EuroSun2026

TECHNICAL-ENERGY ANALYSIS OF THE EXPANSION OF PHOTOVOLTAIC SYSTEMS INTEGRATED INTO A PUBLIC EDUCATIONAL INSTITUTION BUILDING LOCATED IN SOUTHERN BRAZIL USING ADVANCED SIMULATION

Summary

This study presents a technical–energy assessment of the expansion of photovoltaic (PV) systems integrated into a public educational campus located in Southern Brazil. Detailed simulations were performed using PVsyst® based on 12 months of measured electricity consumption data. Existing systems (59 kWp) and a proposed 29.75 kWp expansion were evaluated under real and optimized orientation scenarios. Vertical bifacial façade configurations exhibited energy yield reductions of up to 48% compared to ideal tilt conditions, whereas rooftop systems showed deviations below 10%. Despite geometric constraints, building-integrated photovoltaic (BIPV) systems in tropical latitudes remain energetically viable and architecturally advantageous.

Keywords: Public educational institution, distributed generation, bifacial modules, PVsyst.

Field of application for the findings: Grid-connected photovoltaic systems in institutional buildings.

Addressed audience: Students, researchers, and engineers in solar energy systems.

1. Introduction

Brazil recorded 14.3 GW of new photovoltaic installations in 2024, increasing the cumulative installed capacity to 52.2 GW, with distributed generation representing the largest share and more than 3.1 million grid-connected systems nationwide (ABRASOLAR, 2025). Public-sector initiatives have further expanded PV adoption in educational facilities, including more than 47 MWp installed in state schools in Bahia (SEC/Seinfra, 2025).

The rapid expansion of distributed PV generation reinforces the importance of building-integrated photovoltaic (BIPV) systems. In low-latitude regions, deviations from optimal tilt and azimuth angles may result in limited annual energy penalties due to the high contribution of diffuse solar radiation (Santos and Rüther, 2014). This study evaluates the energy performance of a PV expansion project combining bifacial modules installed on rooftops and fades, emphasizing architectural integration and performance ratio analysis.

2. Methodology

Electricity bills between April 2024 and April 2025 were analyzed to determine the average off-peak demand and the building's consumption profile. Based on these data, three existing PV generators totaling 59 kWp and a proposed 29.75 kWp expansion were assessed.

Energy modeling was carried out using PVsyst®, a widely adopted software for the simulation and performance analysis of grid-connected PV systems. The simulations were based on Typical Meteorological Year (TMY) data for the site, detailed electrical characteristics of modules and inverters, and the actual installation geometry.

The model incorporated comprehensive loss mechanisms, including thermal losses due to module operating temperature, DC and AC ohmic losses, mismatch losses (2%), light-induced degradation (LID, 2%), soiling losses (3%), annual module degradation (0.5%), and system unavailability (1%). Near and far shading effects were modeled using the software's 3D shading analysis tool.

Two scenarios were evaluated:

(i) Real configuration, representing the installed geometry, including architectural constraints, non-ideal orientation, and partial shading.

(ii) Optimized configuration, assuming north-oriented modules with tilt equal to local latitude and negligible shading, representing the maximum technical potential.

Performance indicators included specific yield (kWh/kWp·year), Performance Ratio (PR), capacity factor, system losses, and annual energy production. An economic analysis was also conducted using Net Present Value (NPV), Internal Rate of Return (IRR), and discounted payback period, considering the current Brazilian net-metering framework.

3. Results and Discussion

Table 1 summarizes the simulation results for the three PV generators, comparing the real installation with the optimized configuration (north orientation and latitude tilt).

Tab. 1: Photovoltaic System Performance Indicators (2025).

	Simulation results	**Ger1som**	**Generator 1**	**Ger2som**	**Generator2**	**Ger3som**	**Generator3**
Summary	Orientation	28/90 - 28/-90	28/0	28/-45	28/0	28/45	28/0
	Annual Energy Production (kWh/year)	46.871	60.165	44.562	49.666	6.085	6.741
	Average Monthly Energy Production (kWh/month)	3905,9	5013,8	3713,5	4138,8	507,1	561,8
	Performance Ratio (%)	72,96	81,05	73,74	79,30	71,75	76,28
Global Horizontal Irradiation	Global incident in coll. Plane	-5,60%	9,10%	5,20%	9,10%	4,70%	9,10%
	Near Shadings Irradiance loss	-6,64%	0,00%	-4,36%	-0,08%	-6,58%	-0,51%
	IAM factor on global	-3,02%	-2,60%	-2,52%	-2,60%	-2,20%	-2,59%
	Soiling loss factor	-3,00%	-3,00%	-3,00%	-3,00%	-3,00%	-3,00%
	PV Conversion (%)	19,54	19,54	19,21	19,21	20,31	20,31
Array nominal energy (at STC effic)	Module degradation loss (10 years)	-0,48%	-0,50%	-0,50%	-0,50%	-0,50%	-0,50%
	PV loss due irradiance level	-0,78%	-0,45%	-0,60%	-0,48%	-0,65%	-0,51%
	PV loss due temperature	-7,84%	-5,60%	-8,42%	-5,77%	-5,67%	-5,54%
	Spectral correction	0,11%	0,16%	0,15%	0,17%	0,13%	0,16%
	LID	-2,00%	-2,00%	-2,00%	-2,00%	-2,00%	-2,00%
	Mismatch loss, modules & strings	-3,35%	-3,35%	-3,35%	-3,26%	-2,97%	-2,70%
	Ohmic wiring loss	0,69%	0,74%	-0,50%	-0,50%	-0,15%	-0,15%
Array virtual energy at MPP	Inverter loss during operation (efficiency)	-1,64%	-1,60%	-2,20%	-2,09%	-5,17%	-4,95%
	Inverter loss over nominal inv. Power	0,00%	0,00%	-1,33%	-1,75%	-2,55%	-3,06%
	Inverter loss due to max. Input current	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Inverter loss over nominal inv. Voltage	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Inverter loss due to power threshold	-0,01%	0,00%	-0,01%	-0,01%	-0,03%	-0,02%
	Inverter loss due to voltage threshold	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Night consumption	-0,01%	-0,01%	0,00%	0,00%	0,00%	0,00%

	Available Energy at Inverter Output	47.570	60.791	45.137	50.208	6.167	6.835
	AC ohmic loss	-0,33%	-0,03%	-0,05%	-0,06%	-0,26%	-0,27%
	System unavailability	-1,44%	-1,00%	-1,22%	-1,02%	-1,08%	-1,11%
	Performance comparison	**22,10%**		**10,28%**		**9,73%**	

A significant increase in annual energy production was observed under optimized conditions. Generator 1 increased from 46,871 kWh to 60,165 kWh (+22.10%), Generator 2 from 44,562 kWh to 49,666 kWh (+10.28%), and Generator 3 from 6,085 kWh to 6,741 kWh (+9.73%).

The Performance Ratio also improved consistently, reaching 81.05%, 79.30%, and 76.28% for Generators 1, 2, and 3, respectively. In the real configuration, the main loss contributors were near shading (up to -6.64%), temperature losses (up to -8.42%), and mismatch losses (up to -3.35%). Inverter losses ranged from -1.60% to -5.17%, while AC ohmic losses remained below 0.33%.

These results demonstrate that geometric and shading constraints may reduce annual energy production by up to 22%, highlighting the importance of detailed orientation and shading analysis during the design phase.

4. Conclusions

The findings confirm that geometric configuration and shading conditions exert a direct and significant influence on the energy performance of grid-connected photovoltaic systems integrated into institutional buildings. The comparison between real and optimized scenarios demonstrated annual generation gains of up to 22% and consistent improvements in Performance Ratio, highlighting that architectural constraints may substantially limit solar potential utilization. Thermal, shading, and mismatch losses were identified as the primary contributors to performance reduction. Therefore, comprehensive technical assessment during the executive design phase - including orientation, tilt, and shading studies - is essential to maximize energy productivity and enhance the technical-economic viability of photovoltaic systems in educational buildings located in low-latitude regions.

5. References

ABRASOLAR (2025). Brazilian Photovoltaic Solar Energy Report 2024/2025. Brazilian Photovoltaic Solar Energy Association, São Paulo, Brazil.

Santos, I.P.; Rüther, R. (2014). The effect of shading on building-integrated photovoltaics in low-latitude regions. Solar Energy, 102, 241–253.

Secretariat of Education of the State of Bahia – SEC/Seinfra (2025). Implementation Program of Photovoltaic Systems in Public Schools. Salvador, Brazil.

PVsyst SA (2024). PVsyst Photovoltaic Software – Version 7 User Manual. Geneva, Switzerland. Reference