Honors Thesis

Master's Degree Architecture for Sustainability.

Abstract

Dynamic and Adaptive Photovoltaic Shading Systems: Design and Architectural Integration for Energy Production and Indoor Comfort.

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Buildings play a major role in climate change, accounting for approximately one-third of the world's energy consumption and emitting nearly one-quarter of its carbon dioxide. While over 40% of heat loss and gain of the buildings occurs through facades. This study evaluates Dynamic and Adaptive Photovoltaic Shading Systems (DAPVSS) as a dual-purpose solution that integrates renewable energy generation with responsive environmental control.

This research addresses a critical gap between implementation of current shading systems with photovoltaic technologies and occupant comfort. That is done by a comprehensive performance analysis across multiple parameters and aspects.

In this study, six different shading systems were systematically evaluated by using advanced computational tools, including Rhino, Grasshopper, ClimateStudio, and Ladybug Tools. In order to achieve the best result, DAPVSSs were assessed in energy generation (kWh/year), thermal comfort (PMV/PPD), daylight performance (DF/DA), and glare control (DGP) across three orientations (south, south-east, and south-west) throughout a full year in Turin, Italy.

The mentioned systems are categorized from a simple folding mechanisms (Design 1) to a complex hybrid grid system (Design 6). These systems incorporate amorphous photovoltaic technology with power optimizers in order to maximize the efficiency despite the partial shading conditions.

In terms of architectural integration, the study established a guideline for various building typologies: simple folding mechanisms that are suitable for residential applications, while complex designs are ideal for commercial and landmark buildings because they require both performance and aesthetic integration. Moreover, for assessment of the financial feasibility of these systems, a detailed economic assessment (energy production, installation costs, and payback periods for each design) was conducted.

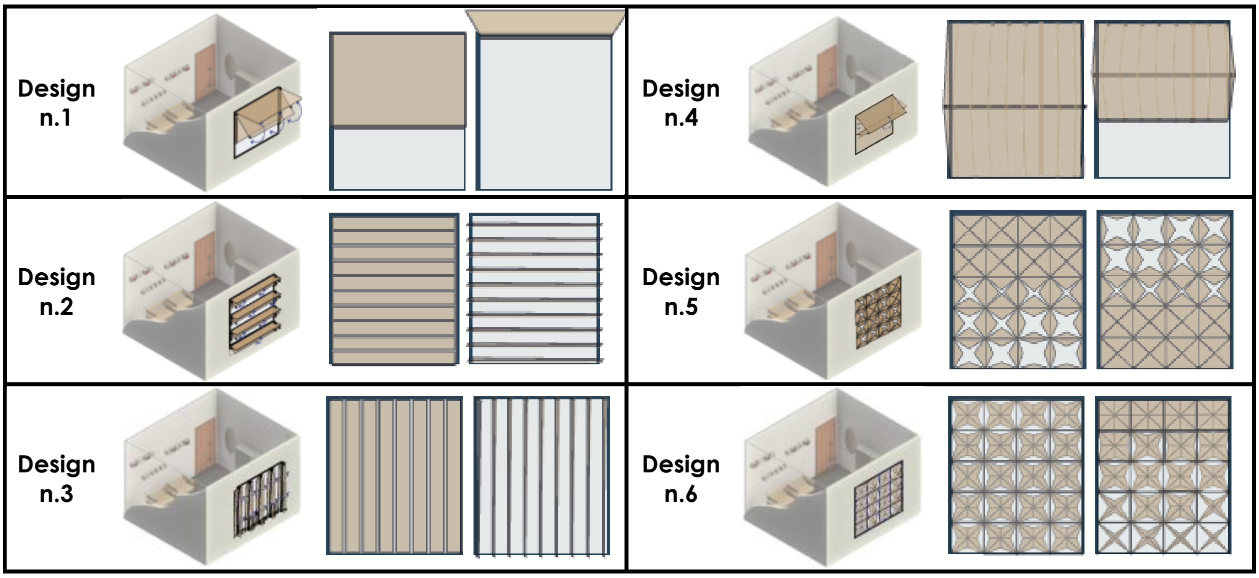

Figure 1 Design systems

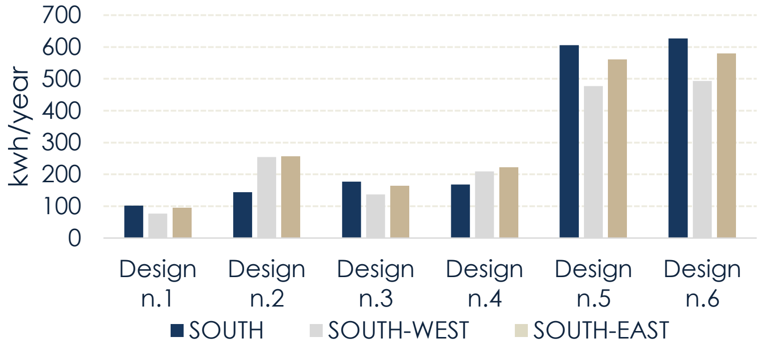

Figure 2 Energy Production

Key Performance Results

• Energy Production: Design 6 outperformed all others, at 1000+ kWh annually in all orientations.

• Thermal Comfort: The complex designs (5&6) obtained 88-90% comfort hour of 60-70 percents for simpler designs.

• Glare Control: Design 6 reached DGP values of 0.17–0.22 (below barely noticeable threshold: 0.35).

• Economic Viability: Commercial designs showed 3–4 year payback periods.

Also, in terms of climate adaptability, three different cities (Oslo, New Mexico, Turin) in 3 different climate zones were chosen and a comparative analysis across them was done. In which New Mexico showed the highest productivity due to higher solar irradiance. This validates the global suitability of using DAPVSS technologies under a range of environmental conditions.

In conclusion, the results shows that complex configurations were more likely to satisfy the performance objectives without sacrificing the appearance criteria or functionality. For instance, Design No. 6 demonstrated the most balanced performance between all the evaluated criteria compare to other mentioned systems, despite its moderate daylight reduction.

The research establishes a comprehensive framework for evidence-based design decisions that can balance energy production, occupant wellbeing, and architectural integration.

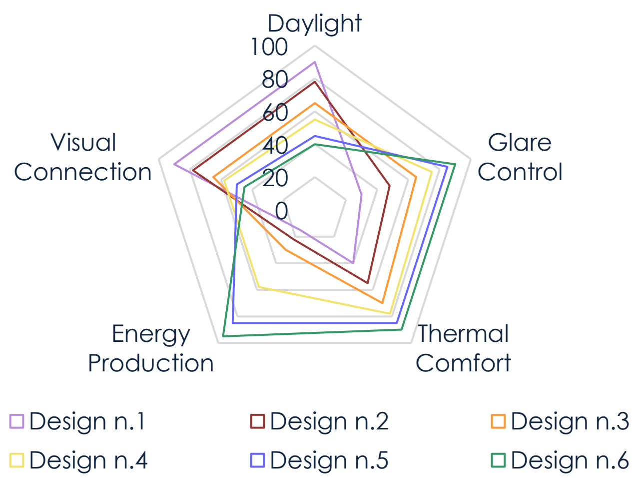

Figure 3 Overall Performance Comparison (%)

Significance of This research demonstrated that architects and designers can successfully integrate aesthetic and performative concerns to create building-integrated technologies that simultaneously enhance energy efficiency and occupant comfort, contributing to the advancement of sustainability.

For future Research studies some aspects such as need of real-time sensor network, mechanical assessment protocols, and cost-optimization strategies for large-scale urban applications can be addressed. Therefore, the results of this study provide a foundation for validating simulation models under various conditions and developing standardized implementation frameworks.

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