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Ideal Tilt Angle of a Photovoltaic System to Enhance Sustainability of the Educational Buildings

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Abstract. Energy availability is essential for every growing country, including Pakistan, to maintain economic progress. To accommodate everyday needs, residential colonies and structures are growing daily. However, this growth is placing a strain on the power sector, which uses traditional sources of energy to generate power and pollutes the environment, contributing to Carbon Dioxide (CO_2) emissions and global warming. In order to run their everyday operations, buildings need electricity and energy from traditional energy sources, which pollutes the environment and contributes to the greenhouse effect. This article presents the design and construction of a cost-effective renewable energy alternative, together with a renewable energy solution for an educational building 6th Block in Institute of Southern Punjab (ISP) Multan, Pakistan's densely populated city of saints, to alleviate environmental pollution and promote sustainable development. The energy source that is growing the quickest around the globe is solar electricity. Geographic and climatic studies indicate that Pakistan has a great deal of potential for photovoltaic (PV) systems. The average sun irradiation on a solar plane surface is 5-6 kWh/m^2/day. Installed on building rooftops, solar power generation is an environmentally friendly and clean source of energy for autonomous, sustainable development. The optimal tilt angle for rooftop solar systems has also been designed and estimated, and performance ratios and losses have been examined using PVSyst modeling software. The simulated system took advantage of rooftop space and a grid-connected system to satisfy the highest demand, leaving adequate space for future system expansion to accommodate growing energy requirements. In order to receive the most solar radiation on the collector plane and produce the most energy with the least amount of module area, a suitable tilt angle is chosen for the summer is 10°-12°, and for winter is 47°-50°, to collect maximum solar irradiation. The analysis of performance ratios revealed that the highest Performance Ratio (PR) of 90.6% was obtained in January and the lowest PR of 82.3% was gained in May. Nonetheless, 85.7% is the average PR for institutional buildings. The reduced power capacity of the system is caused by many sorts of losses. The suggested power generation used a smart, sustainable solar system to generate clean, green energy, saving 10863.891 tons of CO_2 emissions. Using the same methods, proposed study will help reduce carbon emissions and electricity generation from traditional systems while creating and growing grid-connected photovoltaic systems for sustainable buildings worldwide.

Keywords: Building energy; Renewable; Sustainable development; CO_2 Emission; Environment friendly; Optimized Photovoltaic System; PVSyst.

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1. Introduction

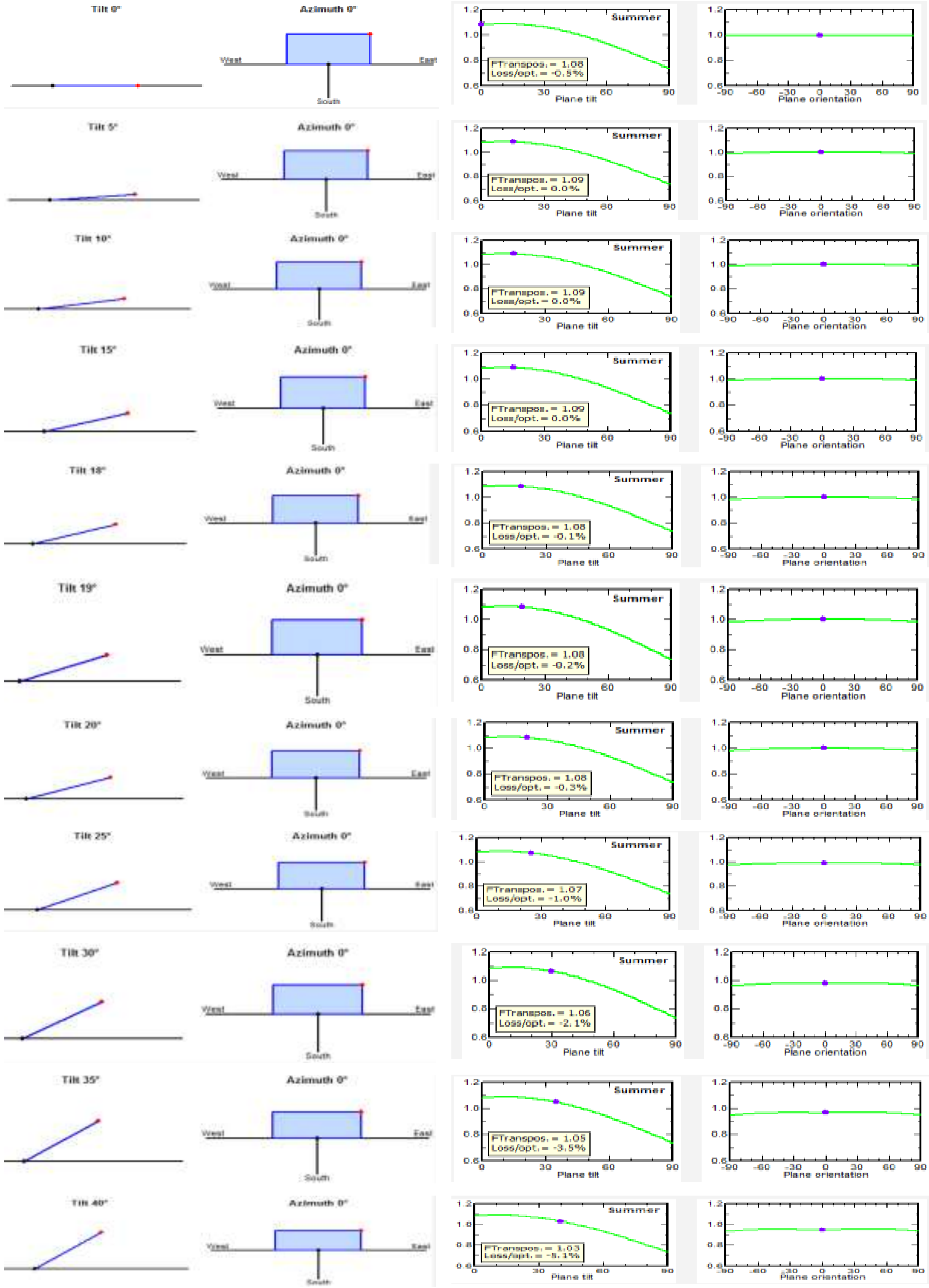
Because of its many advantages, solar energy is a sustainable energy source that is growing in popularity. It is a clean energy source that doesn't contribute to climate change or release any harmful emissions. The primary element in the process of capturing solar energy and turning it into electrical power is solar panels. The photovoltaic cells that make up these panels are responsible for converting sunlight into direct current (DC) power (Khan et al., 2016a). After that, an inverter is used to transform the DC electricity into alternating current (AC) electricity, which can then be utilized to run other electrical appliances and buildings. New and more effective solar panel types are being created as technology develops, increasing the affordability and accessibility of solar energy for both household and commercial usage (Khan et al., 2016b). Regardless of the kind of roof used in each application, solar panels can be put on a broad range of structures, including commercial, industrial, and residential buildings. Pitch roofs are frequently used for residential buildings due to their timeless and attractive appearance. Rainwater is effectively shed by these sloping roofs, avoiding water accumulation (Khan et al., 2023a). On the other hand, because they are more affordable and can accommodate rooftop installations such as air conditioning units, flat roofs are more popular in commercial structures. However, for adequate drainage, flat roofs need small slopes toward the center or borders, which means additional upkeep is needed to guarantee watertight seals (Khan et al., 2024). Both flat and pitched roofs offer advantages for industry buildings. Pitch roofs offer effective insulation and ventilation, whereas flat roofs enable large rooftop workstations and equipment installations. When thinking about installing solar panels, it's important to understand the different loadings that pitched and flat roofs are subject to. The maximum weight that the roof can sustain before failing structurally is known as the design load (Khan et al., 2023b). For instance, flat roofs have to support additional living loads like humans or High Voltage Alternating Current (HVAC) equipment, whereas sloping roofs are exposed to wind and gravity loads. Seeking advice from a structural engineer can help calculate the design load for a certain roof (Shafi et al., 2022a). A solar panel's load can change based on a number of variables, including its size, kind, and brand. Generally speaking, though, a regular 60 solar cell panel that is 1.7 square meters weighs around 18 kg, or 0.10 kN/m2, but a 72 solar cell module that measures 2.3 square meters weighs about 23.5 kg, or 0.10 kN/m2. The average load is usually 16 kg/m2, or 0.16 kN/m2, when the weights of the mounting framework, DC cabling, cable trunking, and other components are included. Because 60 solar cells panels are smaller and may be positioned more effectively on a home's roof, they are frequently employed in residential buildings (Shafi et al., 2022b). However, because 72 solar panels are around 35% larger than 60, it is more difficult to position them effectively on residential roofs. In addition to being heavier, they might be more difficult to handle and maneuver, which raises the cost of installation. As a result, commercial solar arrays and solar farms more frequently use 72 solar cell panels (Khan et al., 2022a) Financial Analysis of PV-Wind Cogeneration for a Remote Village in Gwadar-Pakistan. Southern Journal of Research, 2(2), 23-35. (Khan et al., 2022b). Financial Analysis of PV-Wind Cogeneration for a Remote Village in Gwadar-Pakistan. Southern Journal of Research, 2(2), 23-35 (Khan et al., 2022c). If solar panel installation on a roof is not adequately thought out, it might result in increased load and structural problems (Nasir et al., 2021). These structural problems may show themselves as roof cracks, sagging, bending, or even collapse. Therefore, in order to be sure that the roof can sustain the additional weight of the panels, it is essential to confirm the roof's structural capabilities prior to installing solar panels (Nazir et al., 2023). Techno-Economic and Environmental Perspectives of Solar Cell

Technologies: A Comprehensive Review. Energies 16, 4959. (Nazir et al., 2023). The roof of an industrial structure is already intended to support the live and dead loads, without taking into consideration the additional weight from the solar panels or the wind load. The weight of the steel plate, metal zinc, purlins, insulation materials, and other components contribute to the roof's approximate dead load of 25 kg per square meter, or 0.25 kN/m2. The Uniform Building By-Law (UBBL) states that the living load for both flat and sloping roofs up to 10° slopes is about 25 kg/m2 when access to the roof is restricted to maintenance (Khan et al., 2024). Even if the increased pressure from the solar panels does not cause the roof to collapse structurally, the 0.16 kN/m2 of additional loading will undoubtedly jeopardize the safety margin that was included into the design using the Eurocode or the BS Code. Reinforcing the roof structure may be required to prevent structural failure if the roof is unable to withstand even the unfactored loads (Khan et al., 2024a; Khan et al., 2024b; Khan et al., 2024c). This may entail rebuilding the entire roof structure, adding more supports, or strengthening the rafters or trusses. Serious repercussions may result from attempting to place solar panels on a roof without reinforcing if it is unable to sustain the added weight. There might be a roof failure that results in harm to people or property, or even fatalities. To determine the roof's design load and make sure it can sustain the increased weight of solar panels without jeopardizing the building's structural integrity, it is imperative to speak with a certified structural engineer (M. M. Khan et al., 2024a; M. M. Khan et al., 2024b) Current research with suitable tilt angle analysis will help to receive maximum solar irradiation in summer and winter throughout the year, and mostly there is interference of solar power generation due to the wrong tilt angle and shutting off the majority of appliances in buildings due to the wrong tilt angle mounted solar PV structure on the roofs of buildings.

2. Methodology

Due to increasing air conditioning and electric heater demands during extreme weather, Pakistan suffers an electrical issue. These peak loads disrupt the country's overall power and energy planning and result in load shedding. Reduced PV tilts increase summertime generation and lessen the need for interrow separation, allowing for the installation of more PV in smaller spaces. Installers frequently construct PV systems at high tilt, wasting a lot of space and necessitating more interrow distance. This also results in lower output during times of national electrical crisis. Thus, a reduced tilt strategy can aid in matching the pattern of power consumption with PV generation. In the current study, which was published in Energy for Sustainable Development, PV systems deployed in low- to mid-latitude regions with high summer load demand, such as Pakistan and sub-Saharan countries, typically have title angles equal to the latitude angle of the region in order to achieve the highest solar power generation yield. This study maximizes PV generation with lower tilt angles to meet high summer electricity demand on the Pakistani electricity grid. But while this orientation maximizes solar irradiance striking the PV plane of array (POA) in the winter, it comparatively reduces POA irradiance in the summer, which means that the fixed-tilt PV system produces less electricity during Pakistan's peak electricity demand period. Reduced PV tilt can boost power density and the plant ground covering ratio, which can have a bigger positive economic impact. In order to assess the performance of a 550 kW PV system for an educational facility in south Punjab, the team ran a number of simulations. It made use of Mateonorm-8.1 Database data on solar resources. Additionally, it made use of the PVSyst program to predict hourly energy production and evaluate the effects of inter-row shading and spacing on solar installation. According to the data, PV systems installed at a low tilt angle can generate more solar electricity in the summer.

A. *Ideal Tilt angle selection for Summer*



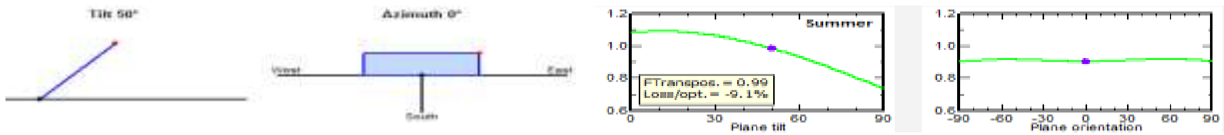


Figure 01: Tilt Angle calculation for Proposed system in Summer

B. *Ideal Tilt Angle selection for Winter*

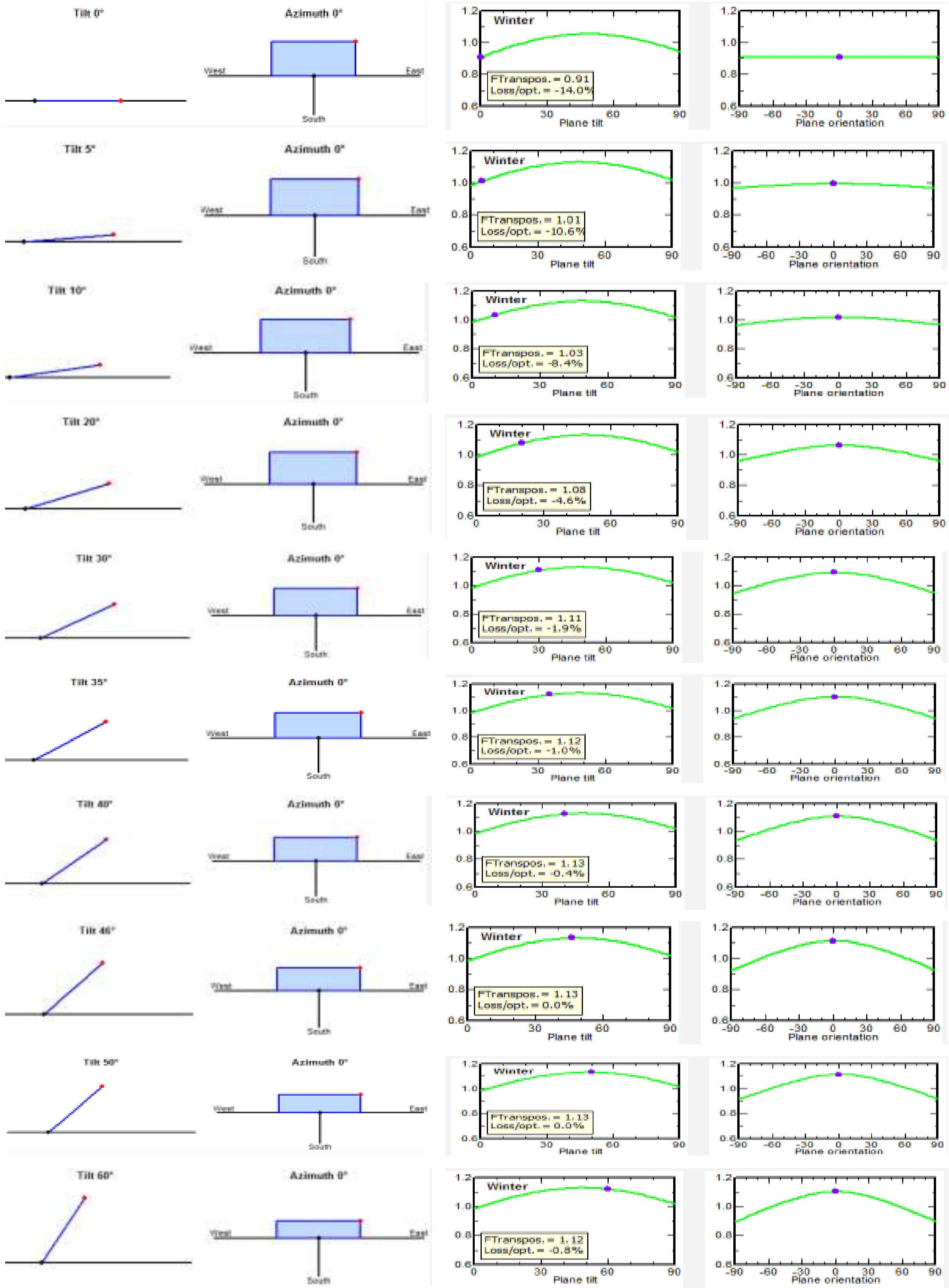


Figure 2: Tilt Angle calculation for Proposed system in Winter

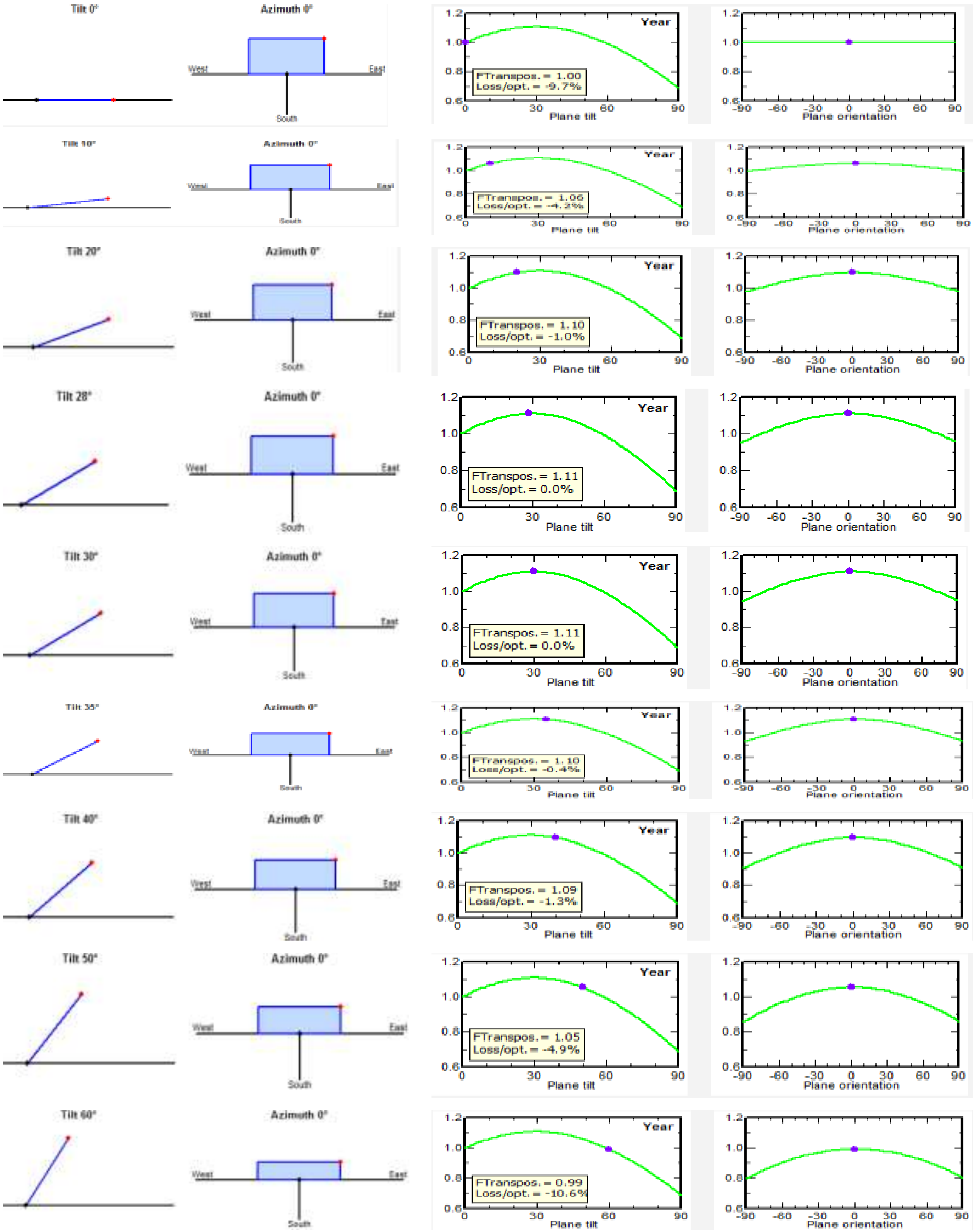


Figure 3: Annual Tilt Angle calculation for Proposed system

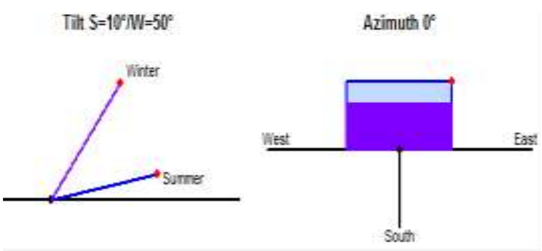


Figure 4: Proposed Tilt Angles for Rooftop Photovoltaic System

Table 01: Tilt Angle Summer Season (Apr-Sep)

Tilt angle in Summer	Transposition Factor (FT)	Optimum Loss	Global (kWh/m²)
0	1.08	-0.5%	1912
5	1.09	0.0	1922
10-12	1.09	0	1926
15	1.09	0	1924
17	1.08	0	1921
18	1.08	-0.1	1919
20	1.08	-0.3	1917
25	1.07	-1.0	1901
30	1.06	-2.01	1880
35	1.05	-3.5	1854
40	1.03	-5.1	1823
50	0.99	-9.1	1746

During example, when PV modules are tilted 10°–12° with regard to latitude tilt, the generation can reach up to 1926 kWh/m^2. However, when tilt angles are increased up to 50°, the amount of irradiation on the collection plane decreases and the recorded amount of energy during the summer season (April to September) is 1746 kWh/m2. pointing out that PV power output was higher in the late afternoon and early morning. Early April is when there is less of a yield improvement since electricity demand is lower. Additionally, they discovered that, in comparison to the latitude tilt angle in winter for the suggested geographical area, a 10°–12° tilt angle enhanced electricity generation by 6%.

Table 2. Yearly Tilt angle Variation

Tilt angle yearly	Transposition Factor (FT)	Optimum Loss	Global (kWh/m²)
0	1.00	-9.7%	1771
10	1.06	-4.2	1878
20	1.10	-1.0	1942
25	1.11	-0.2	1957
28-31	1.11	0.0	1961
35	1.10	-0.4	1954
40	1.09	-1.3	1936
50	1.05	-4.9	1866
60	0.99	-10.6	1754

Summertime collection plane irradiation reaches its peak for building energy at 10°–12°, approximately 1926 kWh/m2, and is thereafter lowered if the tilt angle increases to 50° or decreases to 0°. According to Table 1, the amount of radiation received by the collecting plane at 0° is 1912 kWh/m^2, and at 50°, it is 1746 kWh/m^2.

Table 3. Tilt Angle in Winter Season (Oct-Mar) for tilt plane

Tilt angle in Winter	Transposition Factor (FT)	Optimum Loss	Global (kWh/m²)
0	0.91	-14.0%	1605
5	1.01	-10.6	1788
10	1.03	-8.4	1832
20	1.08	-4.6	1907
30	1.11	-1.9	1961
35	1.12	-1.0	1980
40	1.13	-0.4	1992
46	1.13	0.0	1999
47-50	1.13	0.0	2000
55	1.13	-0.3	1994

Table 4: Main Results and Values

Months	Global Incident kWh/m²	Effective irradiation kWh/m²	Array Energy kWh	User Energy kWh	Solar Energy kWh	Sending to Grid kWh	From the Grid kWh	PR %
Jan	160.0	158.8	81369	89894	70561	9846	19333	90.6
Feb	153.8	152.2	76816	81194	65228	10670	15966	89
Mar	177.3	174.6	86337	89894	71075	14263	18818	86.8
Apr	189.4	186.1	89690	86994	71162	17476	15832	84.4
May	202.0	198.6	93302	89894	72128	20049	17766	82.3
Jun	192.8	189.5	89640	86994	69137	19417	17857	82.9
Jul	190.9	187.5	89612	89894	69209	19353	20685	83.7
Aug	191.8	188.5	90365	89894	71665	17628	18229	84
Sep	181.0	177.8	85771	86994	69499	15272	17495	84.5
Oct	180.2	178.1	86343	89894	72433	12860	17461	85.4
Nov	178.7	177.2	87806	86994	73468	13337	13526	87.6
Dec	153.4	152.2	77851	89894	68468	8469	21426	90.5
Year	2151.3	2121.1	1034902	1058427	844032	178639	214394	85.7

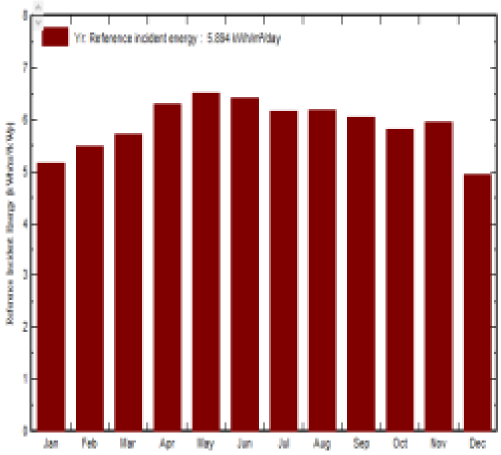


Figure 5. Incident energy for RTSPVS

After selecting a site for an educational facility in South Punjab, Pakistan, we used the PVSyst simulator to validate our planned PV system and determine the best position for solar power generation. According to the software's findings, reference incident energy is normally 5.894 kWh/m^2/day; however, because of high temperatures, which also elevate the temperature of the collecting plane, it is largest in May and lowest in January and December. This is seen in Fig. 5. The first computation of total losses included both the total energy produced and the excess energy added to the grid through a grid-tie system. As a result of the highest and lowest performance ratios (PR), Fig. 6 displays the RTSPVS loss diagram. While there are other losses that matter, these two losses significantly affect the performance ratio for a certain geographic location. The two losses that matter are the temperature-effect-related solar losses and the inverter loss during operation (efficiency). Therefore, temperature and light exposure directly affect photovoltaic cells, and the efficiency of inverters in converting DC power to AC power is an essential aspect of performance assessment. According to recent studies, the position and amount of solar radiation received on the horizontal collector plane affect the temperature-related PV loss. While the inverter efficiency for the suggested sites is measured at 1.2%, it is 9.8% for RTSPVS. Additionally, for the suggested RTSPVS, the conversion efficiency at standard temperature settings is 21.65%, and the rooftop site's total size is 2576 m2 for the 550 MWp RTSPVS. The total energy at array output in Fig. 6 is 1178 MWh/year. The total energy available at inverter output, after subtracting all losses, is 1023 MWh/year. Multan has the greatest potential for the planned solar power project, as evidenced by the above-given facts. All of this data is shown in Table 4.

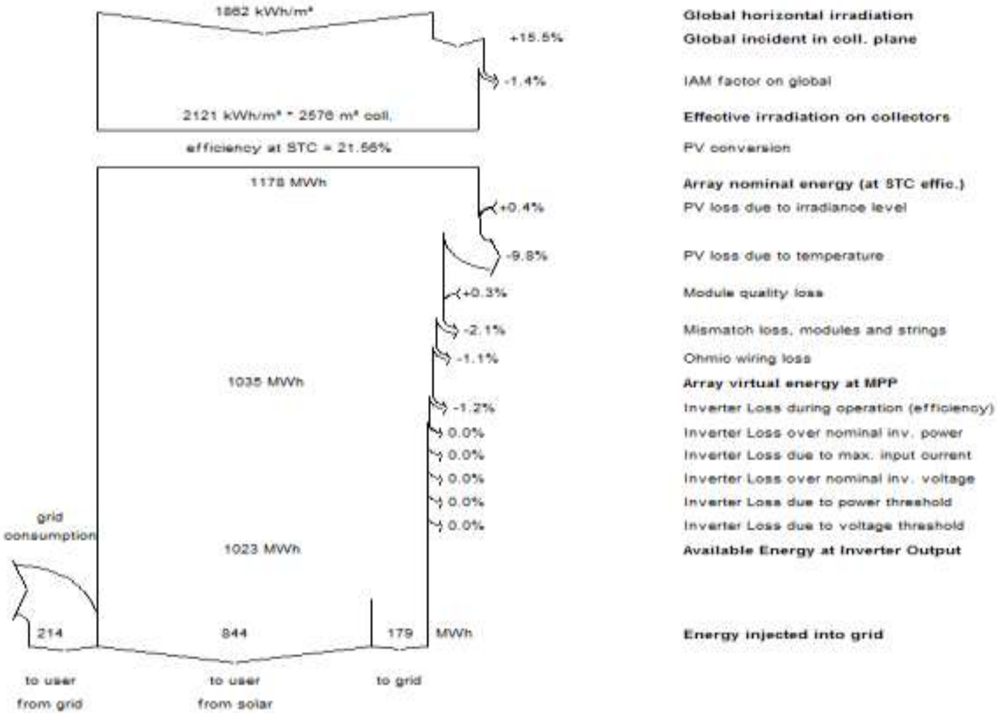


Figure 6: Loss Diagram for RTSPVS

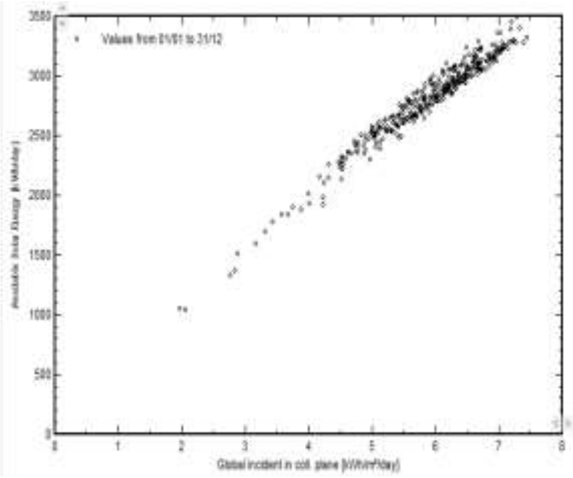


Figure 7. Daily Input and Output for RTSPVS

The amount of solar irradiation on the collection plane determines how much energy is injected into the grid; therefore, raising the value of worldwide incident irradiation on the collecting plane (kWh/m^2) on the x-axis also increases the amount of energy generated by the suggested PV system. Daily solar radiation intake on the solar cell's collector plane throughout the year causes fluctuations in energy output, and the amount of energy injected into the grid similarly fluctuates on the y-axis in response to sun irradiation.

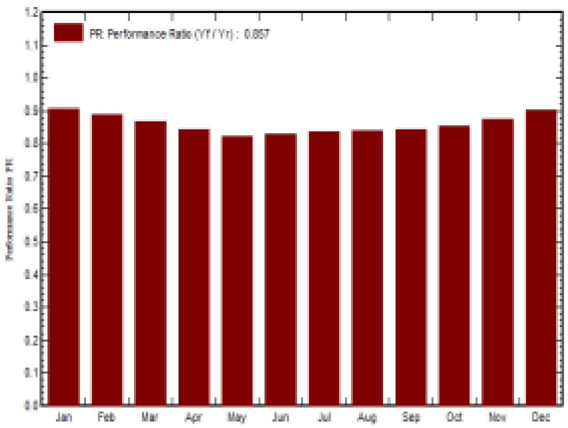


Figure 8. PR of RTSPVS

Figure 9 displays the RTSPVS performance ratio, which is 85.7% on an annual average and reaches its peak in December and January because of the cold weather. The temperature of the module rises along with the irradiance, which lowers the RTSPVS performance ratio and conversion efficiency.

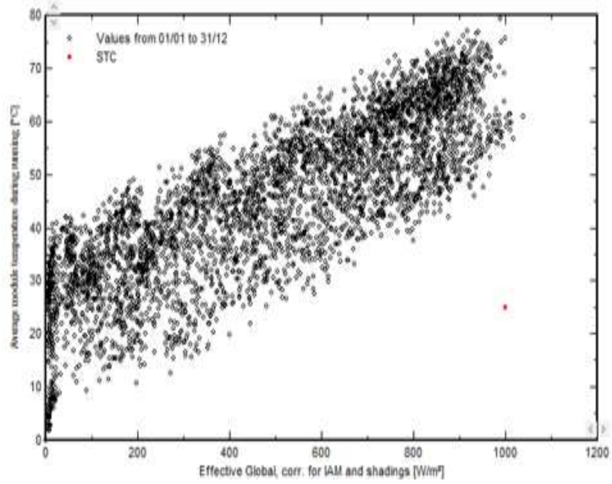


Figure 9. Temperature of Solar Module

Fig. 7 shows the daily input and output as well as the total solar radiation on the collecting plane on the x-axis and the daily energy injected into the grid (kWh/day) on the y-axis. For RTSPVS, the daily maximum energy delivery to the grid through the grid connection system is 2500 kWh.

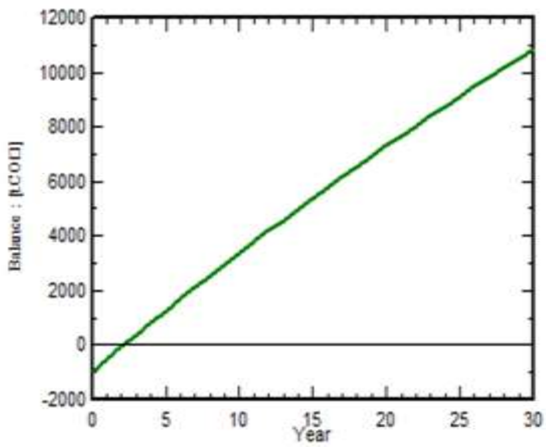


Figure 10. Saving CO_2 emission by installing RTSPVS

Fig. 10 shows the saved CO_2 emissions with the installation of RTSPVS. 10863.891 tons of CO2 emissions were reduced by the installation of photovoltaic systems in institutional buildings for 30 years, as depicted in Fig. 10 by using PVSyst simulation.

3. Conclusions

In conclusion, using solar panels to power buildings is an affordable and environmentally friendly option. However, it's crucial to take into account the building's roof type as well as the panels' weight before installing solar panels. A structural engineer should be consulted to make sure the roof is strong enough to sustain the extra weight of the solar panels. It is possible to guarantee a secure and fruitful solar panel installation for any type of building residential, commercial, or industrial by following these guidelines. According to current research, PV systems with low tilt angles might lessen reliance on pricey grid electricity during times of peak demand, in South Punjab Pakistan. Furthermore, a fixed-tilt PV system's power density may be raised by around 40% to 50% by using less tilt degrees, which would enable PV modules to be arranged more densely. According to the current analysis, lower tilts in summer and higher tilt angle in winters are more advantageous economically. Current research analysis shows that 10°–12° is the ideal tilt angle for sustainable educational buildings in the summer and receives higher global irradiation on the collector surface plane of a solar cell, which is 1926 kWh/m^2. In winter, PVSyst software calculates the ideal tilt angle for the ISP Multan educational building's geographic location to be between 46° and 51°, and the collector plane receives a global horizontal irradiation of 2000 kWh/m^2, which is the maximum irradiation for the specific educational building, 6th Block of ISP Multan. This research useful in converting conventional buildings into clean and green energy and saving the emission of CO_2 noticeably, that pollute our environment.

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