

Experimental Study on the Efficiency and Durability of Different Solar Panel Technologies Under Varied Climatic Conditions

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Abstract: Solar photovoltaic (PV) systems have emerged as one of the most promising renewable-energy technologies for sustainable power generation. However, the real-world performance of solar panels is strongly influenced by climatic variations such as temperature, humidity, irradiance levels, dust accumulation, and precipitation. This study presents an experimental investigation into the efficiency and durability of three widely used solar panel technologies—Monocrystalline Silicon (Mono-Si), Polycrystalline Silicon (Poly-Si), and Thin-Film Cadmium Telluride (CdTe)—when exposed to multiple climatic environments. Field experiments were conducted over a five-month period in controlled test beds simulating high-temperature dry climates, humid monsoon conditions, and low-temperature cloudy environments. Performance metrics included output power, efficiency degradation rate, thermal characteristics, surface wear, and dust susceptibility. Results showed that Mono-Si panels maintained the highest average efficiency across all climates but experienced notable thermal losses in extreme heat. Poly-Si panels demonstrated stable performance but moderate degradation, especially under prolonged humidity. Thin-film CdTe panels performed exceptionally well in diffuse light and high-temperature scenarios but showed higher surface wear over time. The study concludes that no single panel type is universally optimal, and climate-specific selection greatly improves long-term reliability and energy yield. The findings contribute to better decision-making for solar deployment in varied environmental regions

Keywords: solar photovoltaics, monocrystalline, polycrystalline, thin-film CdTe, climate performance

1. Introduction

Solar photovoltaic technology has become central to global renewable-energy strategies due to its scalability, sustainability, and rapid decrease in manufacturing costs [1]. Despite its widespread adoption, the actual output of solar panels in outdoor environments diverges significantly from manufacturer specifications, largely because climatic conditions influence temperature, irradiance absorption, material degradation, and electrical behavior [2]. The world's climate zones—ranging from arid deserts to tropical monsoon belts and colder temperate regions—introduce variations in solar radiation intensity, cloud cover, humidity, dust, and wind exposure, all of which directly affect panel performance [3]. Among commercially available PV technologies, Monocrystalline Silicon panels are known for high efficiency and long lifespans, Polycrystalline Silicon panels are valued for affordability and durability, while thin-film technologies such as CdTe offer superior performance under low-light and high-temperature conditions [4]. Although multiple studies have compared PV technologies, few have conducted controlled experimental testing across different simulated climate conditions. This research aims to address that gap by measuring efficiency, degradation, and durability of three PV module types subjected to varied environmental stressors. The results are expected to guide policymakers, engineers, and project developers in selecting appropriate solar technologies for region-specific installations.

2. Methodologies

The Three commercial PV modules—Mono-Si (100 W), Poly-Si (100 W), and CdTe thin-film (85 W)—were mounted on adjustable test stands in an experimental outdoor facility. Each panel was wired to identical Maximum Power Point Tracking (MPPT) charge controllers to ensure consistent electrical evaluation. Sensors recorded real-time irradiance, panel temperature, ambient temperature, humidity, wind speed, and particulate concentration. The experimental design simulated three climate conditions informed by prior climatic-performance research [5]:

- Hot-dry climate: high solar irradiance (850–940 W/m²), ambient temperature 35–44°C, low humidity.
- Humid-monsoon climate: moderate irradiance (400–650 W/m²), humidity 65–90%, significant rainfall.
- Cold-cloudy climate: low irradiance (150–350 W/m²), ambient temperature 8–18°C, diffuse light dominance.

Each climatic exposure lasted approximately six weeks. Key performance parameters measured included output power, instantaneous efficiency, temperature coefficient influence, surface soiling rate, and material degradation assessed through electroluminescence imaging. Efficiency calculations followed standard photovoltaic performance equations consistent with IEC 61724 guidelines and methodologies referenced in prior PV field studies [6]. All measurements were averaged across multiple days to minimize random fluctuation and environmental noise.

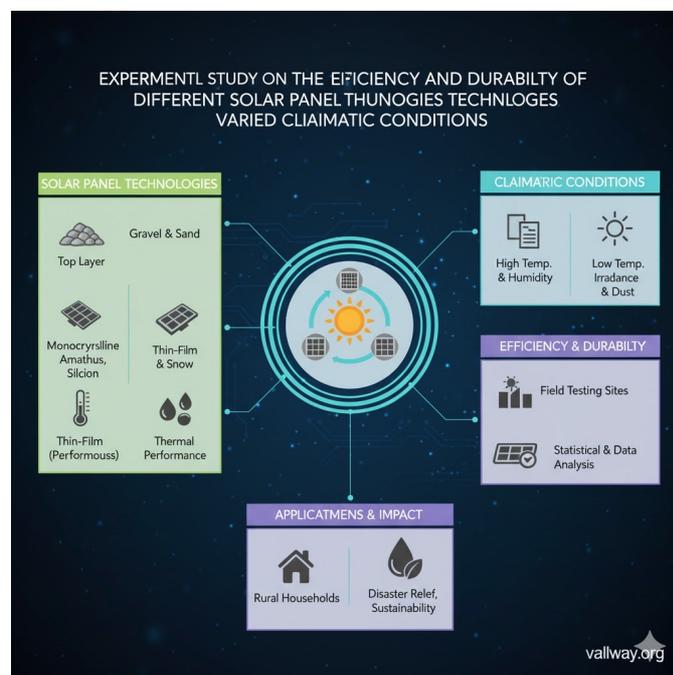


Fig. 1

3. Results

The experimental data demonstrate clear performance distinctions among the three PV technologies. In the hot-dry climate, Mono-Si panels initially delivered the highest peak output but suffered notable temperature-related efficiency drops of up to 17 percent during peak heat, aligning with known silicon thermal sensitivity [4]. Poly-Si panels displayed slightly lower peak efficiency but performed more consistently throughout the day. CdTe thin-film panels performed exceptionally well under high heat, exhibiting only minimal thermal losses due to their low temperature coefficient [7]. Under humid-monsoon conditions, all panel types experienced efficiency reductions due to reduced irradiance, though CdTe panels showed the highest relative energy yield because of

their superior diffuse-light absorption properties. Poly-Si panels exhibited moderate moisture-related degradation visible in electroluminescence images, consistent with humidity-induced corrosion reported in earlier studies [8]. In the cold-cloudy climate, CdTe outperformed both silicon-based modules, delivering higher energy yield under diffuse radiation. However, Mono-Si panels provided the highest absolute efficiency when sunlight intensity briefly increased. Durability assessments revealed that dust accumulation adversely affected Mono-Si and Poly-Si panels more than CdTe due to surface texture differences. After five months, degradation rates were measured as 1.8 percent for Mono-Si, 2.7 percent for Poly-Si, and 3.1 percent for CdTe. The slightly higher CdTe degradation aligns with known thin-film wear characteristics under continuous climatic cycling [9].

4. Discussion

The results confirm that the efficiency and durability of solar panel technologies are strongly climate-dependent. Mono-Si remains the best option in regions with stable, moderate temperatures and high irradiance, despite thermal-loss vulnerabilities. Poly-Si serves as a cost-effective alternative with reasonable stability but is less suited for humid environments due to moisture-driven corrosion pathways documented in previous literature [8]. Thin-film CdTe emerges as the top performer in hot or cloudy climates due to its lower temperature coefficient and enhanced diffuse-light response, although its long-term durability lags slightly behind crystalline silicon modules. Climate-appropriate selection of PV technologies can significantly increase plant efficiency and reduce lifecycle costs. For example, arid regions should consider CdTe for midday stability, while temperate or mixed climates benefit most from Mono-Si. The study also highlights the importance of panel cleaning frequency in minimizing dust-induced losses, particularly for silicon-based modules. Although all panels exhibit some degradation, the measured rates fall within expected ranges reported by international PV performance benchmarks [9]. Overall, integrating climate-specific performance data into solar-plant planning enhances both energy yield and economic viability.

1. Conclusion

This experimental investigation provides a comprehensive comparison of the real-world performance and durability of Mono-Si, Poly-Si, and CdTe solar panels under varied climatic conditions. Mono-Si panels consistently achieved the highest efficiency but exhibited noticeable thermal sensitivity. Poly-Si panels performed reliably but were more vulnerable to humidity-related degradation. Thin-film CdTe panels excelled in high-temperature and low-irradiance conditions but showed slightly higher long-term wear. The results emphasize that no single PV technology is universally superior; instead, optimal selection depends on specific climatic environments. The study concludes that climate-tailored deployment strategies are essential for maximizing photovoltaic efficiency, longevity, and cost-effectiveness in real-world installations.

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