INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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Thesis Title: Performance Evaluation of a Building Integrated Semi-Transparent Photovoltaic Thermal (BiSPVT) Facade

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SHORT ABSTRACT

The 21st century is marked by unprecedented challenges including climate change, environmental degradation, and the widening gap between growing energy demand and its sustainable supply. Rapid urbanization, population growth, and accelerated economic development have placed immense strain on global energy systems, with the building sector emerging as a major contributor. Buildings currently account for 30% of global final energy use and about 34% of greenhouse gas emissions. This intensifies global warming and its consequences underscoring the urgent need for energy transition strategies centered on decarbonization. Renewable energy, particularly solar, offers a strong solution due to its abundance, inexhaustibility, and compatibility with decentralized building-scale applications.

Within this context, Building Integrated Photovoltaic Thermal (BIPVT) systems have gained prominence by embedding photovoltaics into building envelopes to provide on-site electricity while harvesting thermal energy. A key limitation of conventional PV modules is their temperature dependence: as cell temperature rises, resistive losses increase and voltage output decreases, reducing efficiency. To sustain performance, heat must be extracted when integrated into BIPVT facades, this recovered heat can be repurposed for services such as space heating. Semi-transparent facade-based BiSPVT systems address this dual challenge by improving PV efficiency and supplying usable thermal energy, making them highly suitable for cold climates. However, research to date has paid limited attention to the combined performance, lifecycle sustainability, and optimization of such systems under variable weather. This thesis responds through a comprehensive assessment of a ventilated semi-transparent BiSPVT facade for Srinagar, India.

The study employs a detailed numerical modeling and simulation framework to evaluate annual energy, exergy, and thermal performance. A one-dimensional thermal model was developed using geometric design parameters, meteorological data, and solar incidence calculations for a vertical south-facing surface via the Liu and Jordan method. Heat transfer coefficients and thermal balances were then estimated to determine module temperature profiles, outlet fluid temperature dynamics, and indoor room air temperature across four weather types: clear, hazy, hazy and cloudy, and cloudy, representative of real local climatic conditions.

Results show significant performance benefits of the BiSPVT system. Annual outputs included 121.22 kWh/m^2 of electricity, 366.23 kWh/m^2 of thermal energy, and 122.36 kWh/m^2 of useful exergy. Seasonal variations highlighted October as the peak month due to favorable solar radiation and ambient conditions. The ventilated cavity reduced PV overheating while delivering heating benefits indoors, maintaining indoor–outdoor temperature differences up to 12.83°C. The overall effective optical efficiency was 78.3% with a heat loss coefficient of 1.422 W m^{-2} K^{-1}, demonstrating robust thermal management. Exergoeconomic and enviroeconomic analyses confirmed long-term viability. Over a 30-year lifetime at 4% interest, the BiSPVT facade achieved minimal energy and exergy loss ratios, ensuring cost competitiveness against grid electricity. The uniform annualized cost (UAC) was 0.031 $/kWh for thermal and 0.09-0.16 $/kWh for exergy, competitive with current tariffs. Energy Payback Times were 3.2 years (thermal) and 9.8 years (exergy), while Greenhouse Gas Payback Time was 2.5 years, confirming both economic feasibility and sustainability.

From an environmental perspective, the system reduced CO_2 emissions by 2.81 tonnes annually, equivalent to over $40 in avoided costs. Life cycle assessment revealed PV modules and steel framing as major contributors, but total system impact was limited to 0.98 t CO_2- equivalent/m^2, aligning with international benchmarks. Sensitivity analysis further showed that amorphous-Si panels had the lowest overall environmental impact, while single-Si exhibited the highest. These results guide sustainable material choices for building-integrated applications.

The broader significance of this research extends beyond technical optimization. By demonstrating dual benefits of on-site electricity and thermal recovery in cold climates, it positions BiSPVT facades as multifunctional building skins for net-zero architecture. Methodologically, it establishes a replicable framework combining energy, exergy, economic, and life cycle assessment. More broadly, it contributes to global climate action by addressing one of the highest energy-consuming sectors. BiSPVT facades decentralize power generation, reduce grid dependency, enhance energy security in underserved regions, and directly support the United Nations Sustainable Development Goals (SDGs).

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