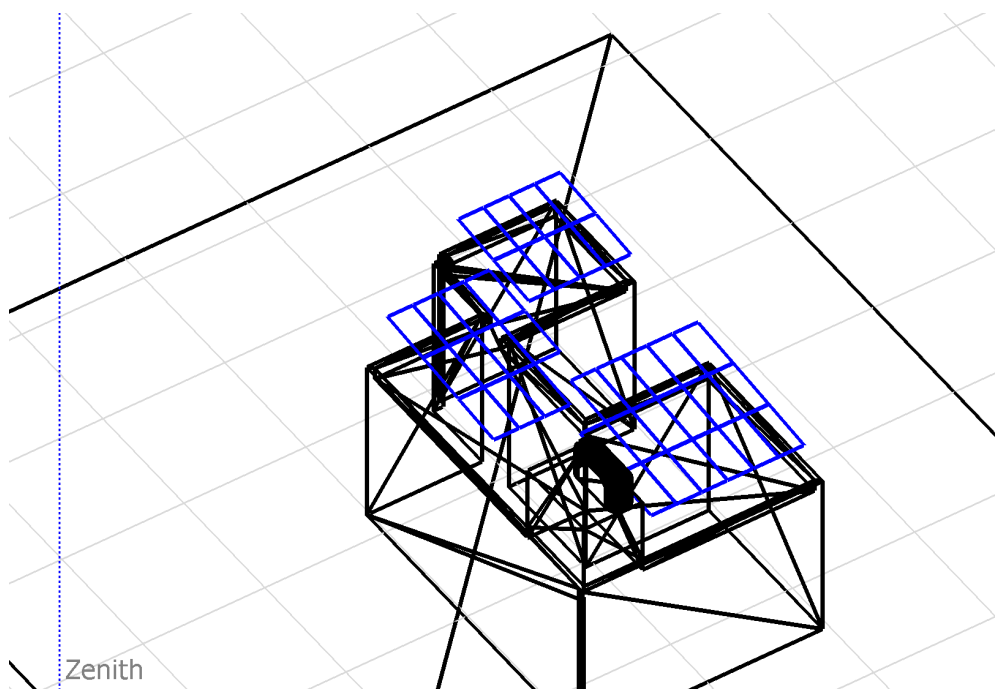
azimuth 0°

Pnom 460 Wp

Pnom total **16.56 kWp**

Pnom 15.00 kW ac

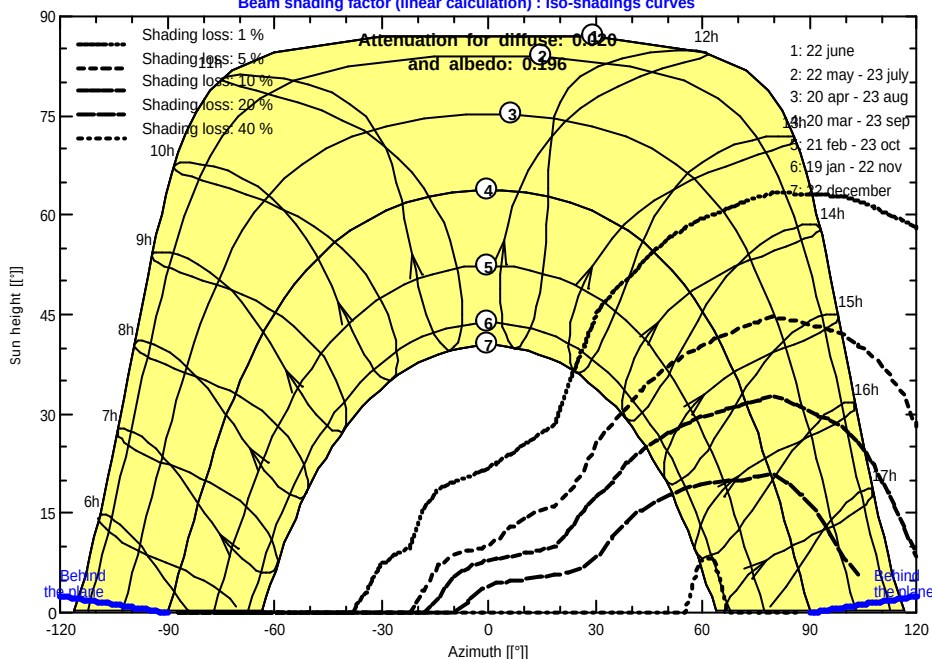
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2A

Beam shading factor (linear calculation) : Iso-shadings curves



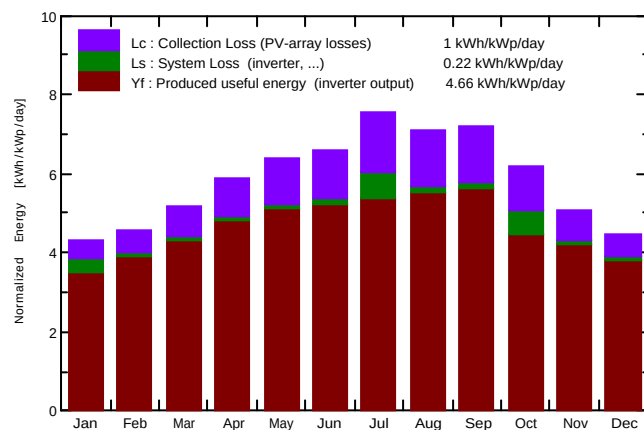
Grid-Connected System: Main results

Project : Villa 2A
Simulation variant : New simulation variant

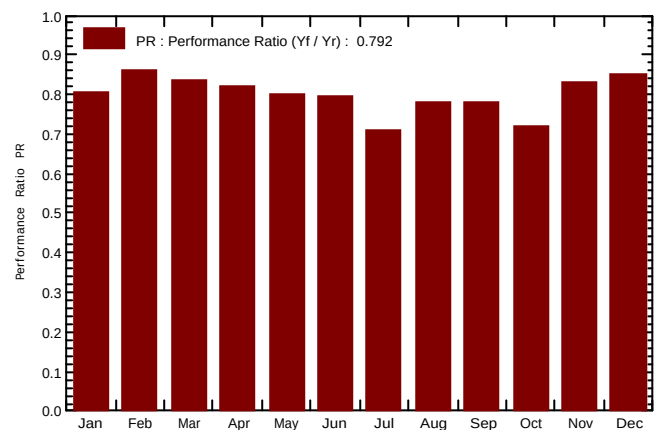
Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	36	Pnom total 16.56 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom 15.00 kW ac
User's needs	Unlimited load (grid)		

Main simulation results
System Production **Produced Energy 28.19 MWh/year** Specific prod. 1702 kWh/kWp/year
Performance Ratio PR 79.24 %

Normalized productions (per installed kWp): Nominal power 16.56 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	126.6	1.971	1.791	0.806
February	121.3	56.57	17.45	128.1	120.9	1.867	1.822	0.859
March	154.6	74.53	21.64	159.9	151.0	2.272	2.218	0.838
April	173.7	83.00	26.31	176.2	167.1	2.448	2.390	0.819
May	198.6	94.05	32.04	198.6	188.4	2.690	2.628	0.799
June	199.0	94.74	34.17	197.8	187.9	2.661	2.601	0.794
July	235.0	78.96	35.63	234.2	222.9	3.087	2.750	0.709
August	218.1	78.31	35.23	220.4	209.4	2.915	2.848	0.780
September	209.8	37.92	32.07	216.5	205.2	2.871	2.804	0.782
October	181.2	34.51	29.31	192.1	181.7	2.606	2.292	0.720
November	140.1	28.92	23.55	152.5	143.7	2.147	2.096	0.830
December	125.0	28.82	18.37	137.9	129.8	1.997	1.949	0.854
Year	2079.7	730.44	26.85	2148.1	2034.4	29.532	28.188	0.792

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

Linear shadings

PV Field Orientation

tilt

5°

azimuth

0°

PV modules

Model

JKM460M-7RL3-V

Pnom

460 Wp

PV Array

Nb. of modules

36

Pnom total

16.56 kWp

Inverter

Model

SUN2000MA-15KTL-M0 TL

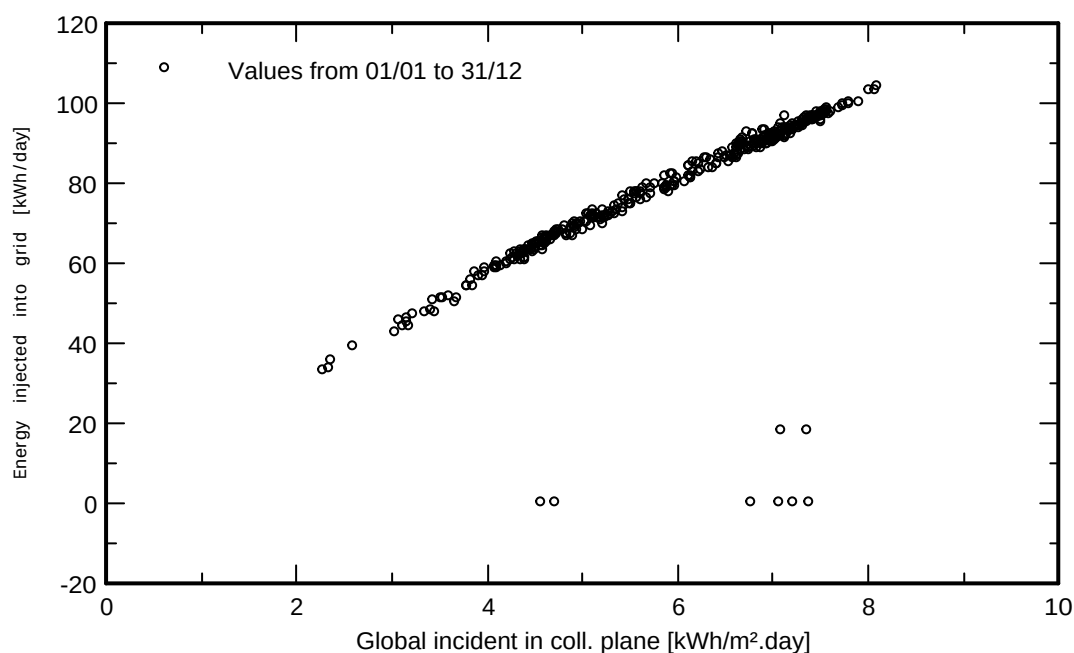
Pnom

15.00 kW ac

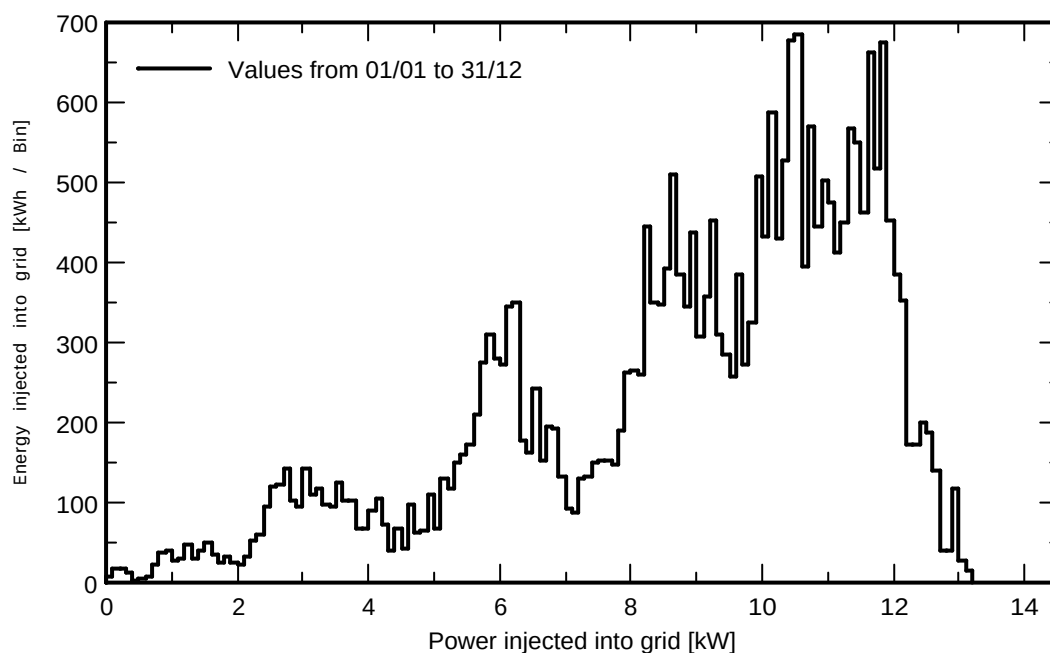
User's needs

Unlimited load (grid)

Daily Input/Output diagram



System Output Power Distribution

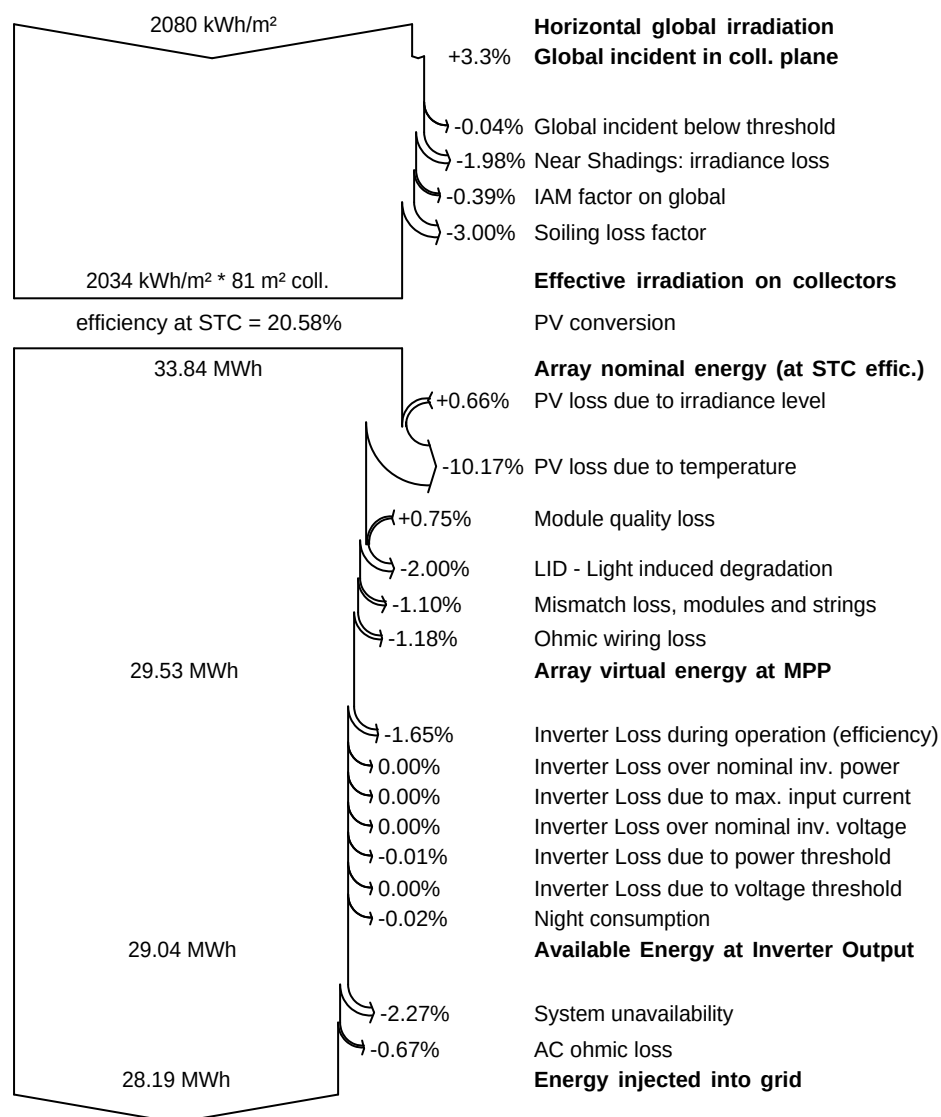


Grid-Connected System: Loss diagram

Project : Villa 2A
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	36 Pnom total 16.56 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 2A
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	36	Pnom total	16.56 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

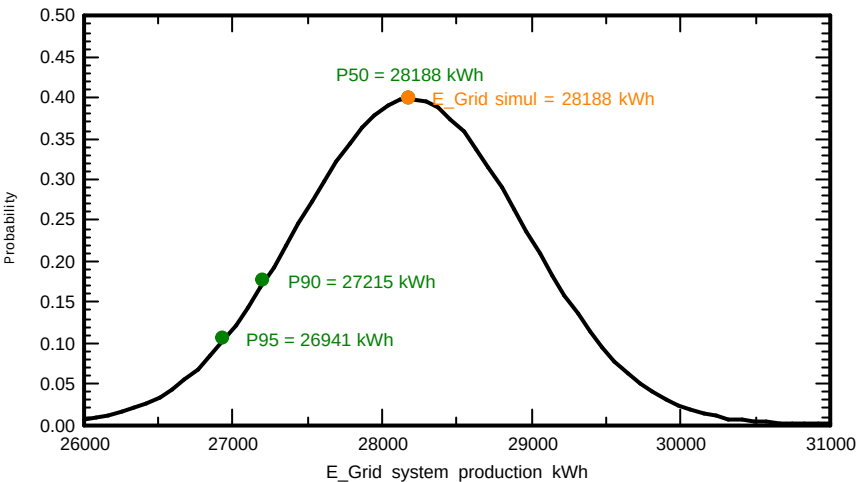
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.76 MWh
	P50	28.19 MWh
	P90	27.21 MWh
	P95	26.94 MWh

Probability distribution

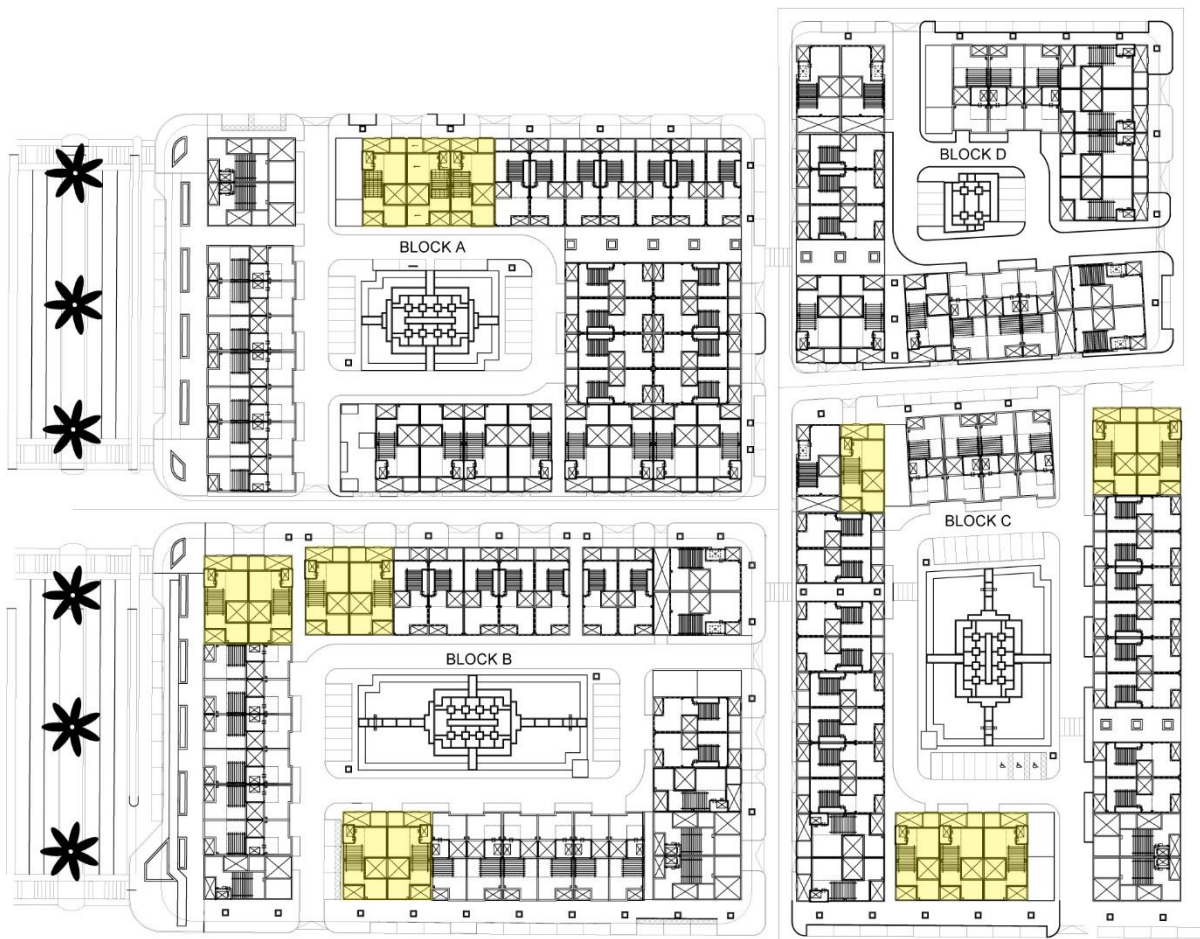


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

3. A2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
C. Orientation 5 & 6	85.3	29.94



PVSYST V6.88	kawar Energy (Jordan)		30/12/20	Page 1/7																																																																	
Grid-Connected System: Simulation parameters																																																																					
Project : Villa 2A																																																																					
Geographical Site		Umm ash Sha'um	Country	Bahrain																																																																	
Situation		Latitude 26.22° N	Longitude	50.58° E																																																																	
Time defined as		Legal Time Time zone UT+3	Altitude	11 m																																																																	
		Albedo 0.20																																																																			
Meteo data:		Umm ash Sha'um	Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic																																																																		
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Grid-Connected System: Simulation parameters

System loss factors			
Wiring Ohmic Loss	Wires: 3x6.0 mm ²	39 m	Loss Fraction 1.3 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 38

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

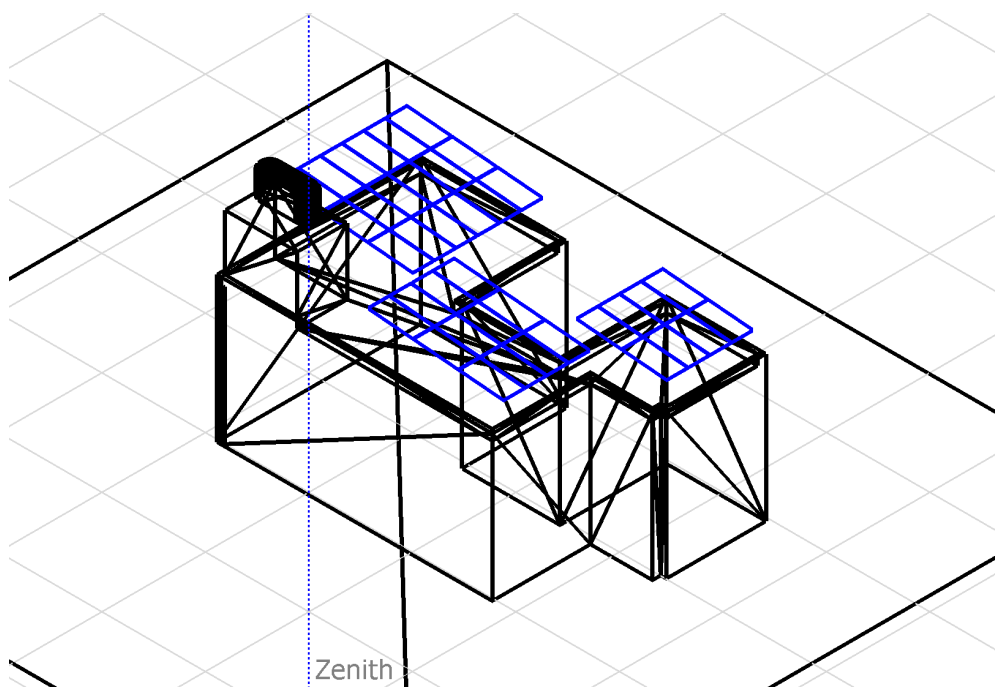
azimuth 0°

Pnom 460 Wp

Pnom total **17.48 kWp**

Pnom 15.00 kW ac

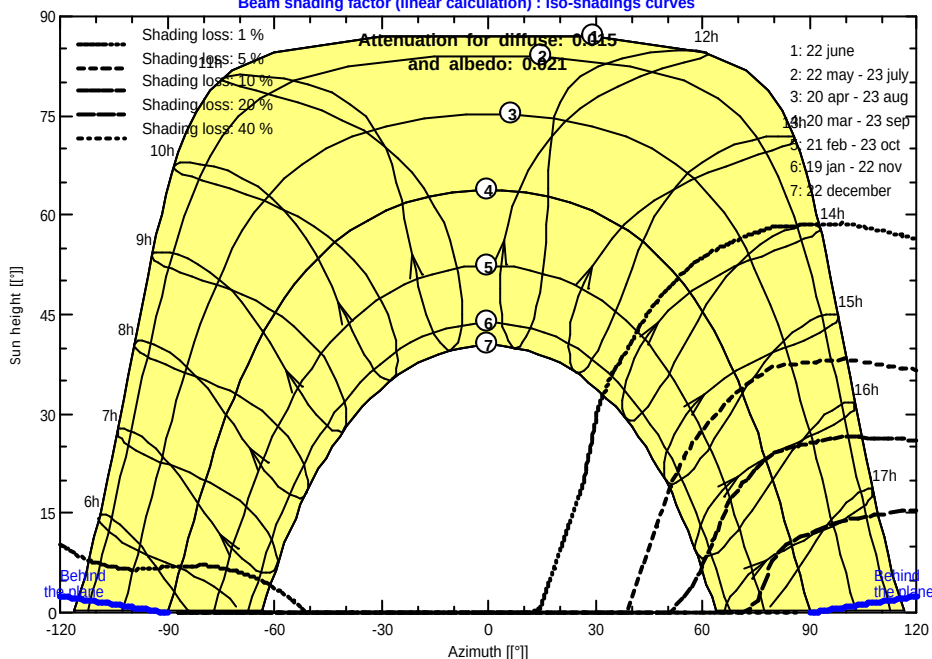
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2A

Beam shading factor (linear calculation) : Iso-shadings curves



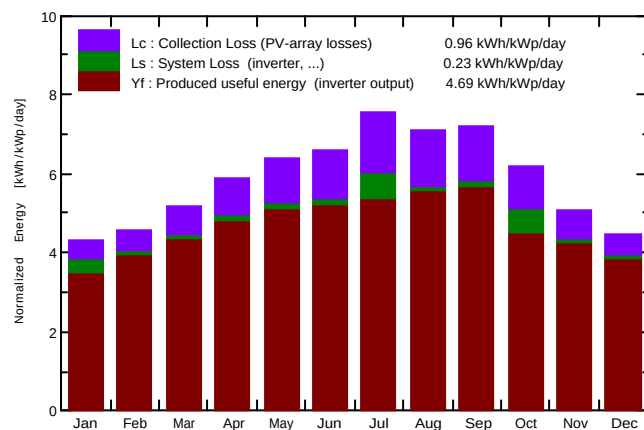
Grid-Connected System: Main results

Project : Villa 2A
Simulation variant : New simulation variant

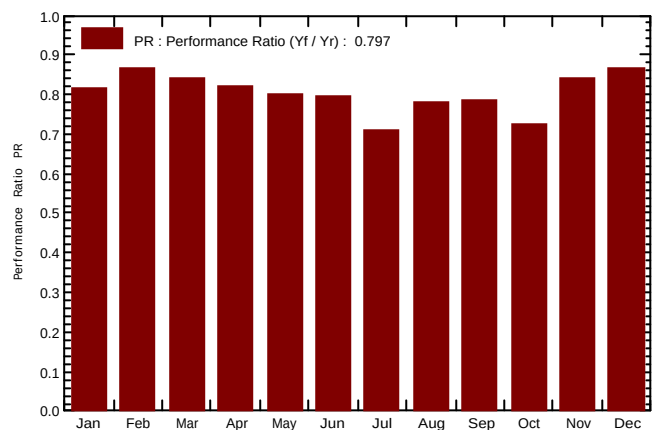
Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	38	Pnom total 17.48 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom 15.00 kW ac
User's needs	Unlimited load (grid)		

Main simulation results
System Production **Produced Energy 29.94 MWh/year** Specific prod. 1713 kWh/kWp/year
Performance Ratio PR 79.74 %

Normalized productions (per installed kWp): Nominal power 17.48 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	128.3	2.107	1.911	0.815
February	121.3	56.57	17.45	128.1	122.2	1.991	1.940	0.866
March	154.6	74.53	21.64	159.9	152.3	2.418	2.356	0.843
April	173.7	83.00	26.31	176.2	168.0	2.597	2.532	0.822
May	198.6	94.05	32.04	198.6	189.1	2.849	2.780	0.801
June	199.0	94.74	34.17	197.8	188.5	2.817	2.750	0.795
July	235.0	78.96	35.63	234.2	223.5	3.267	2.907	0.710
August	218.1	78.31	35.23	220.4	210.3	3.090	3.016	0.783
September	209.8	37.92	32.07	216.5	206.7	3.053	2.978	0.787
October	181.2	34.51	29.31	192.1	183.6	2.780	2.441	0.727
November	140.1	28.92	23.55	152.5	146.0	2.302	2.244	0.842
December	125.0	28.82	18.37	137.9	132.0	2.144	2.089	0.867
Year	2079.7	730.44	26.85	2148.1	2050.6	31.416	29.943	0.797

Legends:	GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
	DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
	T_Amb	T amb.	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

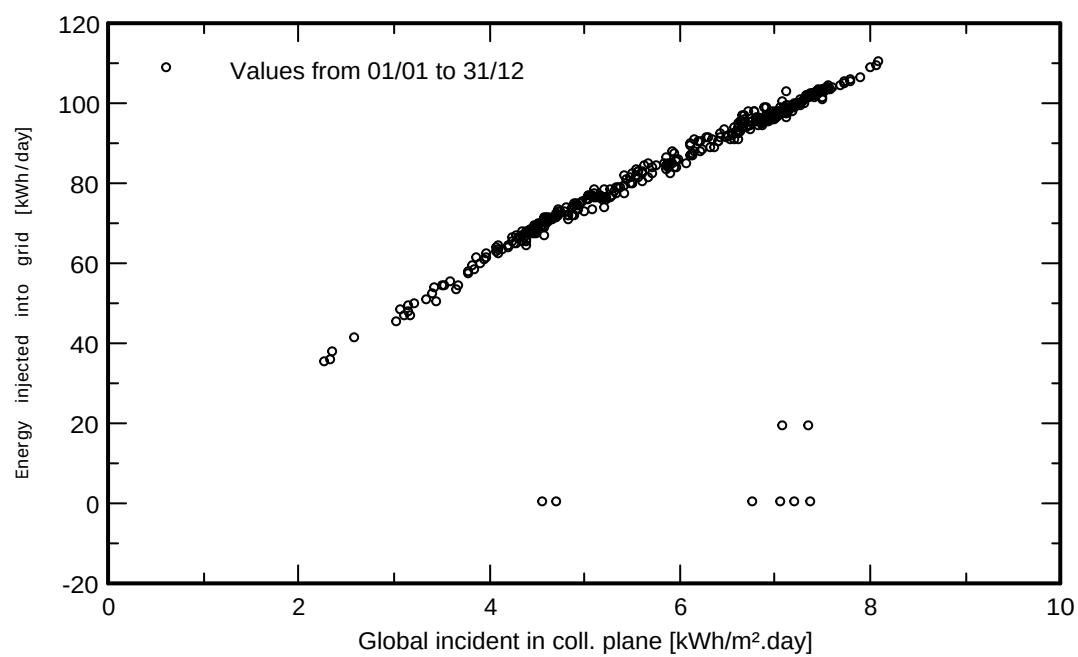
Villa 2A

Simulation variant :

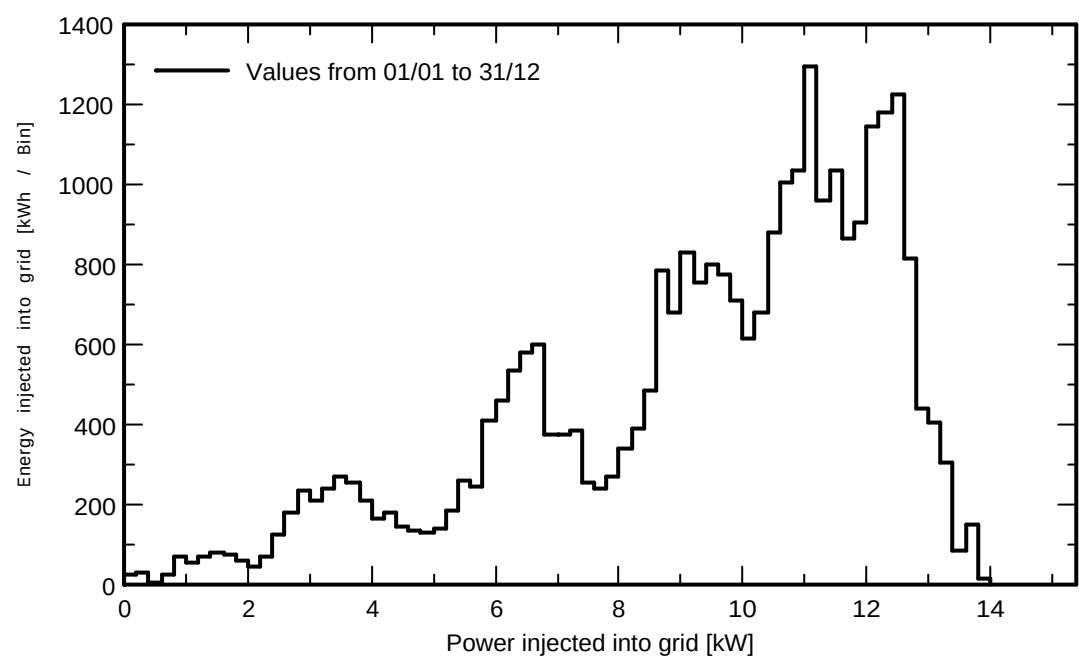
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	38	Pnom total	17.48 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

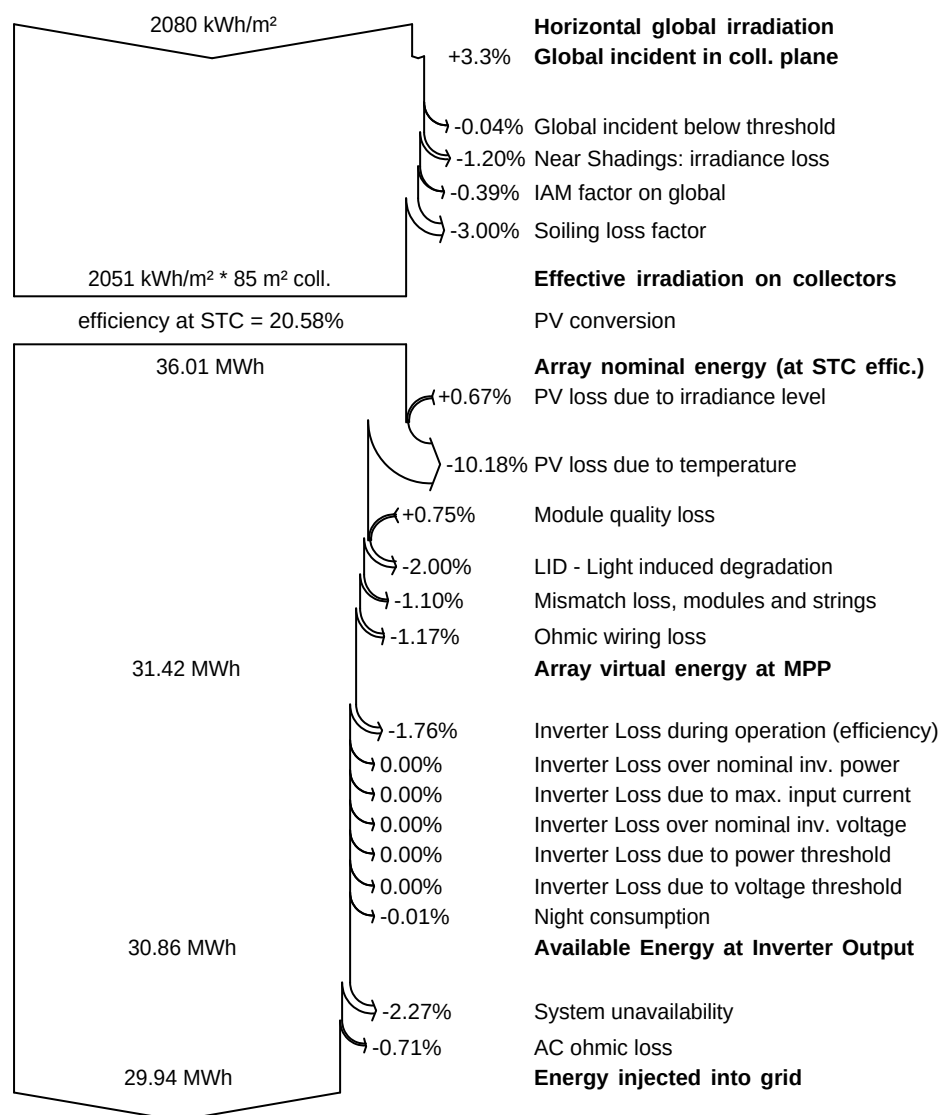


Grid-Connected System: Loss diagram

Project : Villa 2A
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	38	Pnom total	17.48 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year



Grid-Connected System: P50 - P90 evaluation

Project : Villa 2A

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
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User's needs	Unlimited load (grid)				

Evaluation of the Production probability forecast

The probability distribution of the system production forecast for different years is mainly dependent on the meteo data used for the simulation, and depends on the following choices:

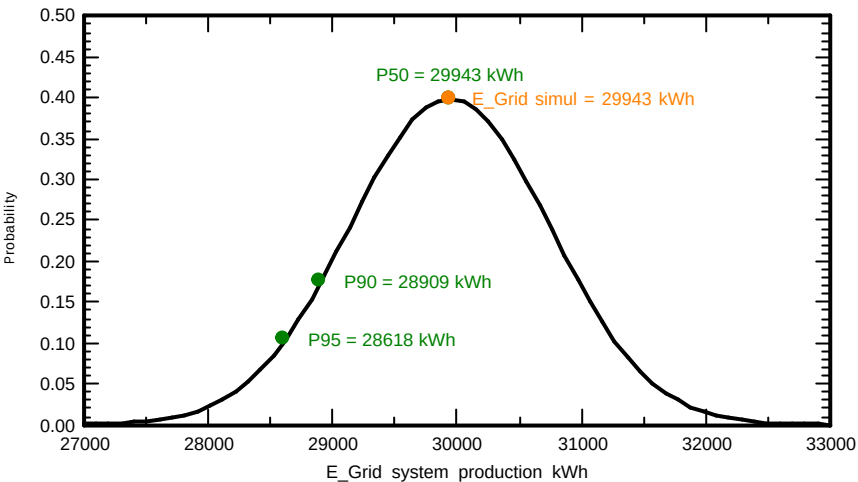
Meteo data source	Meteonorm 7.2 (1998-2002), Sat=100%			
Meteo data	Kind	Monthly averages	Synthetic	Multi-year average
Specified Deviation	Climate change	0.0 %		
Year-to-year variability	Variance	2.0 %		

The probability distribution variance is also depending on some system parameters uncertainties

Specified Deviation	PV module modelling/parameters	1.0 %	
	Inverter efficiency uncertainty	0.5 %	
	Soiling and mismatch uncertainties	1.0 %	
	Degradation uncertainty	1.0 %	
Global variability (meteo + system)	Variance	2.7 %	(quadratic sum)

Annual production probability	Variability	0.81 MWh
	P50	29.94 MWh
	P90	28.91 MWh
	P95	28.62 MWh

Probability distribution

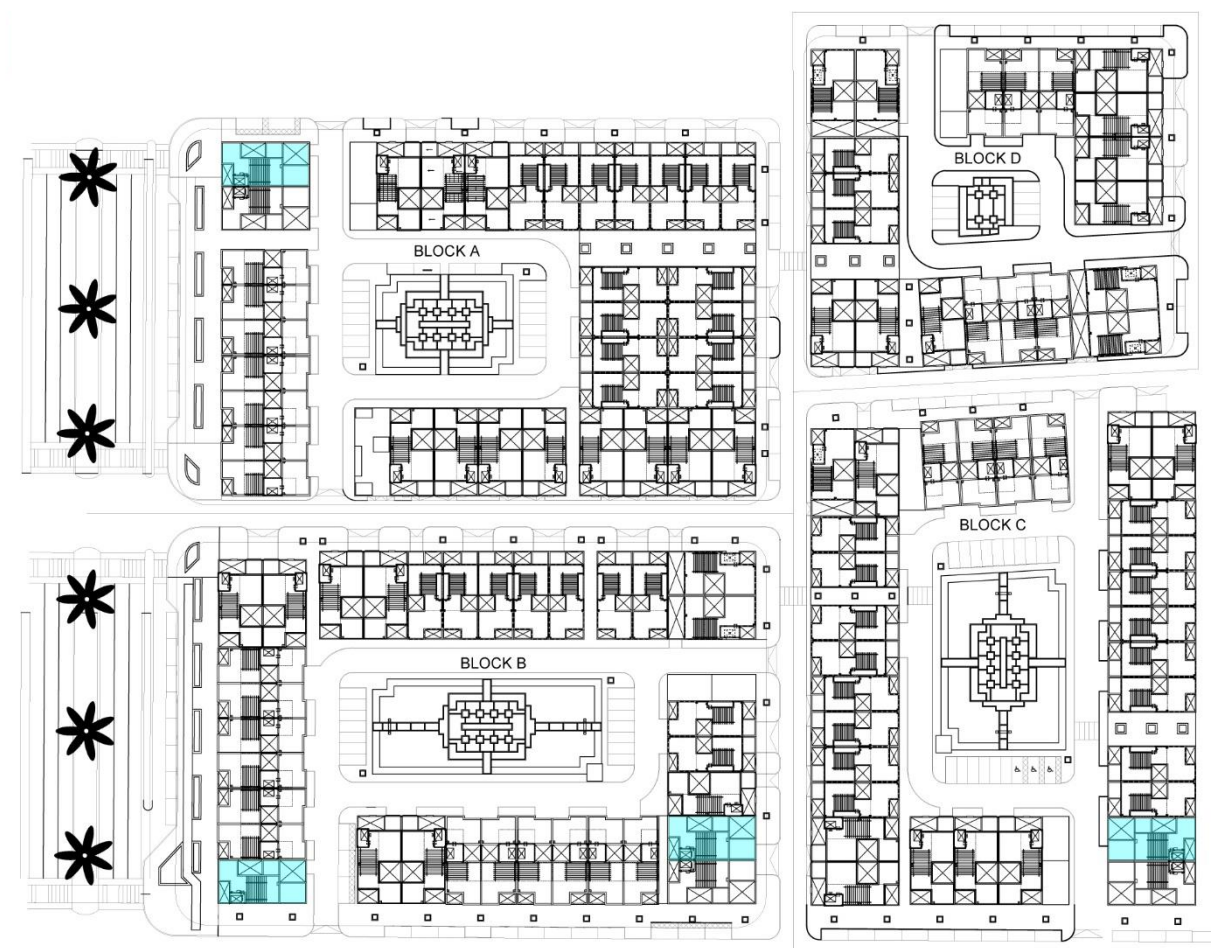


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

4. B2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
A. Orientation 1 & 3	85.3	29.91



PVSYST V6.88	kawar Energy (Jordan)		30/12/20	Page 1/6																																																																						
Grid-Connected System: Simulation parameters																																																																										
Project : Villa 2B																																																																										
Geographical Site		Umm ash Sha'um	Country	Bahrain																																																																						
Situation		Latitude 26.22° N	Longitude	50.58° E																																																																						
Time defined as		Legal Time Time zone UT+3	Altitude	11 m																																																																						
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Grid-Connected System: Simulation parameters

System loss factors			
Wiring Ohmic Loss	Wires: 3x4.0 mm ²	40 m	Loss Fraction 2.0 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2B

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 38

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

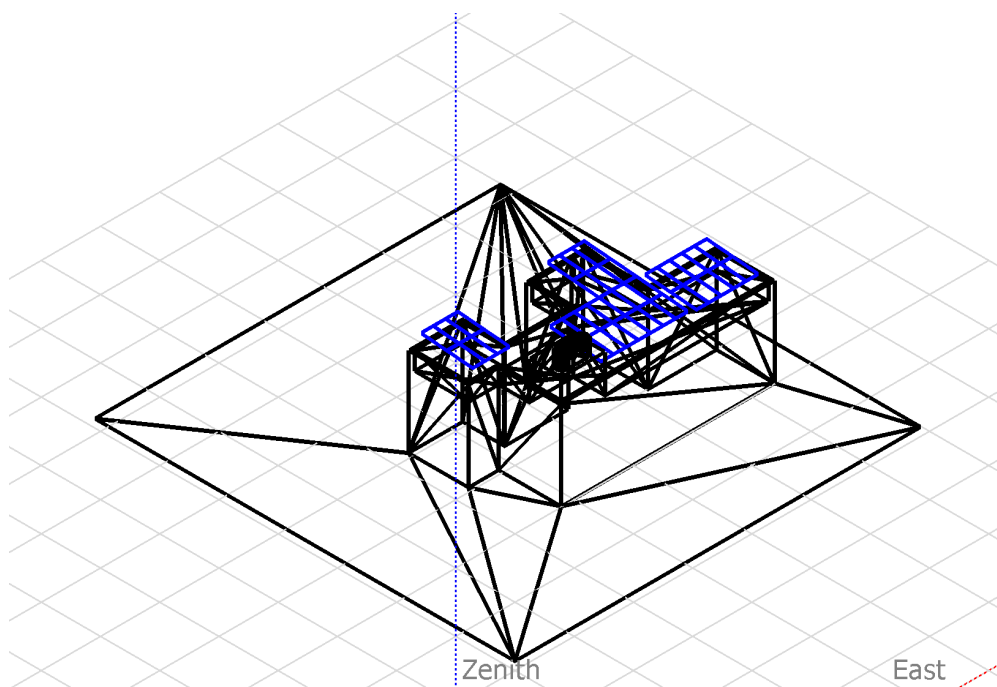
azimuth 0°

Pnom 460 Wp

Pnom total **17.48 kWp**

Pnom 15.00 kW ac

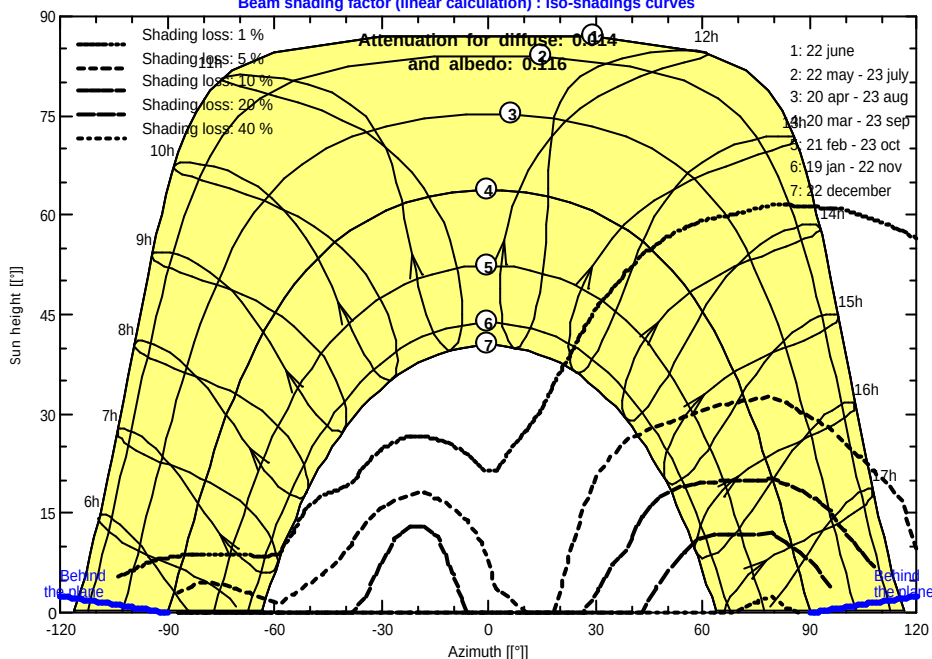
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2B

Beam shading factor (linear calculation) : Iso-shadings curves



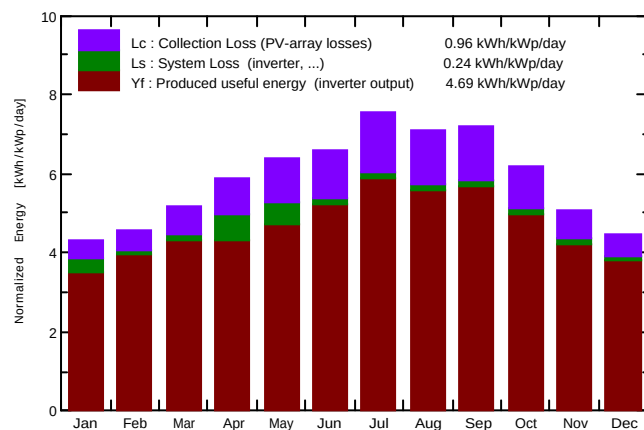
Grid-Connected System: Main results

Project : Villa 2B
Simulation variant : New simulation variant

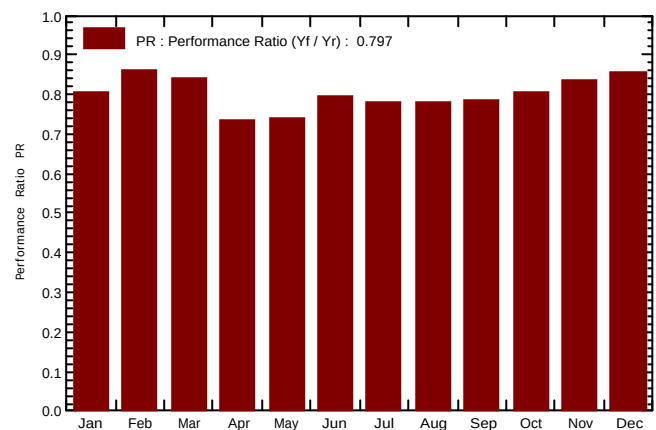
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	38 Pnom total 17.48 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results
System Production **Produced Energy 29.91 MWh/year** Specific prod. 1711 kWh/kWp/year
Performance Ratio PR 79.66 %

Normalized productions (per installed kWp): Nominal power 17.48 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	127.6	2.098	1.894	0.808
February	121.3	56.57	17.45	128.1	121.9	1.988	1.930	0.862
March	154.6	74.53	21.64	159.9	152.2	2.420	2.349	0.840
April	173.7	83.00	26.31	176.2	168.2	2.603	2.260	0.734
May	198.6	94.05	32.04	198.6	189.6	2.860	2.568	0.740
June	199.0	94.74	34.17	197.8	189.0	2.827	2.750	0.795
July	235.0	78.96	35.63	234.2	224.2	3.280	3.188	0.779
August	218.1	78.31	35.23	220.4	210.8	3.100	3.013	0.782
September	209.8	37.92	32.07	216.5	206.8	3.058	2.970	0.785
October	181.2	34.51	29.31	192.1	183.2	2.777	2.698	0.803
November	140.1	28.92	23.55	152.5	145.1	2.290	2.224	0.835
December	125.0	28.82	18.37	137.9	131.0	2.130	2.068	0.858
Year	2079.7	730.44	26.85	2148.1	2049.6	31.432	29.912	0.797

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

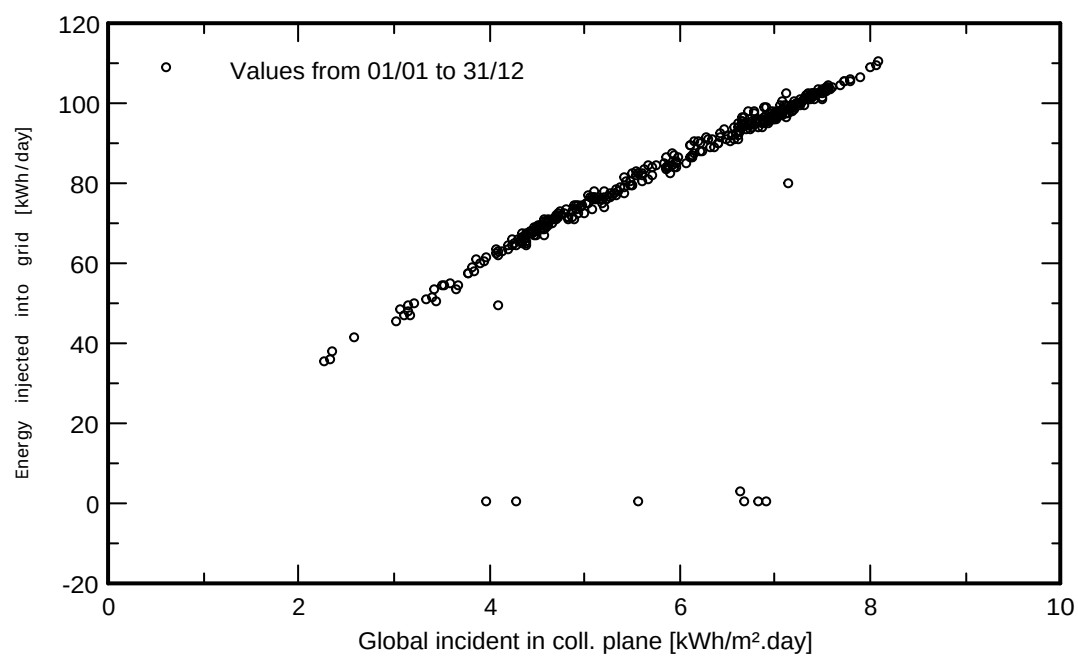
Villa 2B

Simulation variant :

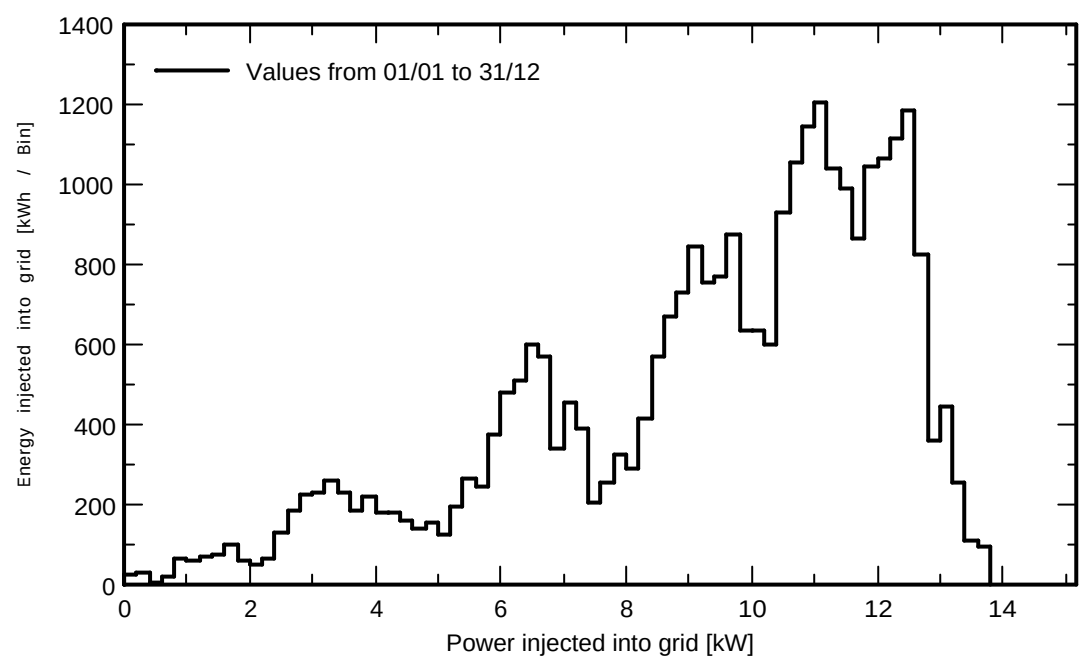
New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	38	Pnom total	17.48 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

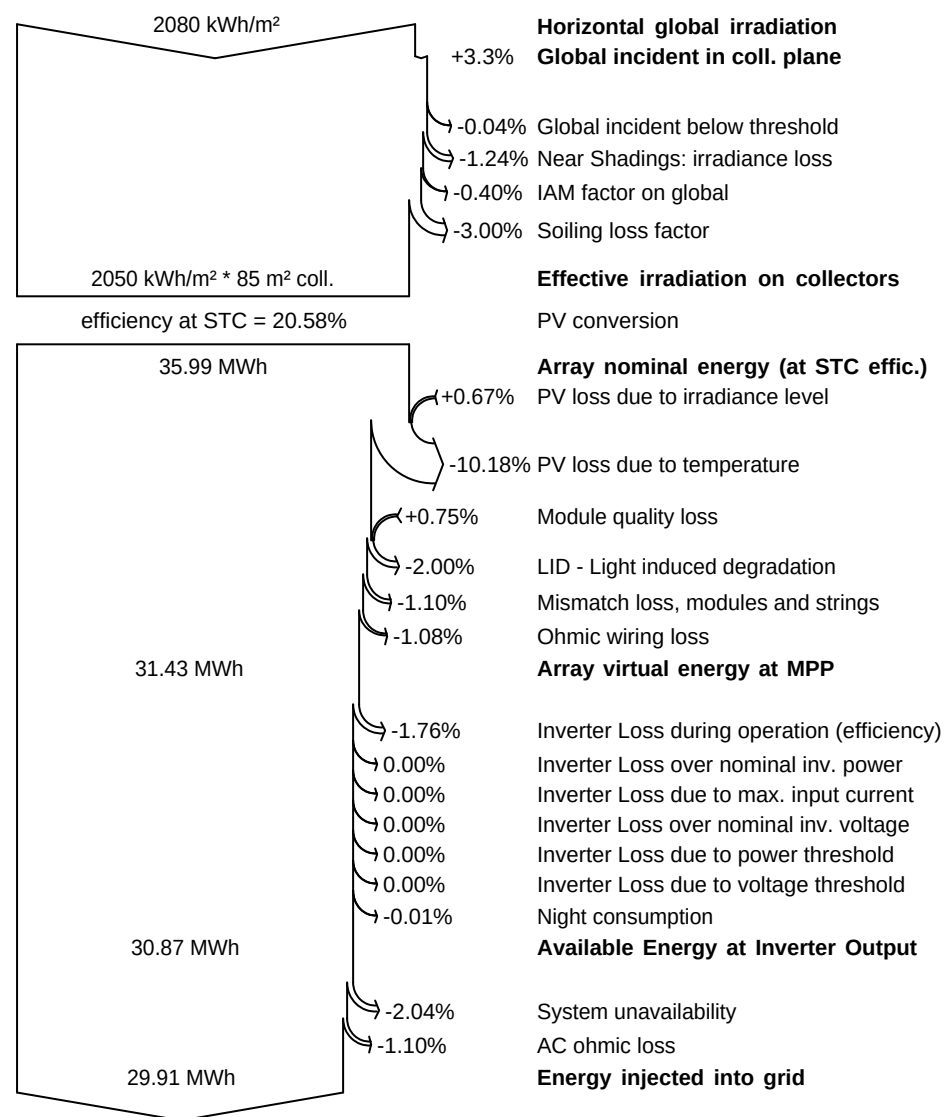


Grid-Connected System: Loss diagram

Project : Villa 2B
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	38 Pnom total 17.48 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year

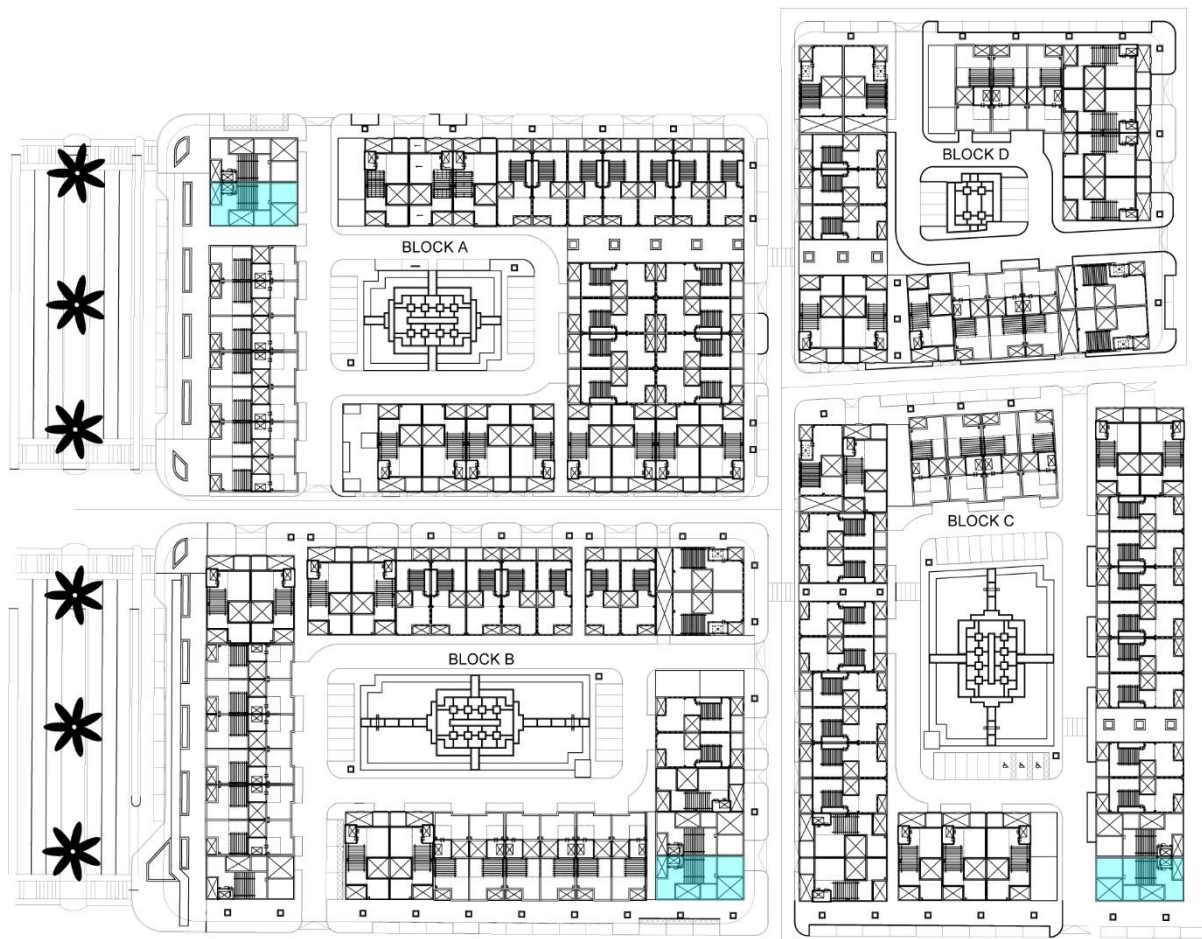


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

4. B2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
B. Orientation 2 & 4	85.3	30.12



PVSYST V6.88	kawar Energy (Jordan)		30/12/20	Page 1/6
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Grid-Connected System: Simulation parameters

Project :

Villa 2B

Geographical Site

Umm ash Sha'ūm

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'ūm

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

30/12/20 23h47

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

36

Sheds spacing

1.08 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

58.7°

Ground cov. Ratio (GCR)

95.3 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

19 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

38

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

17.48 kWp

At operating cond.

16.03 kWp (50°C)

Array operating characteristics (50°C)

U mpp

729 V

I mpp

22 A

Total area

Module area

85.3 m²

Cell area

78.8 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.17

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

549 mOhm

Loss Fraction

1.5 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors			
Wiring Ohmic Loss	Wires: 3x4.0 mm ²	40 m	Loss Fraction 2.0 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction 2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2B

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 38

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

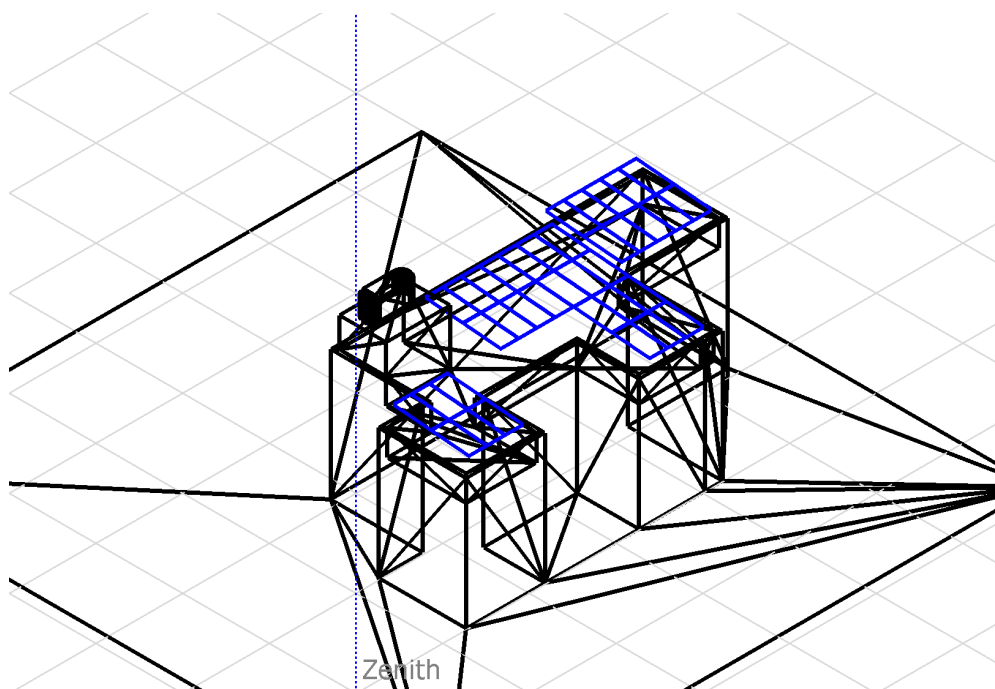
azimuth 0°

Pnom 460 Wp

Pnom total **17.48 kWp**

Pnom 15.00 kW ac

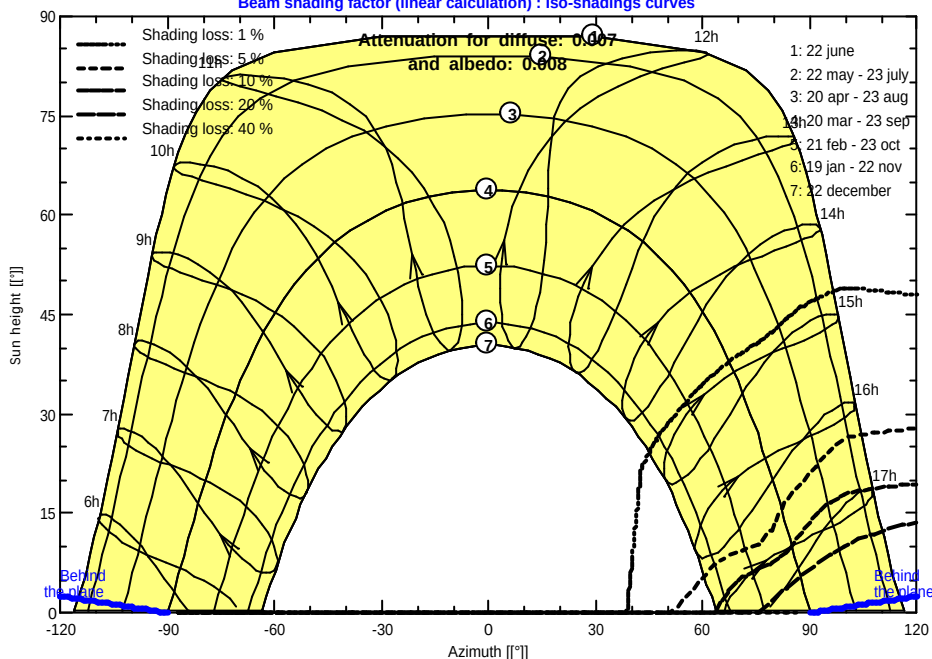
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2B

Beam shading factor (linear calculation) : Iso-shadings curves



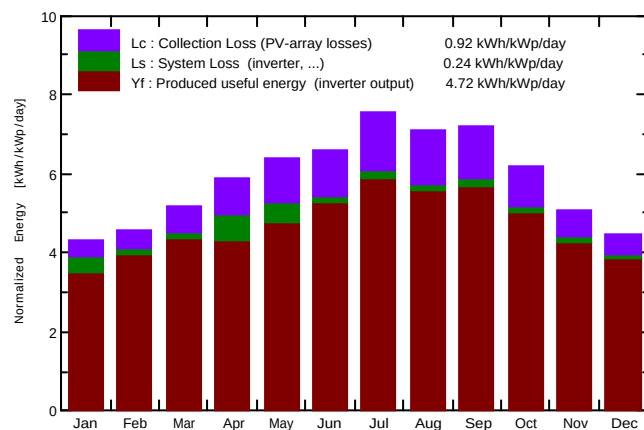
Grid-Connected System: Main results

Project : Villa 2B
Simulation variant : New simulation variant

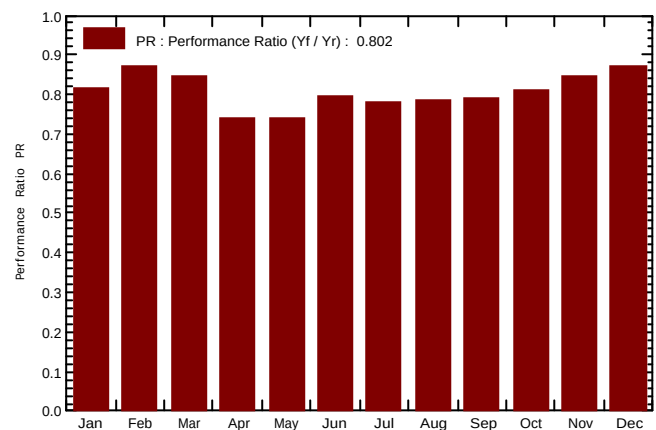
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	38 Pnom total 17.48 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results			
System Production	Produced Energy	30.12 MWh/year	Specific prod. 1723 kWh/kWp/year
	Performance Ratio PR	80.22 %	

Normalized productions (per installed kWp): Nominal power 17.48 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	129.0	2.120	1.915	0.817
February	121.3	56.57	17.45	128.1	123.1	2.007	1.948	0.870
March	154.6	74.53	21.64	159.9	153.5	2.440	2.369	0.847
April	173.7	83.00	26.31	176.2	169.2	2.617	2.272	0.738
May	198.6	94.05	32.04	198.6	190.4	2.871	2.577	0.742
June	199.0	94.74	34.17	197.8	189.7	2.837	2.758	0.798
July	235.0	78.96	35.63	234.2	224.9	3.289	3.197	0.781
August	218.1	78.31	35.23	220.4	211.8	3.114	3.026	0.785
September	209.8	37.92	32.07	216.5	208.5	3.080	2.992	0.791
October	181.2	34.51	29.31	192.1	185.0	2.803	2.723	0.811
November	140.1	28.92	23.55	152.5	146.9	2.317	2.251	0.845
December	125.0	28.82	18.37	137.9	132.8	2.157	2.095	0.869
Year	2079.7	730.44	26.85	2148.1	2064.8	31.653	30.122	0.802

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Special graphs

Project :

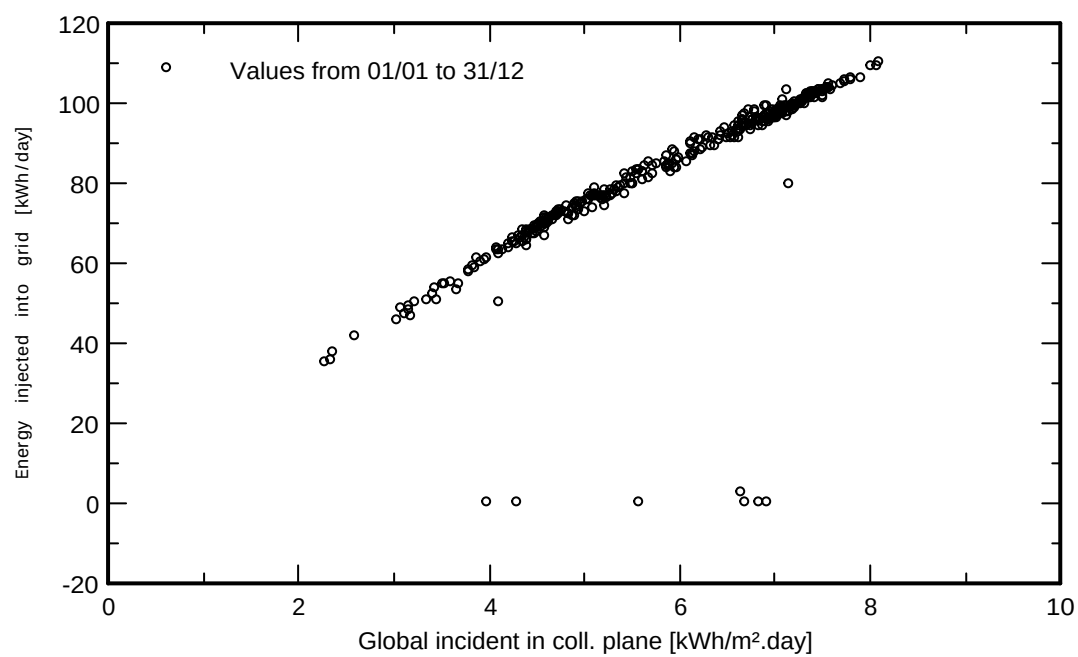
Villa 2B

Simulation variant :

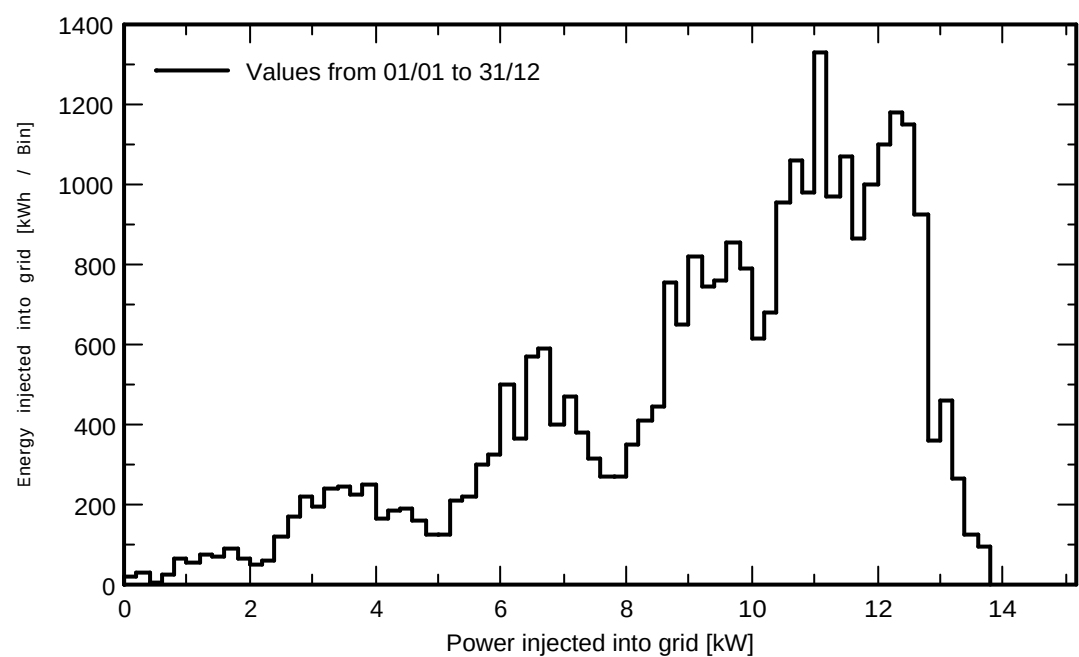
New simulation variant

Main system parameters	System type	Tables on a building			
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PV Array	Nb. of modules	38	Pnom total	17.48 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution



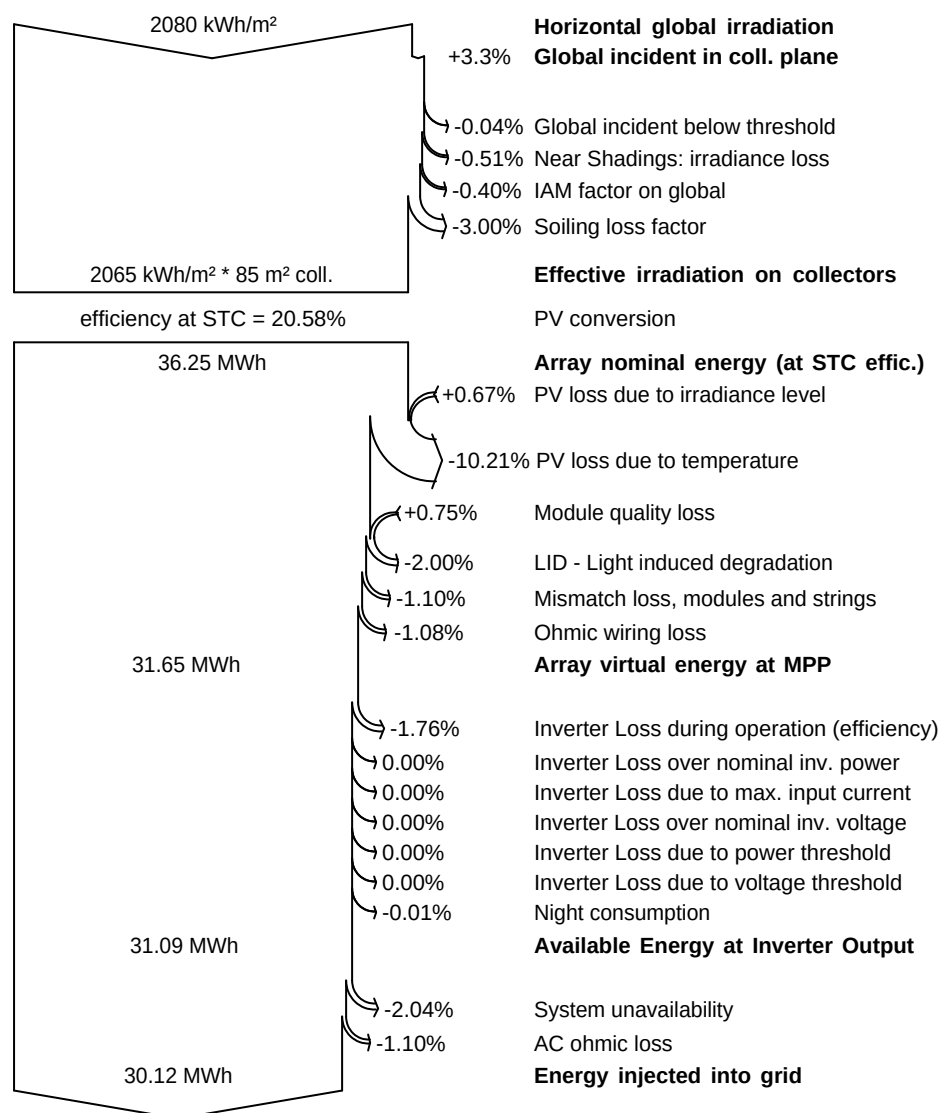
Grid-Connected System: Loss diagram

Project : Villa 2B

Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	38	Pnom total	17.48 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year

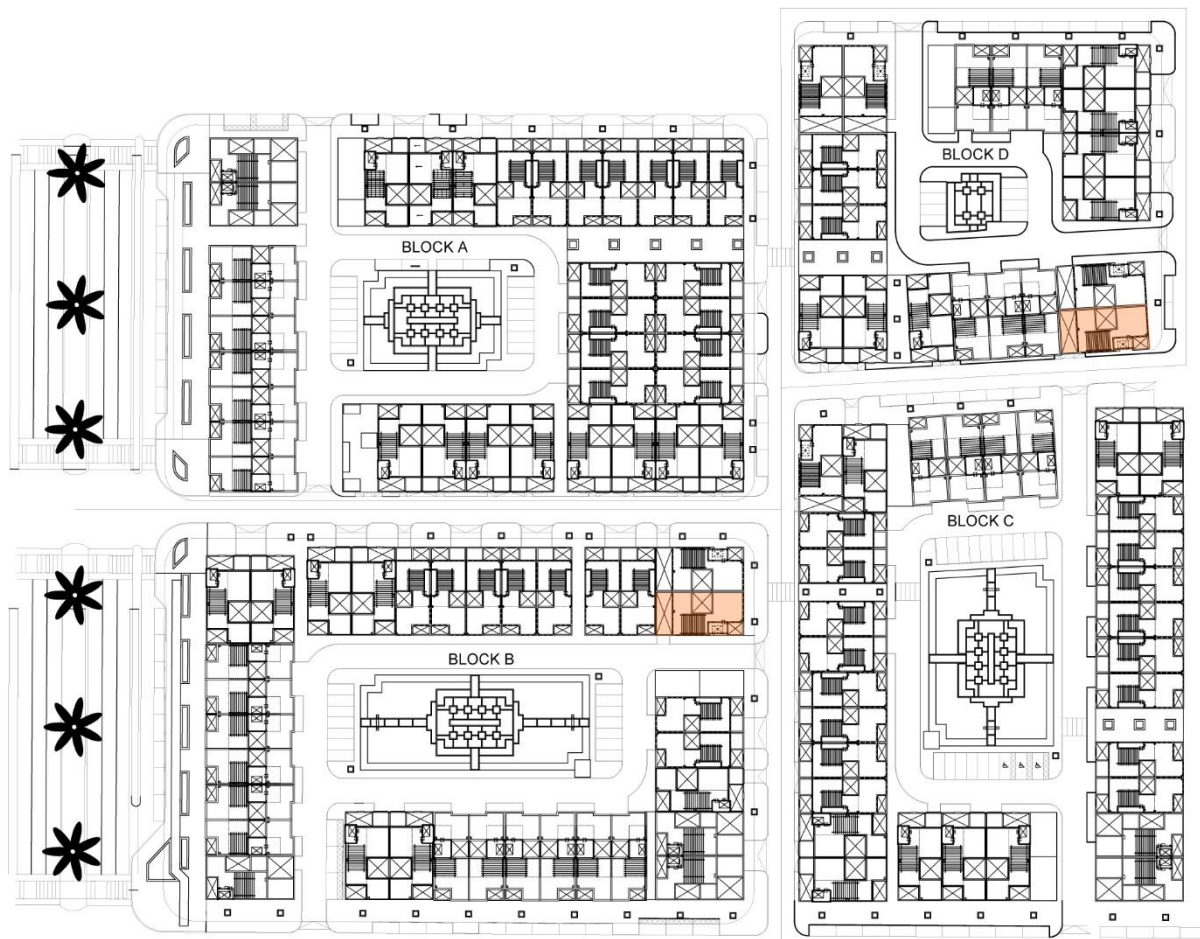


-Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

5. C2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
A. Orientation 1	80.8	28.32



PVSYST V6.88	kawar Energy (Jordan)		31/12/20	Page 1/6
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Grid-Connected System: Simulation parameters

Project :

Villa 2C

Geographical Site

Umm ash Sha'um

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'um

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

31/12/20 01h05

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

36

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.1°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

18 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

36

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

16.56 kWp

At operating cond.

15.19 kWp (50°C)

Array operating characteristics (50°C)

U mpp

691 V

I mpp

22 A

Total area

Module area

80.8 m²

Cell area

74.7 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.10

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

520 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 37 m	Loss Fraction	1.2 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2C

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 36

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

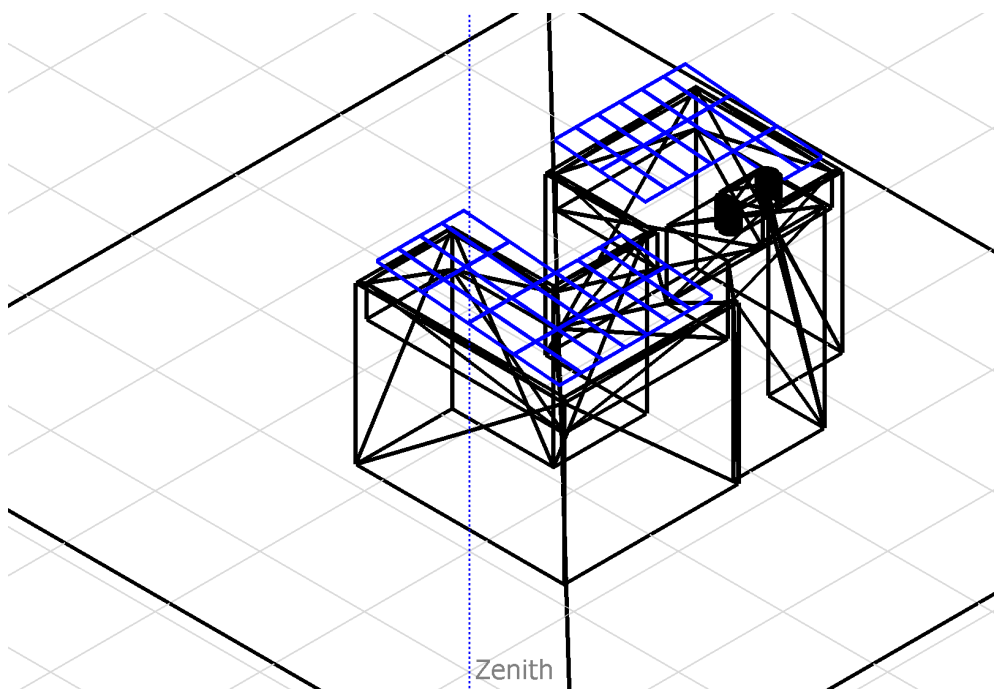
azimuth 0°

Pnom 460 Wp

Pnom total **16.56 kWp**

Pnom 15.00 kW ac

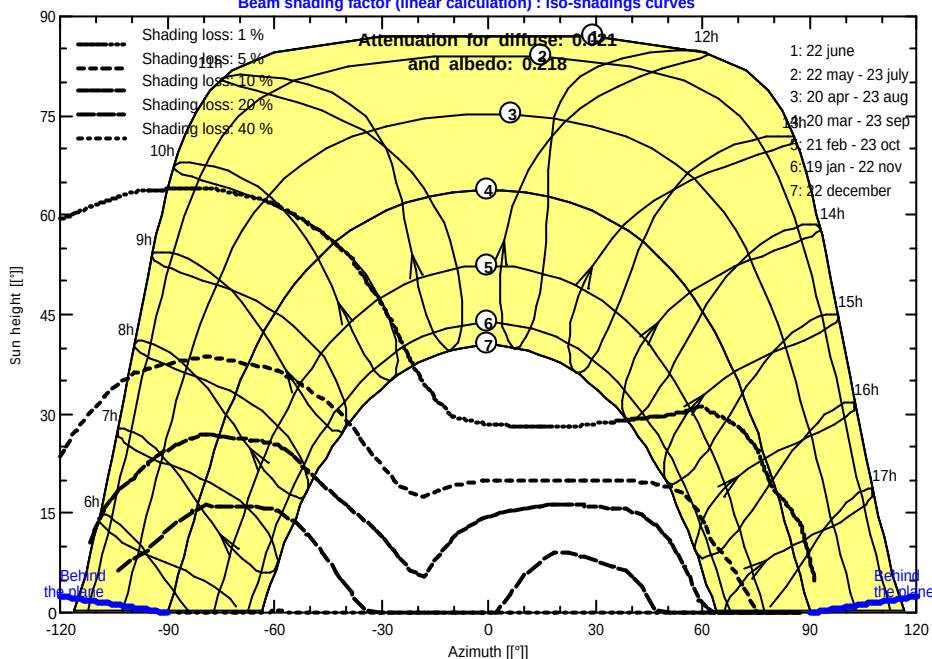
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2C

Beam shading factor (linear calculation) : Iso-shadings curves



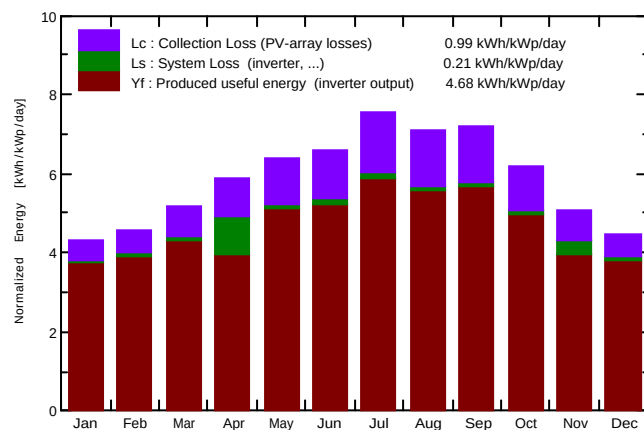
Grid-Connected System: Main results

Project : Villa 2C
Simulation variant : New simulation variant

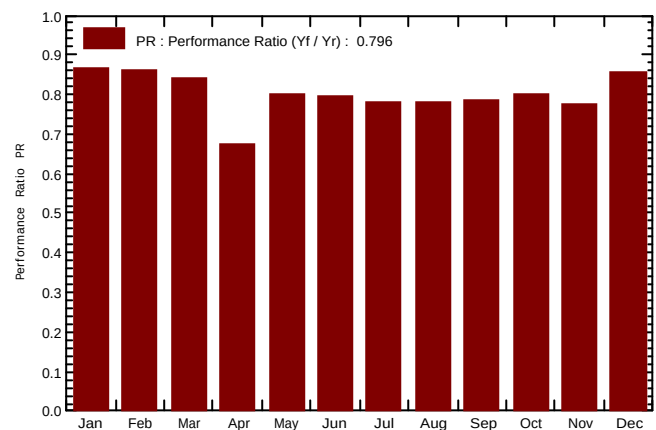
Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	36 Pnom total 16.56 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Main simulation results
System Production **Produced Energy 28.32 MWh/year** Specific prod. 1710 kWh/kWp/year
Performance Ratio PR 79.60 %

Normalized productions (per installed kWp): Nominal power 16.56 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	126.3	1.965	1.919	0.864
February	121.3	56.57	17.45	128.1	121.1	1.869	1.825	0.860
March	154.6	74.53	21.64	159.9	151.4	2.278	2.224	0.840
April	173.7	83.00	26.31	176.2	167.1	2.448	1.964	0.673
May	198.6	94.05	32.04	198.6	188.7	2.694	2.633	0.801
June	199.0	94.74	34.17	197.8	188.1	2.664	2.604	0.795
July	235.0	78.96	35.63	234.2	223.3	3.092	3.022	0.779
August	218.1	78.31	35.23	220.4	209.8	2.921	2.854	0.782
September	209.8	37.92	32.07	216.5	205.8	2.878	2.812	0.784
October	181.2	34.51	29.31	192.1	182.0	2.609	2.550	0.801
November	140.1	28.92	23.55	152.5	144.1	2.152	1.959	0.776
December	125.0	28.82	18.37	137.9	129.9	1.999	1.951	0.855
Year	2079.7	730.44	26.85	2148.1	2037.5	29.572	28.316	0.796

Legends: GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T_Amb T amb.
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Grid-Connected System: Special graphs

Project : Villa 2C

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

Linear shadings

PV Field Orientation

tilt

5°

azimuth

0°

PV modules

Model

JKM460M-7RL3-V

Pnom

460 Wp

PV Array

Nb. of modules

36

Pnom total

16.56 kWp

Inverter

Model

SUN2000MA-15KTL-M0 TL

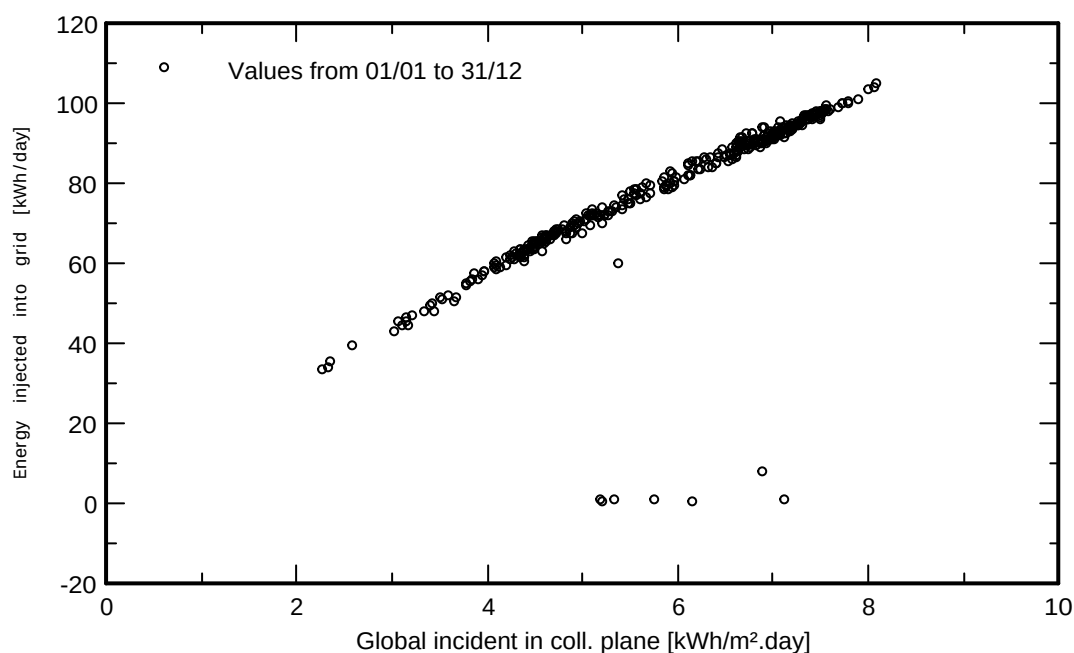
Pnom

15.00 kW ac

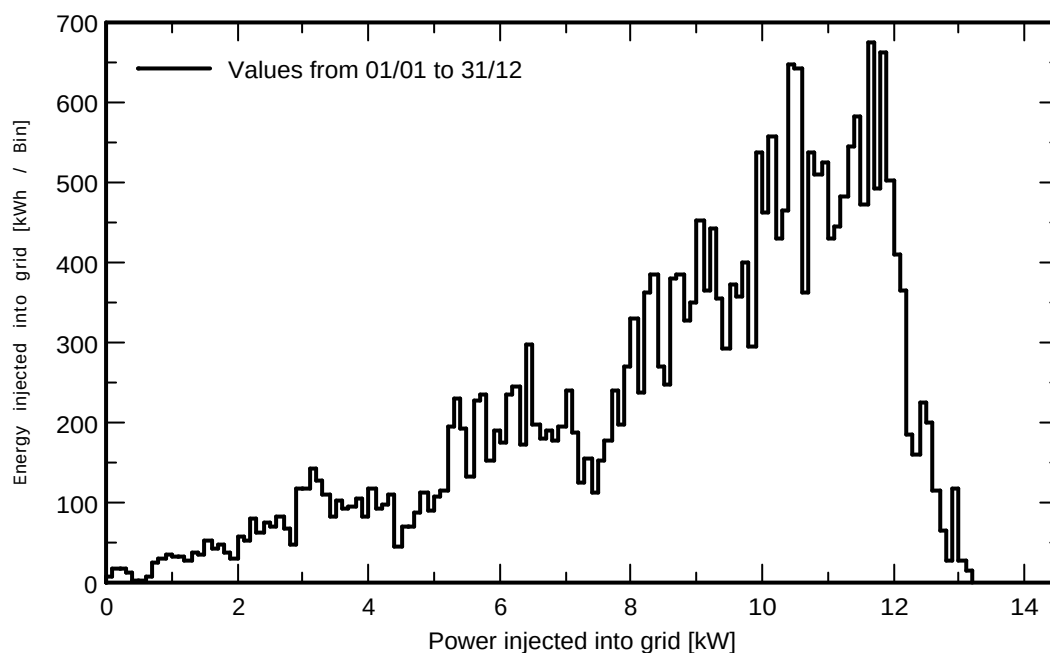
User's needs

Unlimited load (grid)

Daily Input/Output diagram



System Output Power Distribution

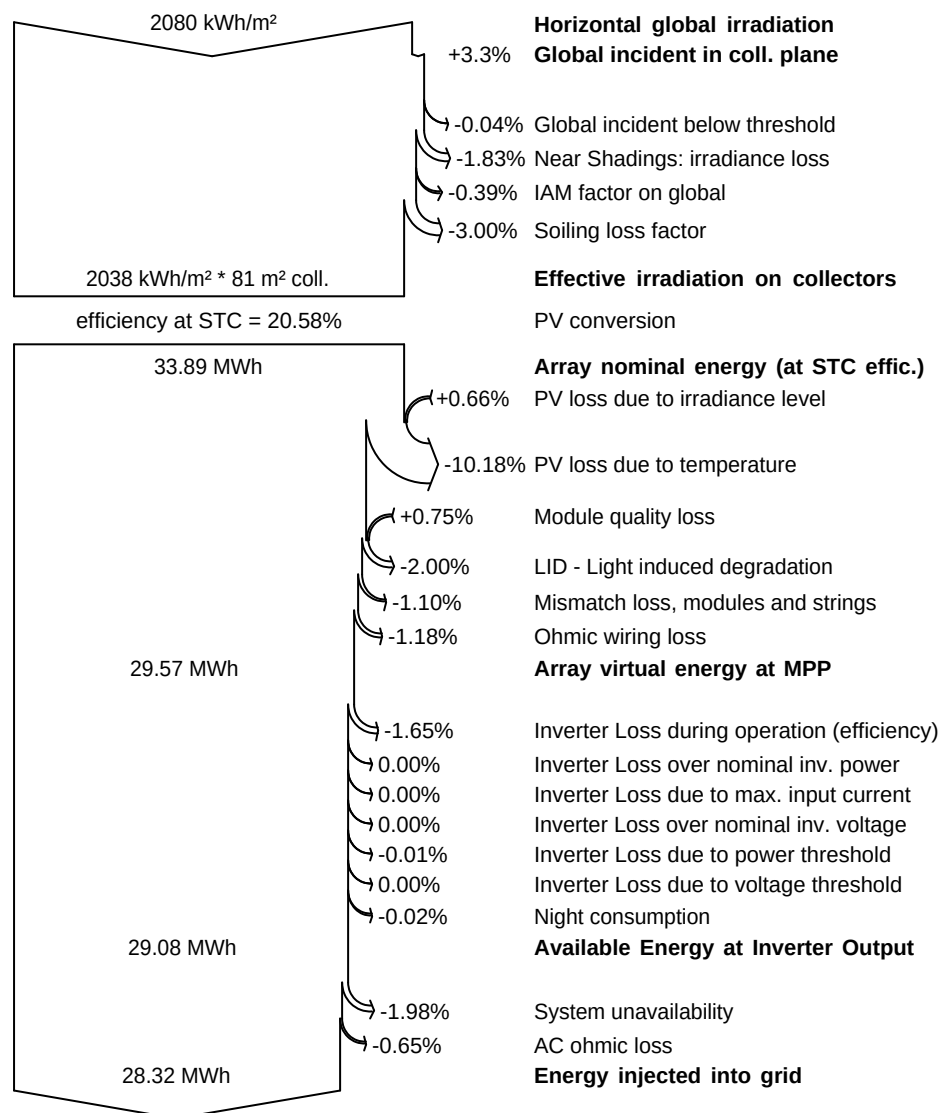


Grid-Connected System: Loss diagram

Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	36	Pnom total	16.56 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Loss diagram over the whole year

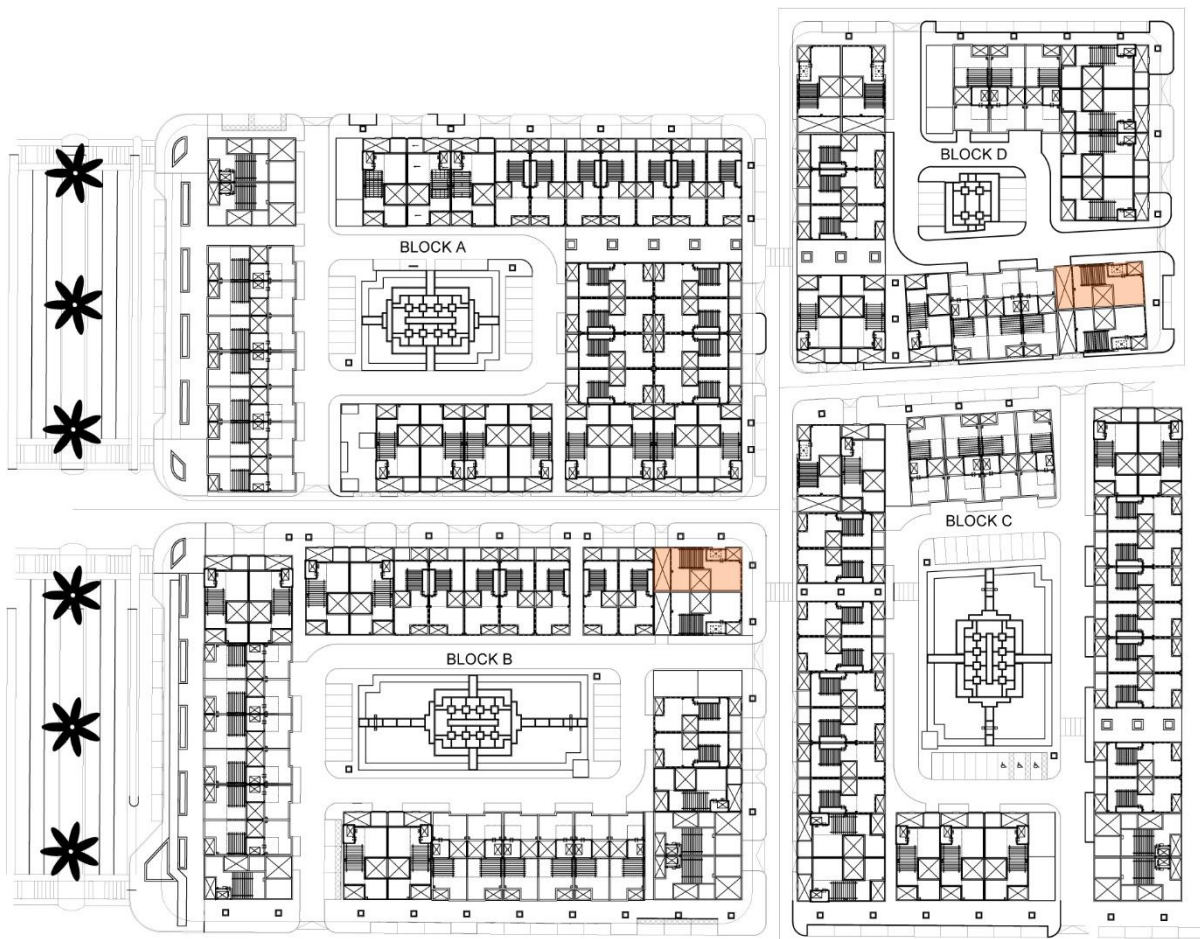


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

5. C2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
B. Orientation 2	89.9	31.55



PVSYST V6.88	kawar Energy (Jordan)				31/12/20		Page 1/6																			
Grid-Connected System: Simulation parameters																										
Project :		Villa 2C																								
Geographical Site		Umm ash Sha'um				Country Bahrain																				
Situation		Latitude		26.22° N		Longitude		50.58° E																		
Time defined as		Legal Time		Time zone UT+3		Altitude		11 m																		
		Albedo		0.20																						
Meteo data:		Umm ash Sha'um		Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic																						
Simulation variant :		New simulation variant																								
		Simulation date		31/12/20 01h12																						
Simulation parameters		System type		Tables on a building																						
Collector Plane Orientation		Tilt		5°		Azimuth		0°																		
Sheds configuration		Nb. of sheds		40		Identical arrays																				
		Sheds spacing		1.05 m		Collector width		1.03 m																		
Shading limit angle		Limit profile angle		75.1°		Ground cov. Ratio (GCR)		98.1 %																		
Models used		Transposition		Perez		Diffuse		Perez, Meteonorm																		
Horizon		Free Horizon																								
Near Shadings		Linear shadings																								
User's needs :		Unlimited load (grid)																								
PV Array Characteristics																										
PV module		Si-mono		Model		JKM460M-7RL3-V																				
Custom parameters definition		Manufacturer		Jinkosolar																						
Number of PV modules		In series		10 modules		In parallel		4 strings																		
Total number of PV modules		Nb. modules		40		Unit Nom. Power		460 Wp																		
Array global power		Nominal (STC)		18.40 kWp		At operating cond.		16.88 kWp (50°C)																		
Array operating characteristics (50°C)		U mpp		384 V		I mpp		44 A																		
Total area		Module area		89.8 m²		Cell area		83.0 m²																		
Inverter		Model		SUN2000MA-15KTL-M0 TL																						
Custom parameters definition		Manufacturer		Huawei Technologies																						
Characteristics		Operating Voltage		160-950 V		Unit Nom. Power		15.0 kWac																		
						Max. power (=>45°C)		16.5 kWac																		
Inverter pack		Nb. of inverters		1 units		Total Power		15.0 kWac																		
						Pnom ratio		1.23																		
PV Array loss factors																										
Array Soiling Losses						Loss Fraction		3.0 %																		
Thermal Loss factor		Uc (const)		20.0 W/m²K		Uv (wind)		0.0 W/m²K / m/s																		
Wiring Ohmic Loss		Global array res.		144 mOhm		Loss Fraction		1.5 % at STC																		
Serie Diode Loss		Voltage Drop		0.7 V		Loss Fraction		0.2 % at STC																		
LID - Light Induced Degradation						Loss Fraction		2.0 %																		
Module Quality Loss						Loss Fraction		-0.8 %																		
Module Mismatch Losses						Loss Fraction		1.0 % at MPP																		
Strings Mismatch loss						Loss Fraction		0.10 %																		
Incidence effect (IAM): User defined profile																										
<table border="1"> <tr> <td>0°</td> <td>30°</td> <td>50°</td> <td>60°</td> <td>70°</td> <td>75°</td> <td>80°</td> <td>85°</td> <td>90°</td> </tr> <tr> <td>1.000</td> <td>1.000</td> <td>1.000</td> <td>1.000</td> <td>0.982</td> <td>0.963</td> <td>0.932</td> <td>0.857</td> <td>0.000</td> </tr> </table>									0°	30°	50°	60°	70°	75°	80°	85°	90°	1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000
0°	30°	50°	60°	70°	75°	80°	85°	90°																		
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000																		

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 37 m	Loss Fraction	1.3 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2C

Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 40

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

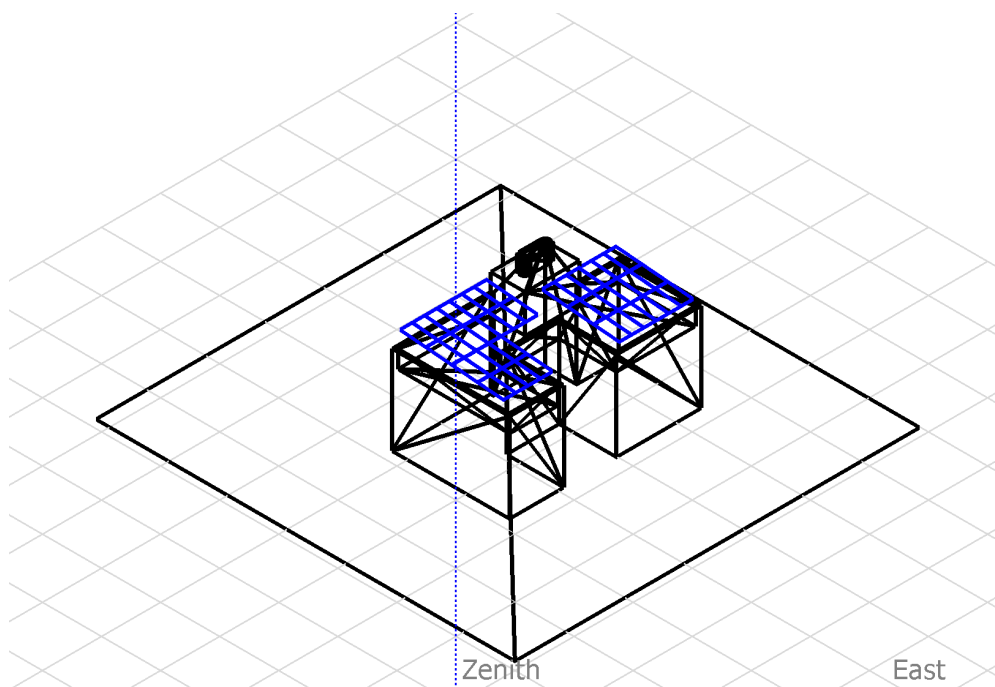
azimuth 0°

Pnom 460 Wp

Pnom total **18.40 kWp**

Pnom 15.00 kW ac

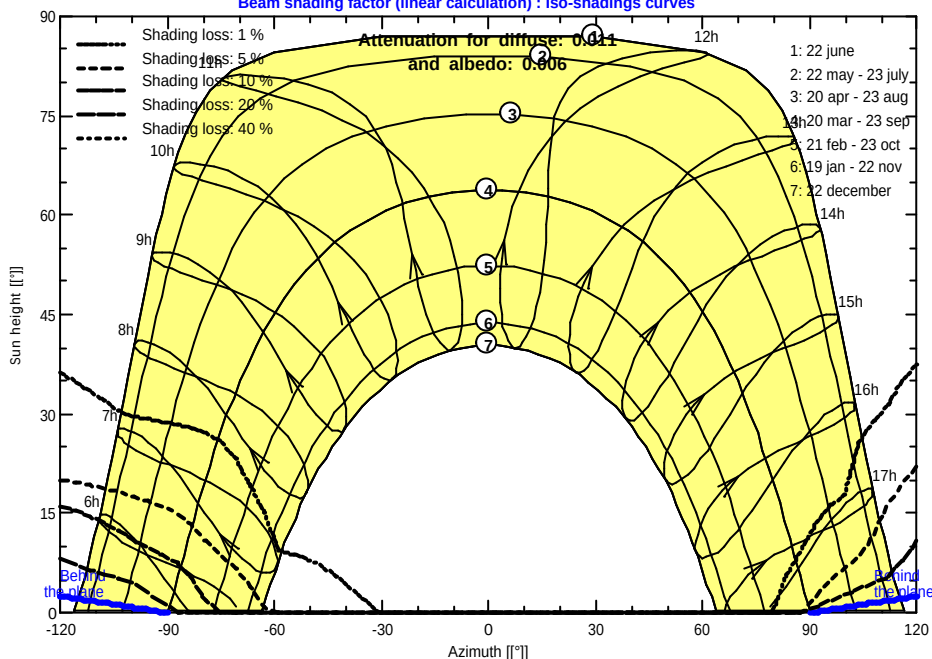
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2C

Beam shading factor (linear calculation) : Iso-shadings curves



Grid-Connected System: Main results

Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

System type

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 40

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

Tables on a building

azimuth 0°

Pnom 460 Wp

Pnom total **18.40 kWp**

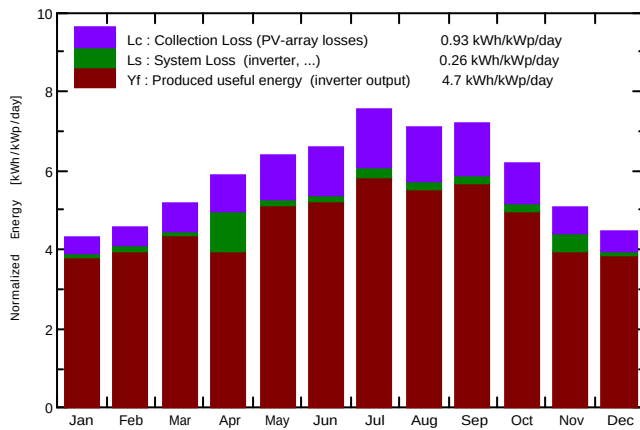
Pnom 15.00 kW ac

Main simulation results

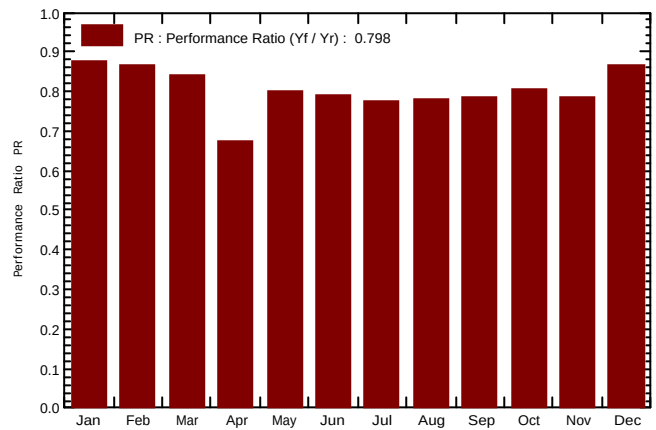
System Production

Produced Energy 31.55 MWh/year Specific prod. 1715 kWh/kWp/year
Performance Ratio PR 79.82 %

Normalized productions (per installed kWp): Nominal power 18.40 kWp



Performance Ratio PR



New simulation variant Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	129.0	2.229	2.163	0.876
February	121.3	56.57	17.45	128.1	123.1	2.108	2.044	0.867
March	154.6	74.53	21.64	159.9	153.5	2.562	2.482	0.843
April	173.7	83.00	26.31	176.2	169.1	2.749	2.183	0.673
May	198.6	94.05	32.04	198.6	190.5	3.017	2.917	0.798
June	199.0	94.74	34.17	197.8	189.7	2.980	2.882	0.792
July	235.0	78.96	35.63	234.2	225.2	3.460	3.341	0.775
August	218.1	78.31	35.23	220.4	212.0	3.274	3.161	0.780
September	209.8	37.92	32.07	216.5	208.7	3.240	3.128	0.785
October	181.2	34.51	29.31	192.1	185.2	2.948	2.850	0.806
November	140.1	28.92	23.55	152.5	147.0	2.437	2.199	0.784
December	125.0	28.82	18.37	137.9	132.9	2.269	2.200	0.867
Year	2079.7	730.44	26.85	2148.1	2065.8	33.273	31.548	0.798

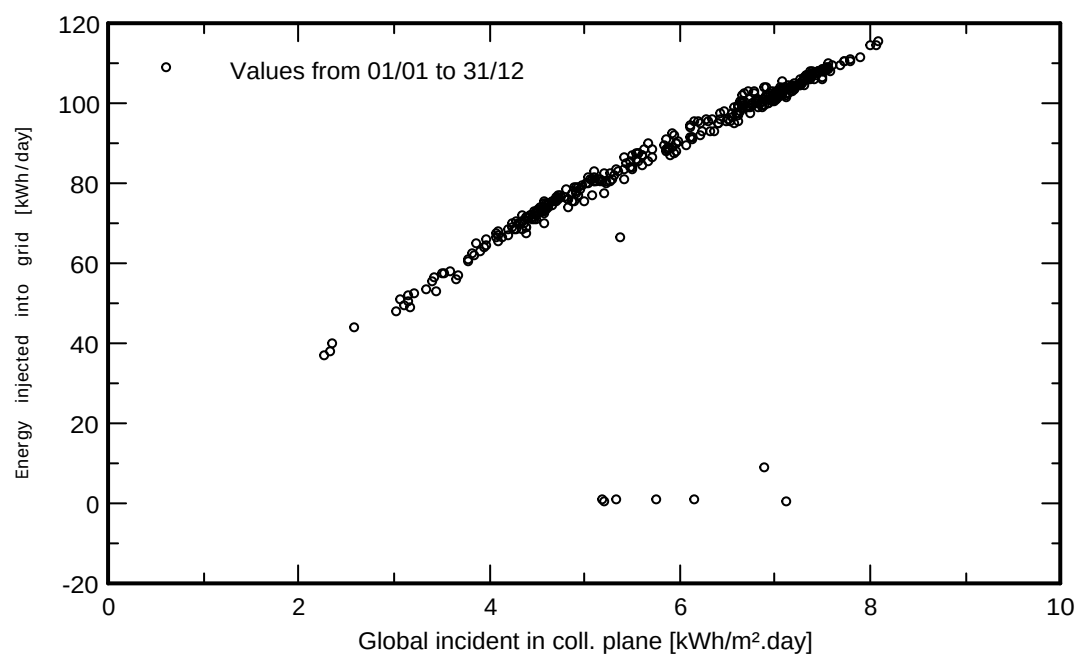
Legends: GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T_Amb T amb.
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Grid-Connected System: Special graphs

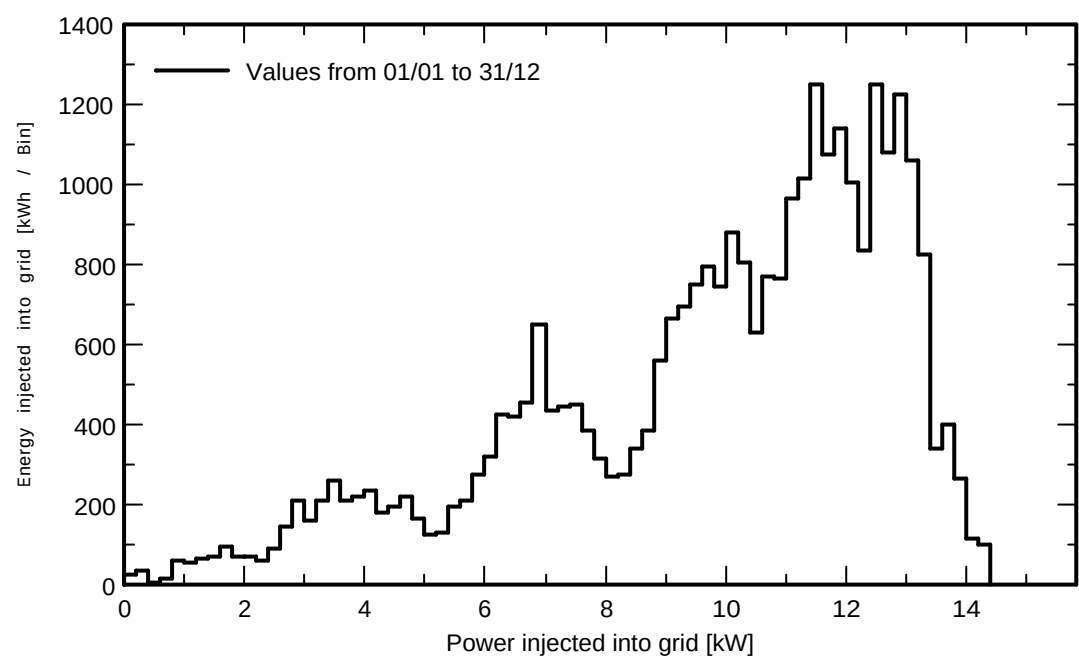
Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building			
Near Shadings	Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°	
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp	
PV Array	Nb. of modules	40	Pnom total	18.40 kWp	
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac	
User's needs	Unlimited load (grid)				

Daily Input/Output diagram



System Output Power Distribution

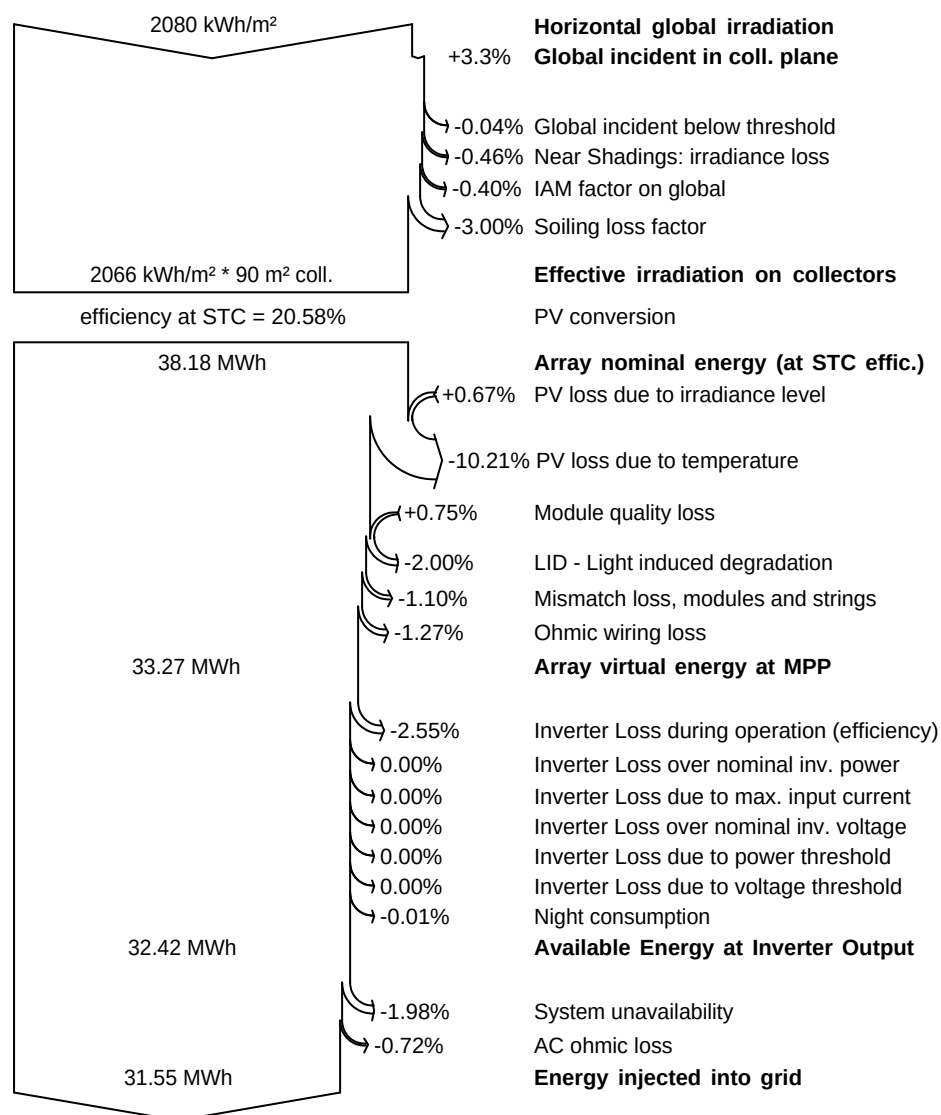


Grid-Connected System: Loss diagram

Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	40 Pnom total 18.40 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year

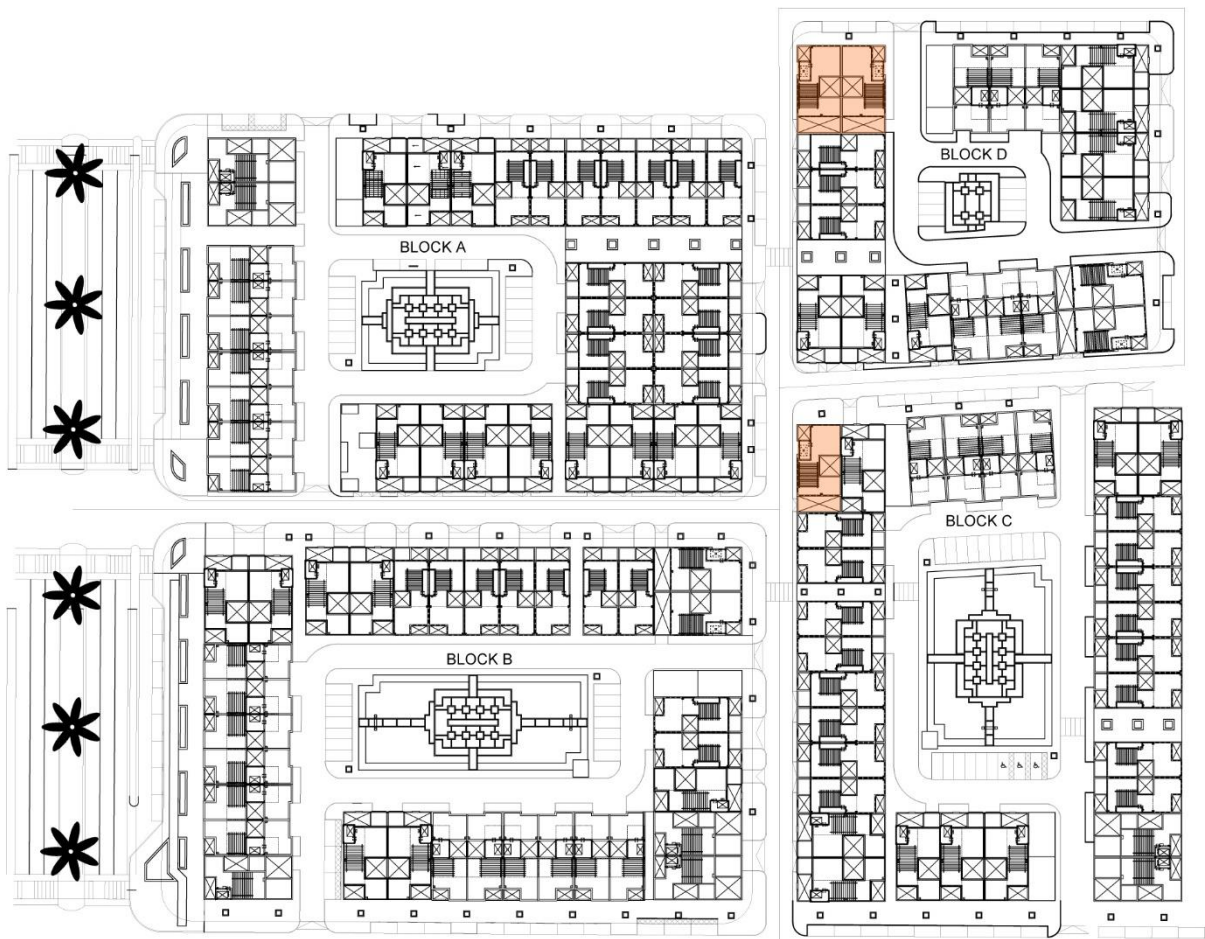


Appendix 3:

PVsyst Simulation Report for the Various Villa Types:

5. C2 Villa Type:

Orientation NO.	PV Area (m2)	Total Prod. Energy (MWh/ year)
C. Orientation 3 & 4	76.3	26.66



PVSYST V6.88	kawar Energy (Jordan)		31/12/20	Page 1/6
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Grid-Connected System: Simulation parameters

Project :

Villa 2C

Geographical Site

Umm ash Sha'ūm

Country

Bahrain

Situation

Latitude

26.22° N

Longitude

50.58° E

Time defined as

Legal Time

Time zone UT+3

Altitude

11 m

Albedo

0.20

Meteo data:

Umm ash Sha'ūm

Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic

Simulation variant :

New simulation variant

Simulation date

31/12/20 00h48

Simulation parameters

System type

Tables on a building

Collector Plane Orientation

Tilt

5°

Azimuth

0°

Sheds configuration

Nb. of sheds

34

Identical arrays

Sheds spacing

1.05 m

Collector width

1.03 m

Shading limit angle

Limit profile angle

75.1°

Ground cov. Ratio (GCR)

98.1 %

Models used

Transposition

Perez

Diffuse

Perez, Meteonorm

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs :

Unlimited load (grid)

PV Array Characteristics

PV module

Si-mono

Model

JKM460M-7RL3-V

Custom parameters definition

Manufacturer

Jinkosolar

Number of PV modules

In series

17 modules

In parallel

2 strings

Total number of PV modules

Nb. modules

34

Unit Nom. Power

460 Wp

Array global power

Nominal (STC)

15.64 kWp

At operating cond.

14.34 kWp (50°C)

Array operating characteristics (50°C)

U mpp

653 V

I mpp

22 A

Total area

Module area

76.3 m²

Cell area

70.5 m²

Inverter

Model

SUN2000MA-15KTL-M0 TL

Custom parameters definition

Manufacturer

Huawei Technologies

Characteristics

Operating Voltage

160-950 V

Unit Nom. Power

15.0 kWac

Max. power (=>45°C)

16.5 kWac

Inverter pack

Nb. of inverters

1 units

Total Power

15.0 kWac

Pnom ratio

1.04

PV Array loss factors

Array Soiling Losses

Loss Fraction

3.0 %

Thermal Loss factor

Uc (const)

20.0 W/m²K

Uv (wind)

0.0 W/m²K / m/s

Wiring Ohmic Loss

Global array res.

491 mOhm

Loss Fraction

1.5 % at STC

Serie Diode Loss

Voltage Drop

0.7 V

Loss Fraction

0.1 % at STC

LID - Light Induced Degradation

Loss Fraction

2.0 %

Module Quality Loss

Loss Fraction

-0.8 %

Module Mismatch Losses

Loss Fraction

1.0 % at MPP

Strings Mismatch loss

Loss Fraction

0.10 %

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.982	0.963	0.932	0.857	0.000

PVsyst Licensed to kawar Energy (Jordan)

Grid-Connected System: Simulation parameters

System loss factors

Wiring Ohmic Loss	Wires: 3x6.0 mm ² 37 m	Loss Fraction	1.1 % at STC
Unavailability of the system	7.3 days, 3 periods	Time fraction	2.0 %

Grid-Connected System: Near shading definition

Project : Villa 2C

Simulation variant : New simulation variant

Main system parameters

System type

Tables on a building

Near Shadings

PV Field Orientation

PV modules

PV Array

Inverter

User's needs

Linear shadings

tilt 5°

Model JKM460M-7RL3-V

Nb. of modules 34

Model SUN2000MA-15KTL-M0 TL

Unlimited load (grid)

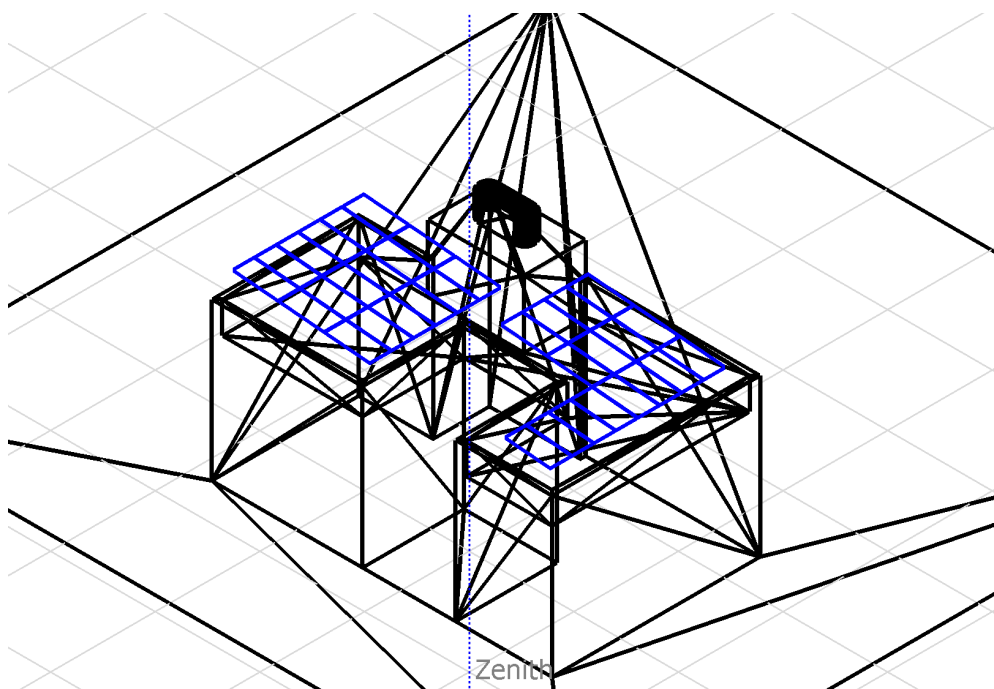
azimuth 0°

Pnom 460 Wp

Pnom total **15.64 kWp**

Pnom 15.00 kW ac

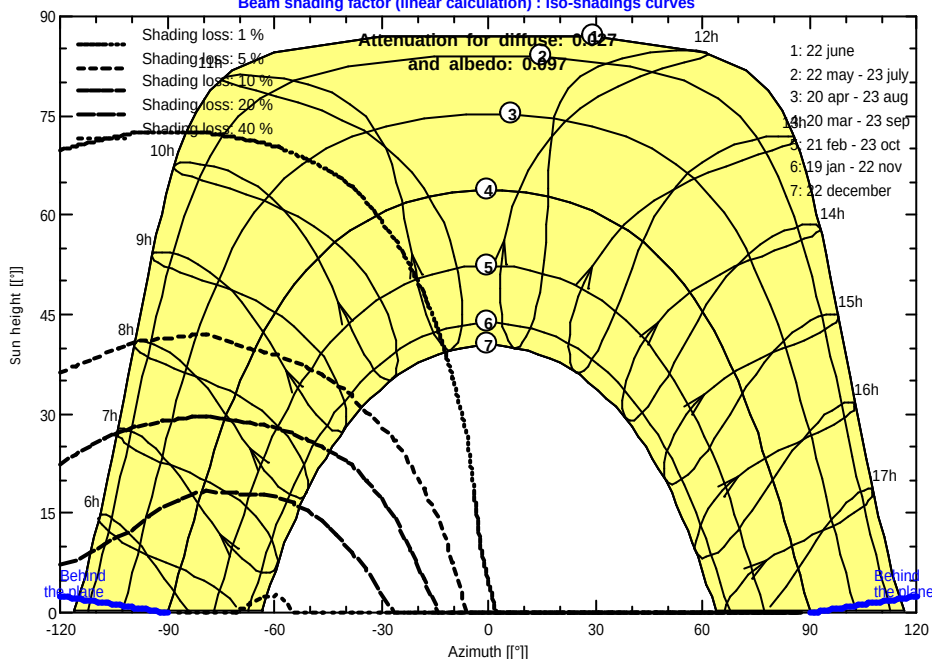
Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Villa 2C

Beam shading factor (linear calculation) : Iso-shadings curves



Grid-Connected System: Main results

Project :

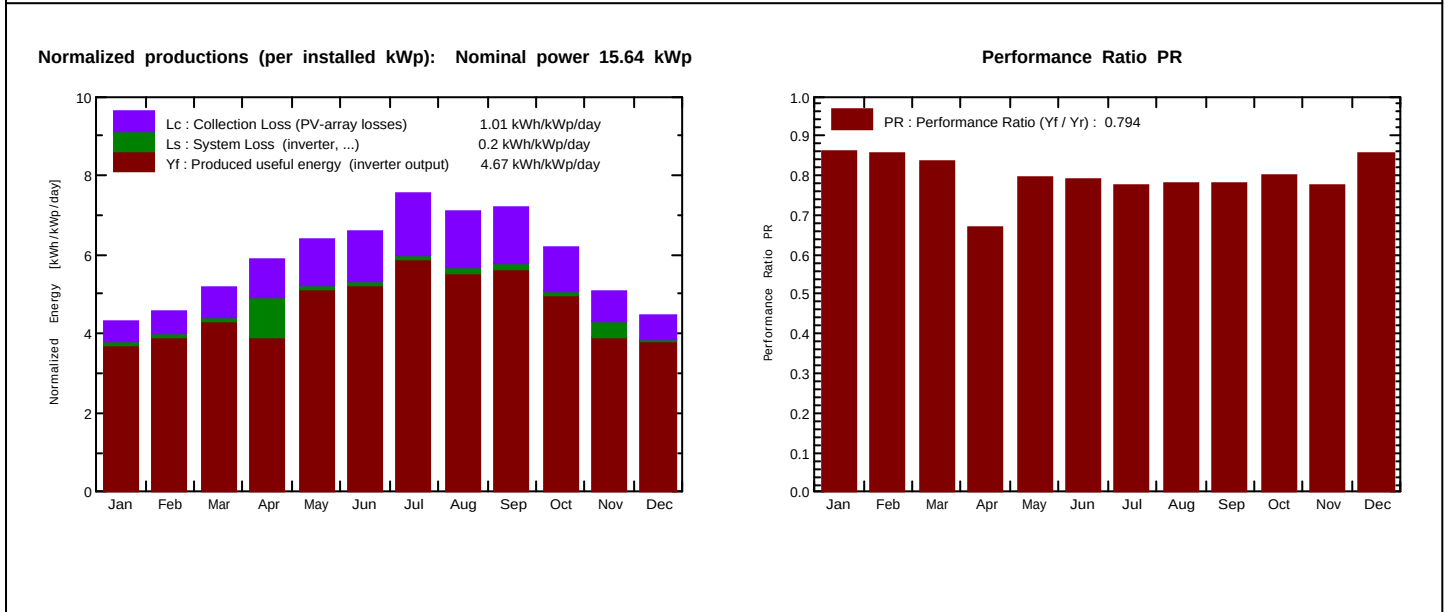
Villa 2C

Simulation variant :

New simulation variant

Main system parameters		System type	Tables on a building			
Near Shadings		Linear shadings				
PV Field Orientation	tilt	5°	azimuth	0°		
PV modules	Model	JKM460M-7RL3-V	Pnom	460 Wp		
PV Array	Nb. of modules	34	Pnom total	15.64 kWp		
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom	15.00 kW ac		
User's needs	Unlimited load (grid)					

Main simulation results				
System Production	Produced Energy	26.66 MWh/year	Specific prod.	1705 kWh/kWp/year
	Performance Ratio PR	79.35 %		



New simulation variant

Balances and main results

	GlobHor kWh/m ²	DiffHor kWh/m ²	T_Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray MWh	E_Grid MWh	PR
January	123.4	40.11	15.80	134.1	125.8	1.850	1.808	0.862
February	121.3	56.57	17.45	128.1	120.6	1.759	1.719	0.858
March	154.6	74.53	21.64	159.9	150.7	2.142	2.094	0.837
April	173.7	83.00	26.31	176.2	166.2	2.301	1.847	0.670
May	198.6	94.05	32.04	198.6	187.7	2.532	2.476	0.797
June	199.0	94.74	34.17	197.8	187.0	2.502	2.448	0.792
July	235.0	78.96	35.63	234.2	222.1	2.907	2.842	0.776
August	218.1	78.31	35.23	220.4	208.8	2.746	2.685	0.779
September	209.8	37.92	32.07	216.5	204.9	2.708	2.647	0.782
October	181.2	34.51	29.31	192.1	181.3	2.457	2.403	0.800
November	140.1	28.92	23.55	152.5	143.8	2.029	1.848	0.775
December	125.0	28.82	18.37	137.9	129.7	1.884	1.842	0.854
Year	2079.7	730.44	26.85	2148.1	2028.6	27.815	26.660	0.794

Legends:

GlobHor

DiffHor

T_Amb

GlobInc

Horizontal global irradiation

Horizontal diffuse irradiation

T amb.

Global incident in coll. plane

GlobEff

EArray

E_Grid

PR

Effective Global, corr. for IAM and shadings

Effective energy at the output of the array

Energy injected into grid

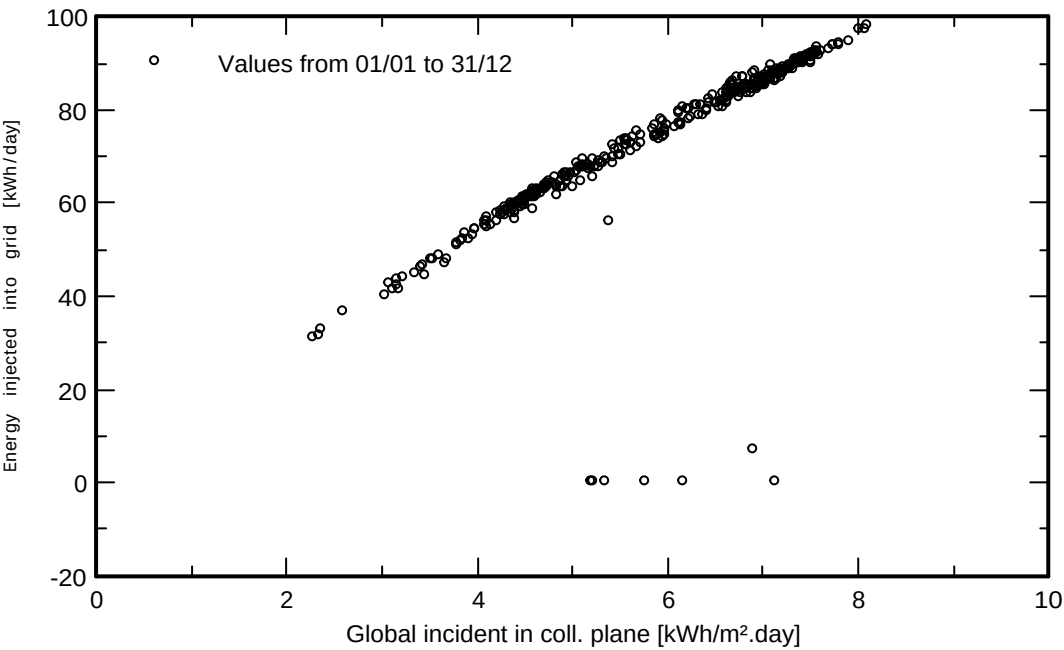
Performance Ratio

Grid-Connected System: Special graphs

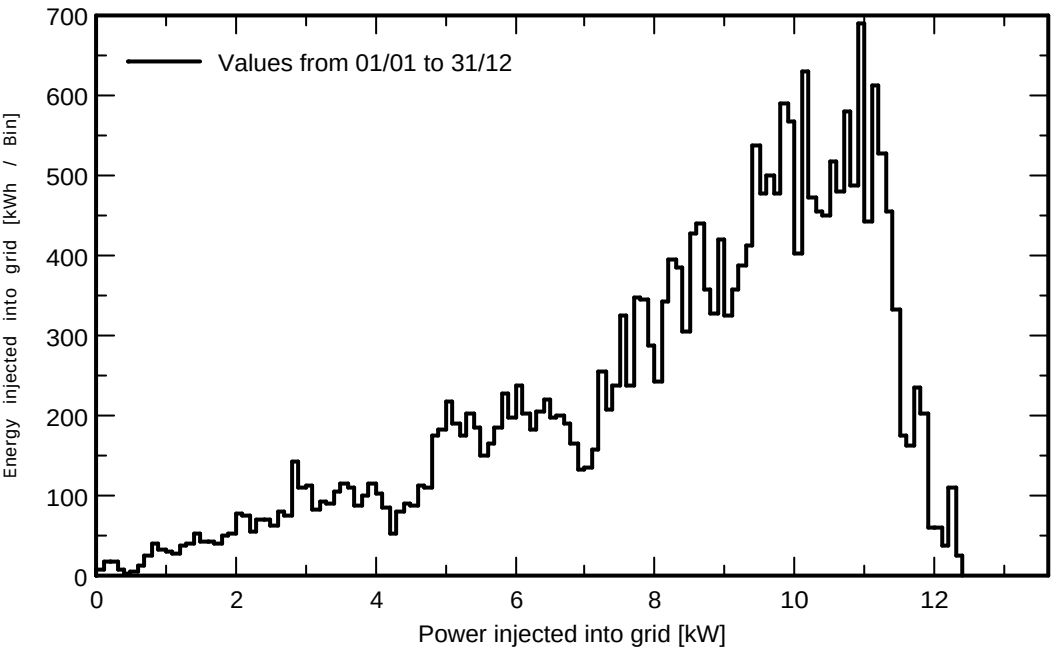
Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building	
Near Shadings	Linear shadings		
PV Field Orientation	tilt	5°	azimuth 0°
PV modules	Model	JKM460M-7RL3-V	Pnom 460 Wp
PV Array	Nb. of modules	34	Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL	Pnom 15.00 kW ac
User's needs	Unlimited load (grid)		

Daily Input/Output diagram



System Output Power Distribution

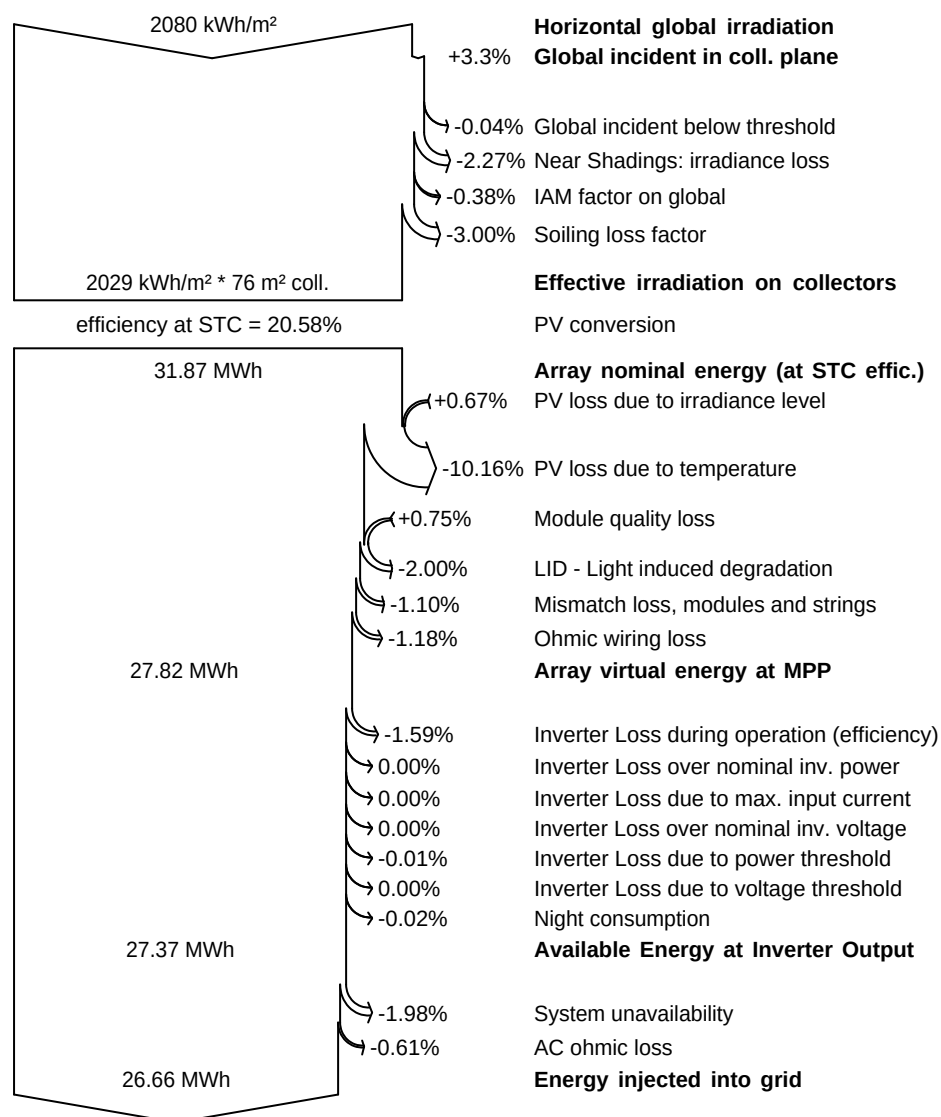


Grid-Connected System: Loss diagram

Project : Villa 2C
Simulation variant : New simulation variant

Main system parameters	System type	Tables on a building
Near Shadings	Linear shadings	
PV Field Orientation	tilt	5° azimuth 0°
PV modules	Model	JKM460M-7RL3-V Pnom 460 Wp
PV Array	Nb. of modules	34 Pnom total 15.64 kWp
Inverter	Model	SUN2000MA-15KTL-M0 TL Pnom 15.00 kW ac
User's needs	Unlimited load (grid)	

Loss diagram over the whole year



المخلص

تواجه البحرين ارتفاعاً في الطلب على الكهرباء نتيجة لأسباب مثل النمو السكاني، وارتفاع معدلات التحضر، وارتفاع مستويات المعيشة، حيث من المتوقع أن يصل معدل النمو الحالي إلى للطلب على الكهرباء ذروة تبلغ 9,500 ميغاوات بحلول عام 2030. إن مجالات الانشاءات لسريعة النمو، بشكل عام، والمباني السكنية، على وجه الخصوص، تخلق أعباءً هائلة للطاقة والبيئة على الدولة. لذلك، فقد حددت البحرين هدفاً وطنياً للطاقة المتجددة من إجمالي الكهرباء المنتجة بنسبة 5٪ بحلول عام 2025. وبالتالي، فإن الهدف من هذه الدراسة هو دراسة إمكانية تطبيق الأنظمة الكهروضوئية (PV) في القطاع السكني في مملكة البحرين، بالاستفادة من أسطح المباني. وقد تم اختيار المدينة الجنوبية الجديدة (**مدينة خليفة**) كدراسة حالة للتحقق من مناطق الأسطح القابلة للاستخدام لتنصيب أسطح الخلايا الكهروضوئية لإنتاج الطاقة الكهربائية. في هذه الدراسة تم إجراء تقييم مساحة السطح ونمذجة النظام الكهروضوئي (PV Panels) باستخدام برنامجي AutoCAD وPVsyst، على التوالي. وتبين من الدراسة أن تركيب 17 كيلووات من الألواح الكهروضوئية لكل فيلا – بميلان قدره 5°، باتجاه الجنوب - سينتج سنوياً 3,129 ميغاوات- ساعة للوحدات السكنية المختارة للدراسة (**120**) ، أي 44,953 ميغاوات- ساعة لعدد 1,724 وحدة سكنية (**إجمالي عدد الفلل في مدينة خليفة**) ، وهي كافية لسد حوالي 43٪ من إجمالي احتياجات المدينة من الكهرباء. وسيؤدي تركيب أسطح الخلايا الشمسية على أسطح المنازل إلى خفض انبعاثات ثاني أكسيد الكربون بمقدار 34,794 طنًا، أي تقليل 21٪ من إجمالي انبعاثات ثاني أكسيد الكربون في هذه المدينة.

ويشير التحليل المالي لمثل هذه المبادرة (**تركيب الخلايا الكهروضوئية على السطح**) إلى أنها تعتبر استثماراً لانفقا فقط إذا اشترت الحكومة (EWA) كل وحدة كهرباء كيلووات- ساعة من نظام الطاقة الكهروضوئية (PV) مقابل 29 فلساً، أي التعرفة للاستخدام التجاري، وسيكون استرداد التكلفة (Payback period) بموجب هذا الحافز هو 9.6 سنة. ومع ذلك، فإذا اشترت الحكومة الوحدة الكهربائية من الزبون بتكلفة تساوي أعلى تعرفة مدعومة للكهرباء للأسرة (3 فلس للاستهلاك الشهري لا يزيد عن 3000 كيلووات- ساعة)، فسيتم اعتبار الاستثمار بمثابة خسارة كبيرة حيث أن فترة استرداد التكلفة للنظام هي حوالي 84 سنة! لذلك، فإن وضع سياسة تعرفة التغذية لشبكة الكهرباء (FIT)، مع ضمان أن استرداد التكلفة لا يزيد عن 6 سنوات، سيشجع الأسر على تركيب أنظمة الطاقة الكهروضوئية على أسطح منازلها، وبالتالي مساعدة الدولة على تحقيق هدفها من نصيب الطاقة المتجددة بالنسبة للطاقة الكهربائية الاعتيادية. كما سيعزز أيضاً تصنيع أسطح الخلايا الشمسية (الكهروضوئية) محلياً، وبالتالي خلق المزيد من وظائف الياقة الخضراء (Green collar jobs). كما أن وجود سياسة FIT ناجحة ستضمن استدامة مدينة خليفة والمدن المخطط أن تكون نظيفة ومستدامة مستقبلاً.



دراسة استخدام أسطح البيوت في مدينة خليفة لتركيب الخلايا الكهروضوئية

رسالة مقدمة كجزء من متطلبات الحصول على درجة الماجستير في البيئة والتنمية المستدامة – الاستدامة
الحضرية

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جامعة البحرين

مملكة البحرين

مايو / 2021