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Research Article

Impact of Photovoltaic Panel Orientation and Elevation Operating Temperature on Solar Photovoltaic System Performance

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Abstract. This study conducts optimum tilt angle and orientation of a standalone c-Si monocrystalline solar photovoltaic (PV) system deploying PVsyst software. The site of the hypothesized solar PV system is at 9, Mountain Rise, Berea, Durban, South Africa. This work presents values of tilt and azimuth angles and battery operating temperature that support optimal solar PV system performance. The range of angles considered for tilt and azimuth for a fixed PV panel mounting is 0° to 90° and -100° to 100°, respectively. Based on the report obtained from PVsyst design and simulation software, this study finds that: the highest available energy, specific energy, used energy, solar fraction, and lowest loss were recorded at tilt 40° and Azimuth 0°. Further, the longest battery service life was attained at an operating temperature between -2 °C to 20 °C. Hence, 40° and 0° are the optimum tilt and Azimuth angles, respectively while running the storage system at a temperature, not more than 20 °C.

Keywords: Solar photovoltaic, PV panel orientation, Optimum tilt and Azimuth angles, Battery service life, Solar battery operating temperature

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1. Introduction

Fossil energy is the fundamental driver of all developments so much that without it there might not have been global north industrial revolution, technological, and socio-economic development (Ebhota & Jen, 2020). It built the foundations of strong economies in Europe, America and Asia. It was previously linked to this saying, "tell me the energy you consume and I will tell you how viable and strong your economy is". Fossil energy played a strong role in the global socio-economic change, and is responsible for the industrial revolution, and the subsequent technological, and socio-economic development that followed it. However, after decades of fossil energy utilisation there came challenges, which the world has responded to with an outcry, triggered by the limited fossil fuel deposit; increasing demand for energy, due to increasing industrialisation and urbanisation; and global environmental issues, such as CO_2 emissions, resulting from fossil-based electricity generation and consumption. The fossil fuel that has dominated the energy space has been proven to have negative effects on the environment and human health and is the main contributor to climate change.

Recently, the 2021 Conference of the Parties (COP), captioned COP26, was held in Glasgow, where the United States was seen playing a leading role (UN, 2021). World leaders, ministers, negotiators, businesses, international organizations, representatives from civil society, and the media usually attend the COP conferences. The governments, which have signed the United Nations (UN) Framework Convention of Climate Change (UNFCCC), constitute the Parties (UNFCCC, 2021). This study observed that the COP26 conference, which brought signatory governments together, reinvigorated the outcry and stand on the need for stricter actions to address climate change.

As a fallout of the actions required for addressing climate change, the world is transiting to renewable energy sources (RESs) as replacements for fossil fuels. At this stage of transition, reduction or elimination of the use of fossil energy will not produce desirable effect, unless there is/are the alternative source(s) to keep the global economy running. This is because adequate energy supply is fundamental to the growth and sustenance of socio-economic development. The outcry for fossil fuel consumption reduction has stirred up the energy sector, evolving new dynamics, energy postulations, and several emerging RE schemes and technologies. Presently, RESs such as solar, wind, small hydropower (SHP), biofuel, and geothermal are receiving huge attention globally (Ebhota & Tabakov, 2019). Amongst these renewable technologies (RETs), solar PV stands out due to its huge potential and spread, coupled with the continuous components price decline, easy installation, and low maintenance cost. In the United States in 2019, cost of multi-and mono c-Si PV

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module fell to about $0.22/W and lithium-ion battery prices dropped by 13% (Feldman, O'Shaughnessy, & Margolis, 2020).

Despite the impressive achievements recorded in PV technology over the years, the conversion efficiency of PV cells of the widely installed panels is hovering about 18% to 20% (Pickerel, 2018). Many parameters account for the total PV system efficiency, which includes PV module dimension, PV panels mounting orientation; and the number of the PV panels (Gulomov *et al.*, 2021; Kabbani & Mohamed Shaik, 2021). Further, operating conditions, such as temperature, wind speed, the minimum distances between rows for cooling, and maintenance operations, and arrangements to avoid effects of shadow must be well thought out. Efforts are ongoing to increase the conversion efficiency of Si monocrystalline and Si polycrystalline PV cells and systems, and other PV cell technologies through different facets.

Hence, this work considers the influence of elevated temperatures and PV panel orientation on solar PV system performance at a defined site location. The result is expected to assist in the design and installation of a solar PV system. PVsyst software will be used to investigate the right orientation of solar PV panels that supports the PV modules to harvest solar energy optimally. In addition, possible loss concerning the optimum orientation of PV panels and battery operational temperature will be examined.

2. Background study: Solar Panel Azimuth and Zenith Orientation

The sun and other celestial bodies are far away from the earth, a sphere with an arbitrary radius is often used to describe their motion and they are concentric to the earth. The sun's position is not stationary; its position is defined by the time of the day and the year, and the location on earth. This phenomenon influences the direct and diffuse spectrum and affects the solar potential availability. Continuous research drive is responsible for the present level of conversion efficiency of PV cells and systems. In reality, to have a PV system that delivers conversion efficiency of 18% to 20% is an uphill task and several variables must be considered. In this regard, several studies have examined the impacts of these parameters on PV cells and systems efficiency (Axelevitch & Golan, 2013; Deb, 2000; Libra & Poulek, 2022; NREL, 2007; Shi & Lin, 2019). The influence of partial shading on a PV module was investigated with four levels of shading states (20 %, 30 %, 50 %, and 80 %) (Sari-Ali et al., 2020). Ouédraogo et al examined the temperature reliance of efficiencies of individual energetic process and complete conversion efficiencies of a Si polycrystalline PV cell in the temperature range 10–50 °C (Ouédraogo, Zouma, Ouédraogo, Guissou, & Bathiébo, 2021). Empirical studies of the effect of using combined phase change materials (PCM) on the thermal behaviour and electrical performance of a PV panel were conducted (Senthil Kumar, Ashwin Kumar, Gowtham, Hari Selva Kumar, & Hari Sudhan, 2021). A study proposes a novel technique for estimating the electrical efficiency of PV modules as a function of the solar radiation, the temperature of the cooling fluid, and the solar incidence angle (Ventura, Tina, Gagliano, & Aneli, 2021). The effect of different physical parameters on greenhouse productivity still coupled with a cylindro-parabolic solar concentrator and an independent PV generator that delays the time of distillation during the night was examined in a study (Mandi et al., 2019).

Solar PV modules are mounted at such an angle and position to counter the adverse effect of the movement of the sun on the harvestable solar resource. The quantity of the local insolation received by a solar PV panel determines the amount of solar energy that will be produced. The use of appropriate inclination and orientation during the installation of a PV panel maximizes the daily reception of solar radiation (Ebhota & Tabakov, 2021). It has been shown empirically that solar PV panels work optimally when their absorbing surface is perpendicular to the sun's rays (Burger & Rüther, 2006; Chang, 2009; Chen, Li, Zhao, Ma, & Wang, 2018; González-González, Martín-Jiménez, Sánchez-Aparicio, Del Pozo, & Lagüela, 2022). Two angles, azimuth and tilt, are used to parameterize their positions and is most convenient to use the horizontal coordinate system in PV applications (Jäger, Isabella, Smets, Swaaij, & Zeman, 2014). In this case, the horizon of the observer constitutes the fundamental plane. In some PV installations, tracking systems are used to follow the course of the sun, so the daily solar energy received by PV panels can be maximised. However, the use of these devices is limited because of the high cost and the energy that is required for their operation and hence, a defined tilt and azimuth angles are used (Hailu & Fung, 2019).

At the beginning of a fixed PV system design, angles of installation, which are often referred to as the annual optimum tilt and azimuth angles, are considered. The selected angles should offer a maximum PV power output yield yearly. In this regard, the baseline practice among professionals is that PV module surfaces are made to face the equator, and be tilted at an angle about the site latitude (Chen et al., 2018). This is why the direction and roof orientation and the angle of inclination are being considered before installation.

2.1. Azimuth angle (α)

The performance of solar panels reaches its peak when the orientation is in the right direction. Many studies have shown that the best direction to place the panels is south if you live in the northern hemisphere, otherwise north. This implies that PV panels perform optimally when they are placed in the south, in countries such as China, Canada, Europe, America, and India. Conversely, PV panels for countries in the southern hemisphere, such as Indonesia, Brazil, New Zealand, Zambia, Australia, and South Africa would perform best if placed northwards.

2.2. Tilt angle (β)

Generally, the optimal tilt and azimuth angles depend on the Hemisphere; southward orientation is optimal for North Hemisphere, while northward orientations for the South Hemisphere optimization (Guo *et al.*, 2017). Attention is normally given to PV module spatial configuration aimed at maximising the daily, monthly, and annual energy performance. Many studies have reported that the tilt of solar modules is relative to the location, period, and duration. Several theoretical and experimental attempts were made to determine the impact of tilt angle on solar energy collection. The maximum energy collection occurs when solar radiation strikes a surface at a vertical angle of incidence, and this is the basis of the optimal tilt angle concept. Many methods have been advanced to evaluate the optimum tilt angle of solar collectors, which includes a general estimation method of optimum tilt angle by using a clear-day solar radiation model. Other methods are optimum tilt angle as a half-yearly average for the summer and winter months, and a half-yearly average for the months. The daily, monthly, and yearly solar energy collection of tilted and the optimum tilt angles for spring, summer, autumn and winter was conducted in a study (Bakirci, 2012).

The only input parameters that are required in the evaluation of tilt angle are altitude, longitude, and nature of climate of a chosen location. Many studies have extensively addressed tilt angle quantitatively and qualitatively for PV system optimisation. Some of the suggested estimates for solar optimal tilt (β) by different studies for collectors facing the equator are as follows: $\beta = \phi - 10$ (Heywood & H., 1971); $\beta = \phi + 10$ (Kern & Harris, 1975); $\beta = \phi + 20$ (Hottel & Woertz, 1942); $\beta = \phi + (10 \rightarrow 20) + 10$ (Stevens, 1977); $\beta = \phi + (0 \rightarrow 30)$ (Löf & Tybout, 1973); and $\phi + (10 + 30)$ (Elminir et al., 2006). Where ϕ is the latitude of the location in degree (°). In another study, the focus was on the estimation of optimal tilt based on the period and the following relations were reported (Yellott, 1975): $\beta = \phi \pm 20$ and $\beta = \phi \pm 8$, where + and – are for winter and summer respectively. Several other studies investigated the effects of tilt angle on the amount of energy collected by a solar PV panel and some of these studies and the conclusions are presented in Table 1.

2.3. *Transposition factor*

The ratio between the incident irradiation on the plane, to the horizontal irradiation, is termed transposition factor. It refers to the gain or loss when tilting the collector plane. Transposition in PVsyst is the evaluation of the incident irradiance on a tilted plane based on the horizontal irradiance data. Two transposition models, Hay and Perez, are available in PVsyst. The Hay model is a classic and robust model, which offers good results even with some irregularities in the knowledge of the diffuse irradiation. Perez model is a more intricate model that requires good knowledge of horizontal data.

2.4. *Power storage device: Solar Battery*

The incorporation of battery storage in a solar PV system is an upward trend for residential off-grid systems. This is due to the merits of the off-grid systems, such as minimising grid dependency, electricity bill, CO_2 emission, and power outage. Therefore, it is necessary for the designers, network operators, and consumers to critically consider and plan PV-battery systems optimisation. To effectively do this, some parameters and factors that are socio-econo-technological come into play, such as: design and operating constraints, objective functions, optimization algorithms, energy management systems, and electricity pricing programmes (Khezri, Mahmoudi, & Aki, 2022). Amongst the operating conditions, ambient temperature is the most important factor that affects the ageing of the battery and promotes premature failure. Extreme temperatures, cold and hot, can substantially influence the lifecycle, safety capabilities, performance, and depth of discharge (DOD) of solar storage systems. Elevated ambient temperature accelerates faster battery's chemical reaction, which increases both corrosion and water loss. The optimum operating temperature of valve-regulated lead-acid (VRLA) batteries is between 20-25°C. A 10% temperature constant increase above this recommended temperature reduces the battery service life by 50%.

3. Methodology

This study exploits the rapidly, flexible, and advanced process of computer-aided engineering (CAE) in executing its objectives, using PVsyst software applications on a c-Si - crystalline silicon (mono) standalone PV system. The influence of three parameters tilt angle, Azimuth angle, and battery-operating temperature on the performance of a PV system in a site at Mountain Rise, Berea, Durban, South Africa, will be investigated. In this study, the PVsyst software will be exploited to investigate the influence of each of these parameters through simulation in the following ways:

1. Two sets of range of angles, 0° to 90° and -100° to 100° will be considered for a fixed PV panel mounting, like tilt and azimuth angles, respectively.
2. A temperature range of -20° to 60°, at an interval of 10, will be used to examine the effect of elevated operating temperature on the battery performance in a PV system
3. The generated simulation report will be used to analyse the results and the optimum values identified. The same procedure will be followed to examine the effects of elevated temperatures on the performance of a battery.

Table 1
Summary of previous studies on the tilt angle

Study	Name Location	Location latitude (°N), longitude (°)	Tilt angle (°)	Method
(Asl-Soleimani, Farhangi, & Zabihi, 2001)	University of Tehran, Iran	35.7022, 51.3957	30	Empirical
(Hussein, Ahmad, & El-Ghetany, 2004)	Cairo, Egypt	30.0444, 31.2357	20-30	Software (TRNSYS)
(Mondol, Yohanis, & Norton, 2007)	Northern Ireland	54.7877, 6.4923	30	Software (TRNSYS)
(Guo et al., 2017)	Batang County, Western Sichuan Plateau, China	30.0054, 99.1105	40	Statistical method
(Kaldellis & Zafirakis, 2012)	Island, Kythnos, Greece	37.3934, 24.4173	26	Experimental
(Bakirci, 2012)	Istanbul, Turkey	41.0082, 28.9784	32.6	Statistical method

Fig 1. A section of Mountain Rise, South Africa

4. Location information and system description

4.1. Location

A site at 9 Mountain Rise, Carrington Heights, Berea, KwaZulu-Natal, South Africa, a residential area, was hypothetically selected for this study. A section of Mountain Rise Street is shown in Fig 1, as obtained from Google Map. The climate is described as humid subtropical climate, Köppen classified and represented as Cfa (Mindat.org, 2022). Durban's climate is temperate, hot summer, and without dry season, there is always significant amount of rainfall during the year. The average annual temperature and rainfall are about 20.9 °C and 893 mm yearly, respectively.

The site is on Latitude (46.20 °N), longitude (6.15 °E) and other location based information of the selected site is presented in Table 2.

4.2. The solar PV system description

The installation type used in this study is a rooftop mount, meaning that the 6 kW_p-installed capacity of the PV system was hypothetically mounted on a tilted roof of a residential building. The Azimuth and angle of tilt of the PV panels are harmonised such that the panels do not overlap or shade each other. The mounting of PV panels on rails that are attached to a tilted roof gives room for backside ventilation. A low-voltage grid connection, which is in a parallel circuit connection, through an inverter without storage is suitable for this type of PV system. Monocrystalline PV cell material was selected because of the quest for higher efficiency and the system is on a fixed stand type that can adequately power a household of a small family. Details of other inputs used in this study are presented in Table 3.

Table 2
The site location and the system information

Site location information	
Project name	Impact of Photovoltaic Panel Orientation
Address	9 Mountain Rise, Carrington Heights, Berea, South Africa
Geographical coordinates (°)	-29.85185°,030.99337°
Latitude (°N), longitude (°E)	46.20, 6.15
Time zone	UTC+01
Elevation (m)	8
Land cover	Urban areas
Population density (inh./km²)	14175
Terrain azimuth (°)	quasi flat
Terrain slope (°)	2
Annual air temperature at 2 m (°C)	20.9

Table 3
System information and details of user's needs

PV system type		**Standalone with backup generator**			
User's need	Household	Night ratio (%)	49.6		
Average power (W)	139	Daily energy	3.3 kWh/day		
PV Field Orientation					
Fixed plane Tilt/Azimuth (°)		Azimuth: -100 to100; Tilt: 0 to 90	Installation type	Roof mount	
Nb. of modules		7 units	Pnom total	2100 Wp9,kl	
PV module type (%)		c-Si - crystalline silicon (mono)			
Battery pack					
Technology	Lead-acid, vented, plates	Nb. of units	16 units	Voltage/Capacity	800 Ah/24 V
Detailed User's needs					
Electrical appliances	**Quantity (*q*)**	**Capacity (W)**	**Total watts, W_{total} (W)**	**Hours per day (h)**	**Energy consumptions, $W_{h/day}$ (Wh/day)**
Compact fluorescent lamp (CFL)	2	10	130	9	180
Laptop	1	150	150	9	1350
Fan	1	75	75	9	675
Television	1	70	70	4	280
Refrigerator	1	50	50	24	1200
Washing machine	1	2	2	0.5	1
Mobile set	6	6	6	5	180
Standby consumers				24	24
Total daily energy (Wh/day)					3890

5. Simulation results and analysis

In this section, the results as obtained from the PVsyst report used to analyse the influence of fixed PV panel tilt and azimuth angles, and extreme temperatures on PV harvesting performance and battery servicing life, respectively.

5.1. Impact of Photovoltaic Panel Orientation

As stated previously, the orientation and the site climatic conditions are the key parameters that account for the performance of solar PV systems. The Azimuth and tilt angles define the PV modules orientation and hence, are key factors that contribute to solar PV system performance. Proper orientation ensures that adequate quantity of sunlight falls on the PV modules, and the output depends on the amount of solar irradiation it receives. Therefore, for maximum performance of the system, PV modules are inclined at optimum Azimuth and tilt angles with respect to the site location. According to a study (Le Roux, 2016), the annual solar irradiation is about 10% more for optimally-fixed collectors and about 45% more for solar-tracking collectors (Le Roux, 2016). In this subsection, the flexibility of computer aided engineering (CAE) will be leveraged on, using PVsyst software programme to investigate the optimum orientation of the chosen site location.

Azimuth

To determine the optimal Azimuth, a constant latitude (30°) with a range of angles, from -100° through 100°, at an interval of 10°, as longitude were chosen. This implies that a constant tilt (30°) was used against varied Azimuth angles. The tilt angle of 30° was used because some previous studies suggested so (Le Roux, 2016; Suri, Cebecauer, Skoczek, & Betak, 2012).

The simulation result obtained from PVsyst, as presented in Fig 2, suggests that:

i. The points of least performance are at angles with the highest loss and lowest of global collection. These were recorded at -100° and 100° of about 0.88 transposition.

ii. The PV system performed best at point 0°, where the loss is zero, and the global collector and transposition are highest, as shown in Fig 4(b).

iii. The direction of the Azimuth does not influence the PV system performance; -100° and 100° have the same occurrences, likewise other angles.

The result is aligned with the previous studies (Barbón, Bayón-Cueli, Bayón, & Rodríguez-Suanzes, 2022; Oon, Tan, Wong, & Chong, 2020; Yadav, Panda, & Hachem-Vermette, 2020), which hold that the largest annual irradiation levels are obtained when the orientation of PV modules is due north of the Southern hemisphere where the Azimuth is 0°.

Tilt

The PV system performance result, corresponding to a constant Azimuth (0°) was reported. The range of chosen angles for the investigation of tilt influence on PV system performance is 0° through 90°, at an interval of 10°. The report obtained from PVsyst, shows that:

i. The highest and lowest GlobEff, occurred at tilt 40° and 90°, respectively, as shown in Fig 3(a).

ii. The highest and lowest E_Avail occurred at tilt 40° and 90°, respectively, as shown in Fig 3(b).

iii. The remaining energy (unused) after the user's need is highest and lowest at tilt angles 40° and 90°, respectively, as presented in Figs 3(b).

Where GlobEff is the effective global, optical losses (shadings, IAM, soiling) and E_Avail is the available solar energy.

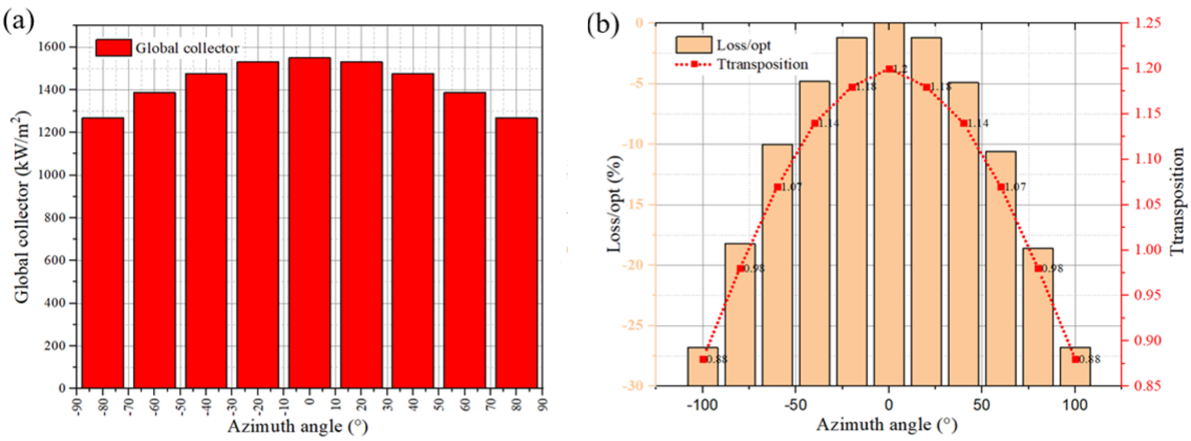

Fig 2. Effect of Azimuth angle

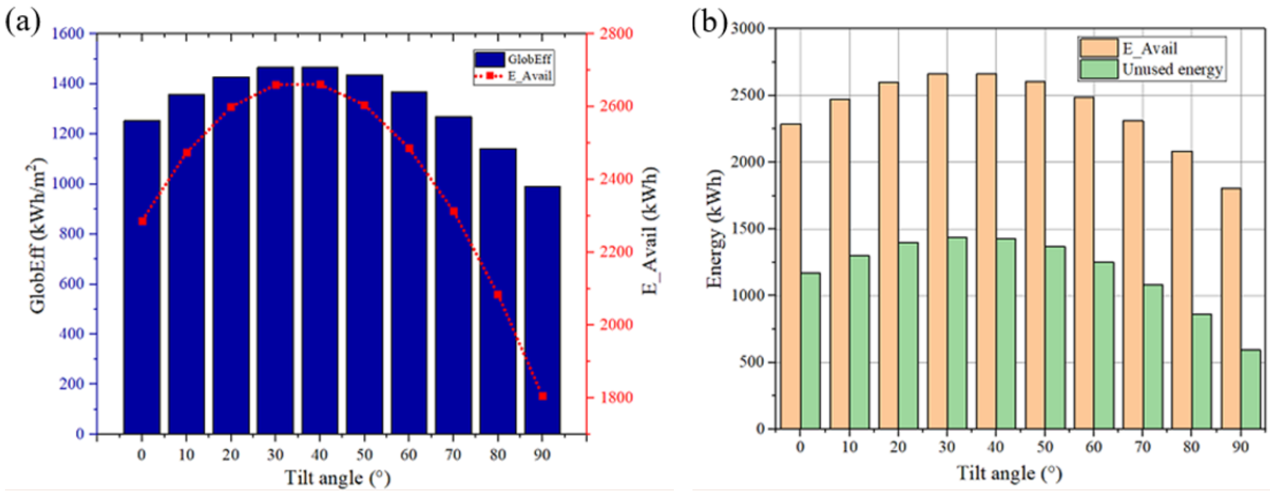

Fig 3. Effect of tilt angle on (a) effective global and (b) available solar energy

5.2. Effect of orientation on transposition factor and losses

The transposition is the irradiation gained or lost due to a tilted collector plane; hence, it is important in PV module orientation for optimisation purposes. This factor is influenced by PV module orientation (tilt and Azimuth), and consequently, it affects the energy production of solar PV modules. The highest transposition factor is in direct correlation with the orientation of the PV module that produces the highest incident irradiation. The transposition and loss of energy are functions of PV panel orientation (Azimuth and tilt). The simulation result obtained from PVsyst shows that:

i. Azimuth 0° produced the lowest energy loss (0%) and highest transposition (1.20), as presented in Fig 4(a).

ii. The lowest energy loss (0) and highest transposition (1.2) occurred at tilt angles 40°, as shown in Fig 4(b).

iii. The lowest transposition occurred at tilt angles 90°, as shown in Fig 4(b).

This result further demonstrates the influence of PV module orientation on the performance of PV system.

Further, the GlobalEff is impacted by both the Azimuth and tilt and are relative to optical losses. The results, as presented in Fig 5(a), shown that:

i. The roof fixed installation of solar PV system performed best at tilt 40°. In this context, 40°, which is about 6° lower than the site location latitude (46.20 °N), is the optimum tilt for the site. This agrees with and $\beta = \phi \pm 8$ (Yellott, 1975).

ii. At tilt 40° and Azimuth 0°, the highest available energy, specific energy, used energy, solar fraction, and lower lowest loss were recorded.

Additionally, the occurrences again support Azimuth 0° and tilt 40° as the optimum orientation of the site under investigation.

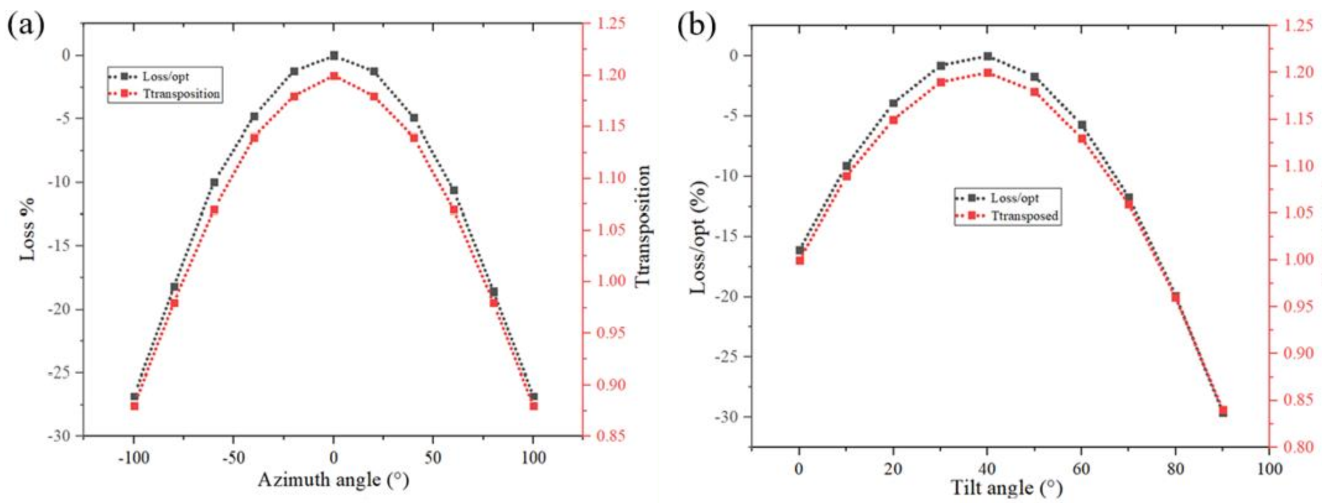

Fig 4. Effect of tilt angle on (a) loss and (b) transposition

Table 4
Summarised performance of the PV system

zimuth	Tilt	Available energy (kWh/year)	Specific energy (kWp/year)	Used energy (kWp/year)	Solar fraction (%)
0°	30°	2660	1267	1170	95.96
0°	40°	2662	1268	1218	96.31
100°	40°	2108	1004	1218	87.43

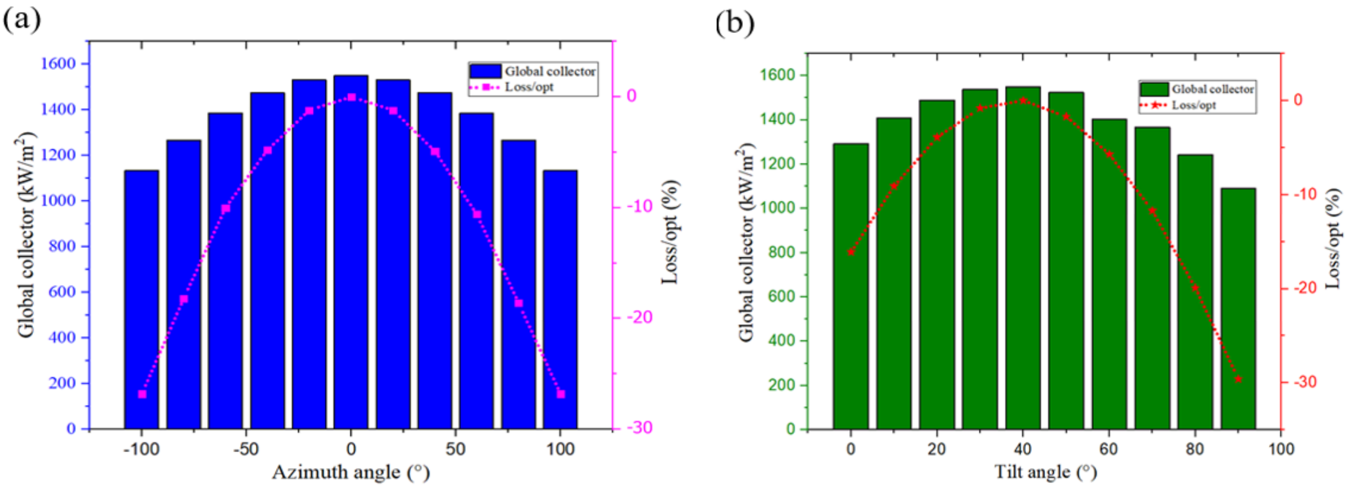

Fig 5. Effect of angle of (a) azimuth and (b) tilt on PV panel global collector and loss

From the summarised performance of the PV system, as presented in Table 4, the optimum PV module orientation components (Azimuth and tilt) values are 0° and 40°. This negates previous studies(Le Roux, 2016; Suri et al., 2012) that stated 0° and 30° for Azimuth and tilt, respectively.

5.3. Effect of temperature on battery performance

According to several literature, the solar battery service life is subjected to the ambient temperature of about 20° to 25° (Prine-Robie & Michael, 2020; Wu, Keil, Schuster, & Jossen, 2017). This was used to validate the influence of extreme temperatures (hot and cold) using PVsyst software and -20 °C to 20 °C was the range of temperature considered in an interval of 10 °C. The simulation result shows that the highest service life of 10 years for 800 Ah, lead-acid battery at ambient temperatures of -20° to 20°, was obtained as shown in Fig 6. The battery lifespan of 7 years, 3.7 years, 2 years, and a year was reported for ambient temperatures of 30 °C, 40 °C, 50 °C, and 60 °C, respectively. The very low lifespan observed in the ambient temperature of 60° shows the influence of elevated temperature on the service life of a battery. The obtained PVsyst simulation result for the battery, as shown in Figure 6, agrees with the previous studies (Sunmaster, 2019). Hence, extreme temperatures (hot and cold) should be factored in during design and operation planning processes because they influence battery performance. Battery attributes, such as safety, lifespan, and performance are affected by elevated temperature, which increases the chemical reactions that occur in a battery (Gabrisch, Ozawa, & Yazami, 2006; Kar & Evans, 2008; Markevich, Pollak, Salitra, & Aurbach, 2007)

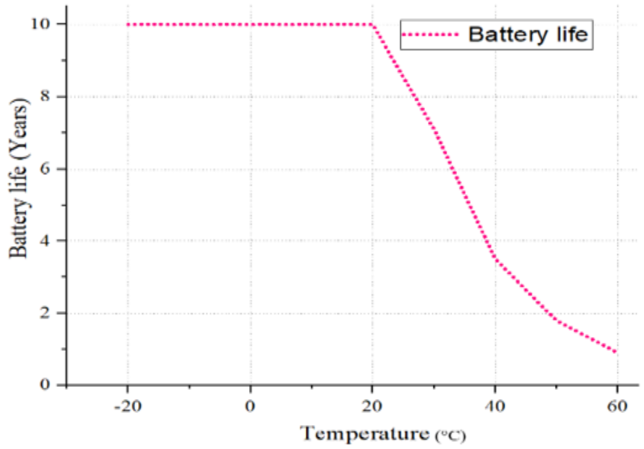

Fig 6. The effect of elevated temperature on battery service life

6. Conclusion

A solar PV system is installed with specified tilt and Azimuth angles depending on the site location. Several methods and models both empirical and theoretical have been proposed by authors for determining the optimum tilt angle. The models utilise similar techniques in determining the tilt concerning the site location latitude and, in some cases, the tilt is considered as the same as the latitude. In this study, PVsyst design and simulation software was used to design, simulate, and investigate the influence of tilt and Azimuth angles on the performance of a solar PV system. A site was hypothetically selected at Mountain Rise, Carrington Heights, Berea, KwaZulu-Natal, South Africa, a residential area, for this study. The study considered 0° to 90° and -100° to 100° as ranges of angle for tilt and azimuth, respectively, for a fixed PV panel roof mounting. The study observed that:

i. At tilt 40° and Azimuth 0°, the highest available energy, specific energy, used energy, and solar fraction; and lowest loss and transposition were recorded

ii. The longest battery service life was attained at an operating temperature between -2 °C to 20 °C.

The study then concludes that 0° and 40° are the optimum Azimuth and tilt angles, respectively, while running the storage system at a temperature, not more than 20 °C. This negates studies that have 0° and 30° for optimum Azimuth and tilt, respectively.

7. Further study

As an extension of this research, an empirical study is required to validate the presented results. This should involve the direct collection of data through measurement of outputs from a 6-kWp installed capacity of a monocrystalline silicon rooftop PV system at Mountain Rise, Carrington Heights, Berea, KwaZulu-Natal, South Africa.

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