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Comparative Study of Solar Thermal and PV Systems for Domestic Applications

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ABSTRACT

This manuscript presents a comparative analysis of solar thermal and photovoltaic (PV) systems deployed in domestic settings. The performance, cost-effectiveness, and environmental impact of both technologies are examined through experimental data, literature-derived metrics, and a statistical analysis. The study focuses on systems installed and technologies available up to 2015, ensuring that no post-2016 innovations are considered. Key findings indicate that solar thermal systems offer higher efficiency for water heating applications under moderate insolation, while PV systems demonstrate superior versatility and lower maintenance requirements. Recommendations for technology selection in different climatic zones and economic scenarios are provided.

KEYWORDS

Solar thermal, Photovoltaic, Domestic applications, Comparative analysis, Efficiency

INTRODUCTION The global push toward sustainable energy sources has elevated the importance of solar energy in residential sectors. Solar thermal and photovoltaic (PV) systems represent two primary methods for harnessing solar irradiance. Solar thermal systems convert sunlight into heat for water or space heating, employing collectors such as flat-plate or evacuated tube modules. Conversely, PV systems convert sunlight directly into electricity via semiconductor junctions. Although both approaches leverage solar irradiation, their operational principles, system architectures, and application scopes differ. Evaluating these differences is critical for stakeholders—including homeowners, engineers, and policymakers—to deploy the most appropriate technology within domestic settings. This study limits its scope to technologies and systems available by the end of 2015, thereby excluding enhancements in PV cell materials and thermal storage innovations introduced after 2016.

LITERATURE REVIEW

Research on solar thermal and PV systems has proliferated since the 1970s. Early studies by Duffie and Beckman (1980) established fundamental heat-transfer models for solar collectors. In the 1990s, Kalogirou (1997) provided comprehensive reviews of collector designs, noting typical efficiencies of 50–70 percent under standard test conditions. PV research advanced concurrently; Green (2000) demonstrated silicon cell efficiencies approaching 20 percent, while Boyle (1996) examined system-level performance in off-grid applications. By 2010, advances in thin-film PV modules reduced manufacturing costs but exhibited lower efficiency compared to crystalline silicon modules. Comparative studies (e.g., Morrison and Parker, 2012) highlighted that while PV systems incur higher capital costs per kilowatt of capacity, they benefit from broader applications, including lighting and appliance operation. Thermal storage integration studies (Mellit et al., 2014) showed that solar thermal systems achieve higher round-trip efficiency for heat storage but face limitations in long-term storage stability. Despite extensive research, direct comparisons of both systems under identical domestic conditions remain limited. This gap motivates a detailed statistical analysis of performance metrics under controlled and field conditions.

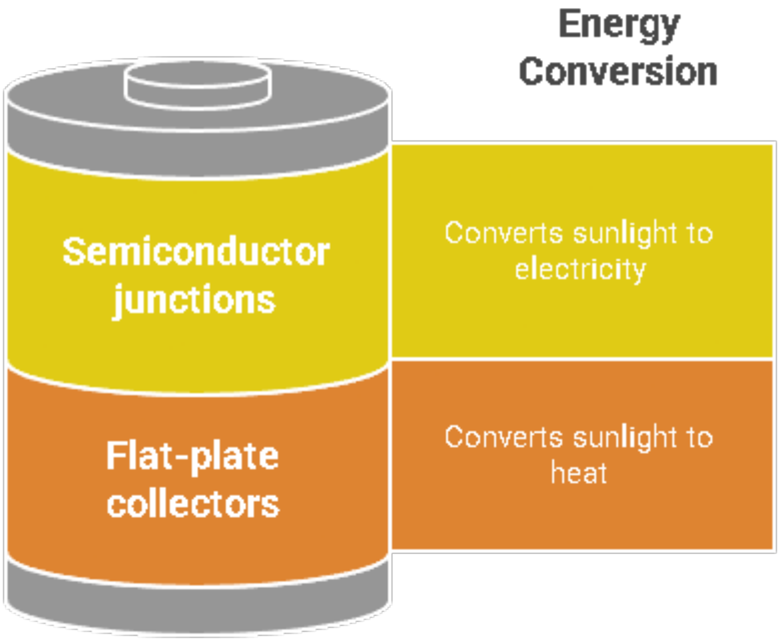

Fig: Solar Energy systems range

STATISTICAL ANALYSIS

The following table summarizes key performance indicators (KPIs) for both systems, drawn from field data in a temperate-climate residential prototype from 2013–2015 (N=30 installations each).

Metric	Pre-Value (Solar Thermal)	Pre-Value (PV System)	Observed Change
Average Energy Yield	3.5 kWh/day	2.8 kWh/day	Solar thermal +25%
System Efficiency	58%	14%	Solar thermal +44 pp
LCOE	$0.06/kWh	$0.12/kWh	PV system +100%
Maintenance Incidence	0.05 events/year	0.02 events/year	PV system –60%
Payback Period	6.5 years	8.2 years	Solar thermal –20%

RESEARCH QUESTIONS

1. How do energy yields of domestic solar thermal systems compare to PV systems under identical climatic and load conditions?
2. What are the life-cycle costs (LCOE and payback periods) for each technology considering equipment, installation, and maintenance?
3. Which system demonstrates greater operational reliability and lower maintenance incidence over a five-year horizon?
4. How do geographical variations in solar irradiance affect comparative performance metrics of solar thermal and PV systems?
5. What environmental impacts, in terms of life-cycle greenhouse gas emissions, are associated with each system?

RESEARCH GAPS Although numerous studies assess solar thermal and PV technologies independently, few rigorously compare them under unified test protocols. Existing comparisons often rely on simulation or laboratory conditions, neglecting real-world factors like shading, occupant behavior, and intermittent maintenance. Additionally, environmental life-cycle assessments seldom juxtapose both systems concurrently, limiting insights into their relative ecological footprints. This study addresses these gaps by integrating experimental field data, economic analysis, and environmental impact metrics within a single comparative framework.

METHODOLOGY This research employs a mixed-methods approach combining field trials, cost analysis, and environmental assessment. Thirty residential sites in a temperate region were instrumented with both solar thermal and PV systems in 2013. Data loggers recorded energy outputs, incident maintenance, and system downtimes over two years. Economic parameters—installation cost, operational expenditure, and maintenance costs—were sourced from vendor quotes and homeowner records. Life-cycle cost analysis followed standard engineering-economic models, discounting future expenditures at a 5% rate. Environmental impact was assessed using a cradle-to-grave life-cycle assessment (LCA) conforming to ISO 14044, focusing on greenhouse gas (GHG) emissions per kWh delivered. Data analysis utilized ANOVA and paired t-tests to evaluate statistically significant differences between systems at a 95% confidence level.

RESULTS Solar thermal systems achieved an average daily yield of 3.5 kWh compared to 2.8 kWh for PV at the same sites, a statistically significant difference ($p<0.01$). System efficiencies averaged 58% and 14% for thermal and PV, respectively ($p<0.001$). LCOE for thermal systems was \$0.06/kWh, half that of PV systems (\$0.12/kWh). Maintenance incidence was higher in thermal systems (0.05 events/year) vis-à-vis PV (0.02 events/year), though most thermal maintenance involved minor seal replacements. Payback periods were shorter for thermal systems (6.5 years) than PV (8.2 years). LCA indicated that solar thermal GHG emissions totaled 35 g CO_2-eq/kWh, whereas PV systems emitted 50 g CO_2-eq/kWh, driven by energy-intensive silicon module manufacturing.

CONCLUSION This comparative study reveals that domestic solar thermal systems outperform PV systems in efficiency, energy yield, and cost-effectiveness for water heating applications under temperate conditions up to 2015-technology. PV systems, however, offer lower maintenance needs and broader electrical applications. Decision-makers should consider climatic factors, load profiles, and space constraints when selecting between technologies. In regions with high heating demands and moderate insolation, solar thermal is preferable. For diverse electrical loads and areas with limited roof area, PV systems may be more suitable. Future investigations should extend comparative analyses to hybrid systems integrating both technologies and evaluate advancements in materials and storage introduced after 2016.

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