Toward the Perfect Glazed Façade Via Integration of an AI-driven Energy Control System

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Introduction

Windows account for an estimated 20–40% of energy loss in buildings, making them a major source of inefficiency and cost [3]. Simultaneously, daylighting strategies have shown significant potential: studies in California office buildings report annual lighting savings exceeding $3.7 million [1], while research at Cornell links increased daylight exposure to a 51% reduction in eyestrain, 63% fewer headaches, and 56% less drowsiness among workers [2].

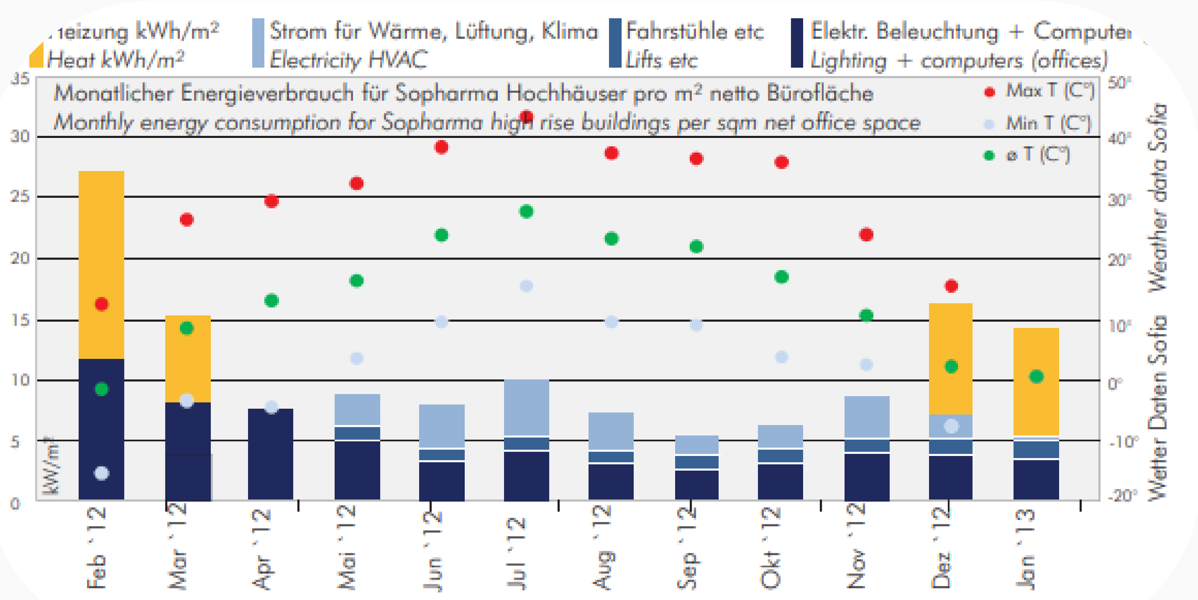

Figure 1: Energy consumed in German high rise by use over one year in units of kW/m^2 [4]

Current Gaps

Conventional glazing is static and cannot adapt to changing conditions for solar gain, daylighting, glare control, or blackout needs. Emerging "smart coatings" (electrochromic, thermochromic, and photochromic) offer dynamic regulation but face limitations in terms of uniformity, durability, and cost. This research proposes a multifunctional glazing system that maximizes energy efficiency and occupant comfort while preserving transparency and views.

The envisioned design combines high thermal resistance, acoustic insulation, seasonal solar control, sectional daylighting and glare management, and full blackout capability.

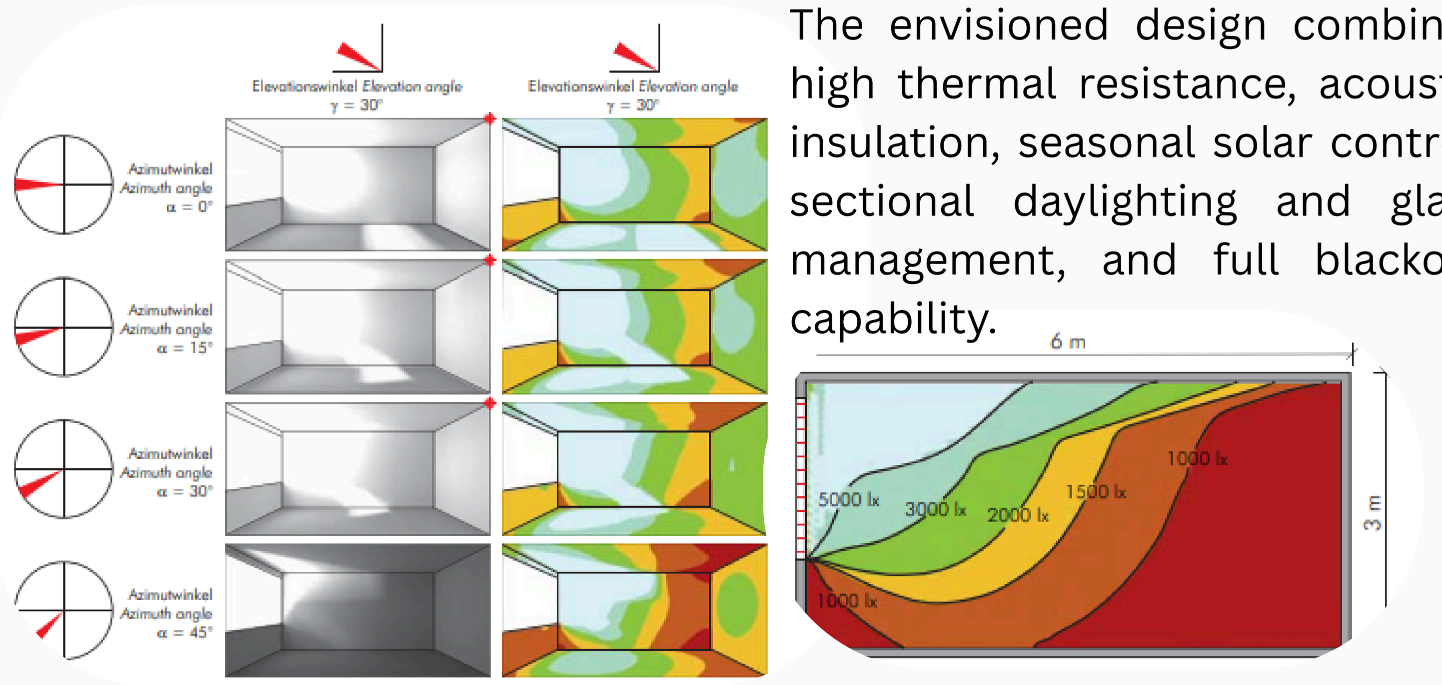

Figure 2: Light distribution in room using RetroLux Blinds at set elevation angle and varying azimuth [4]

Experimental Setup

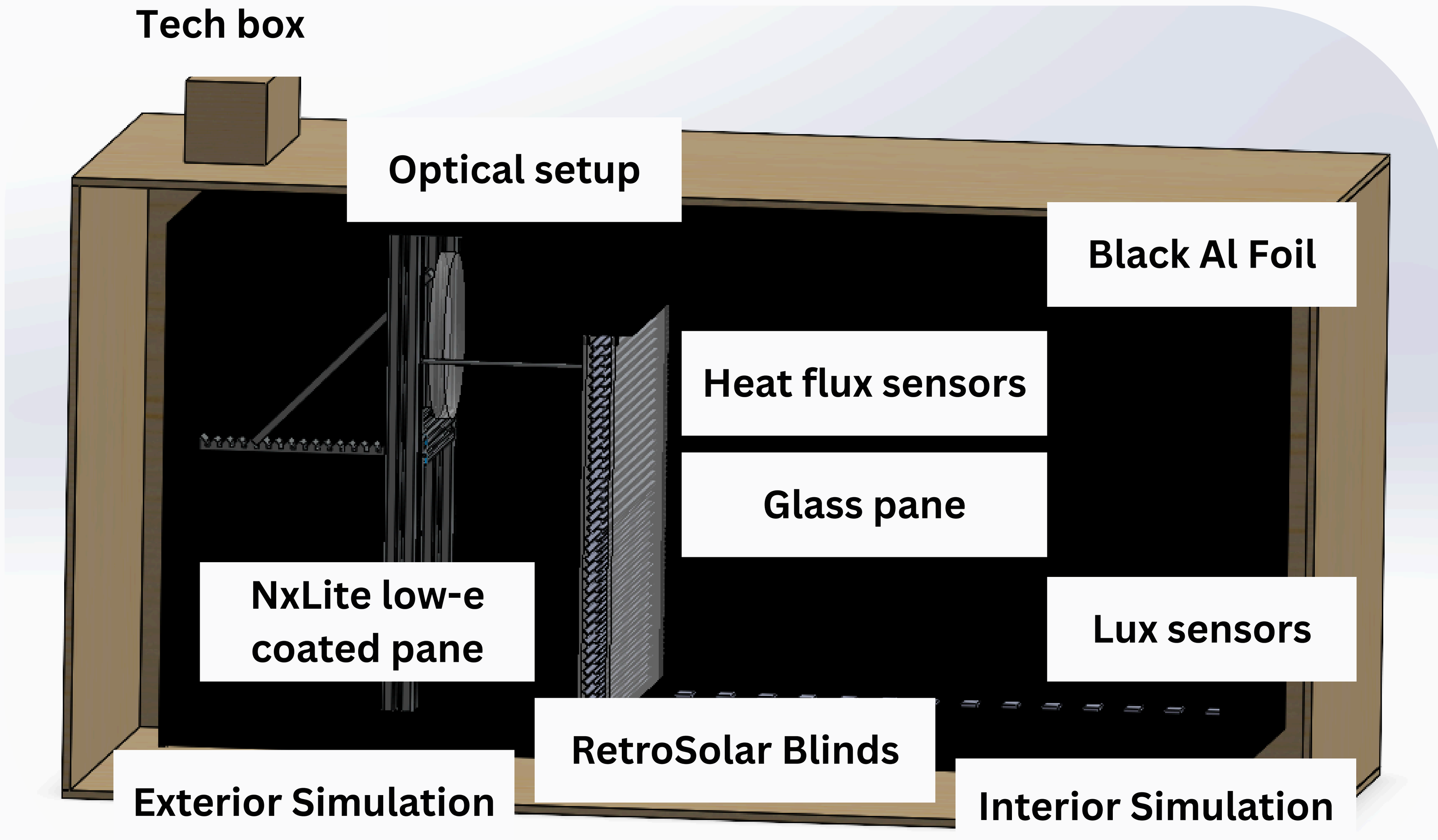

Figure 3: Box setup including the exterior, interior and window assembly divisions.

Testing is conducted within a custom three-box apparatus simulating exterior, interior, and window interface. A collimated LED-mirror assembly approximates solar radiation, while sensors record lux and thermal flux. This research addresses that need through the design and testing of a novel window assembly. Four configurations are evaluated: a standard single-pane window, the same pane with conventional blinds, a low-emissivity PMMA pane, and a proposed hybrid system combining a glass pane, custom slatted blinds for daylight modulation, and a rear low-e PMMA panel. The system is intended to perform dynamically under varying solar angles and environmental conditions. Results suggest the system will redirect much of the daylight toward the ceiling, reducing glare in the lower visual field, and will show a higher R-value than conventional designs.

The window assembly will test various blind systems. Those provided by RetroSolar will consist of an upper set of slats used to redirect light towards the ceiling and a lower set of slats for glare reduction. Custom stepper and servo motors will be used in conjunction with a unique pulley system to test the various angles of slats to find desirable angles for various incidence rays. This will be used to configure an AI algorithm to dynamically control the slats.

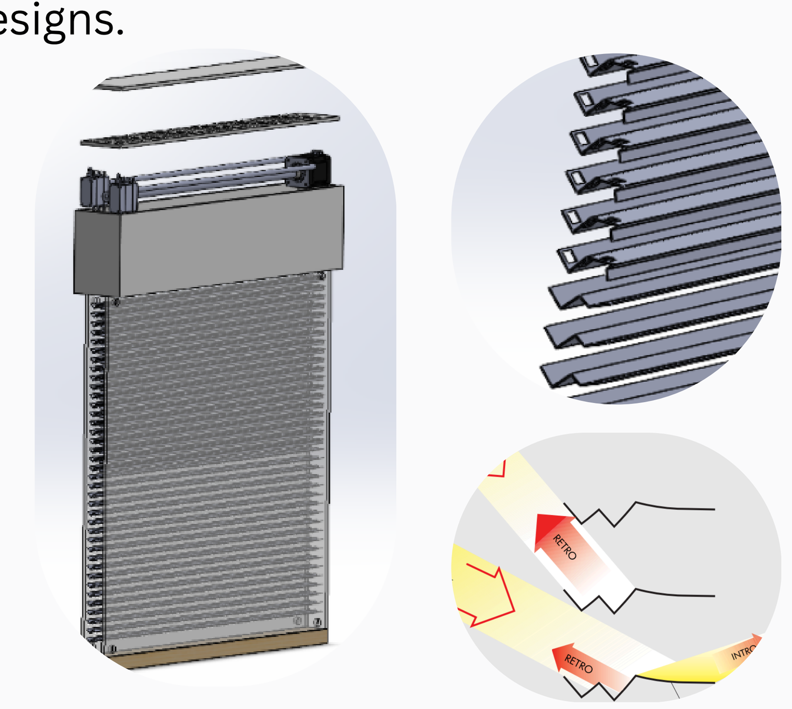

Figure 4: Window assembly closeup

The Optical Approach

The apparatus employs a parabolic mirror aligned with a compact, high-intensity LED to generate collimated light (<1° divergence) exceeding 10,000 lux, closely replicating solar radiation. The mirror-lamp assembly can be adjusted to reproduce the full range of solar incidence angles. Light transmission is evaluated in a 1.5-meter interior enclosure equipped with 30 evenly spaced lux sensors to measure spatial distribution, enabling assessment of daylighting performance and glare control. All interior surfaces are lined with laboratory-grade black aluminum foil (<5% reflectance) to suppress stray reflections and ensure optical accuracy.

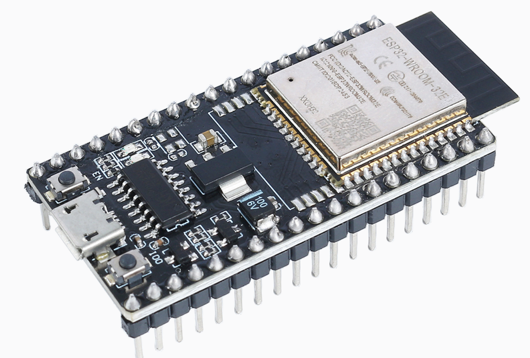

Figure 5: ESP32 MCU (primary microcontroller used for the setup)

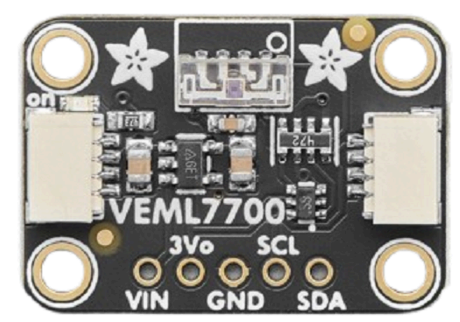

Figure 6: VEML7700 LUX sensor (used in box)

The Thermal Approach

Thermal behavior is assessed at the window interface, positioned between the two enclosures. Heat flux sensors are mounted on both interior and exterior surfaces to measure thermal transfer, while integrated heating and cooling systems in the exterior enclosure provide controlled temperature modulation. Future iterations will incorporate an infrared heat source to more accurately simulate the thermal component of solar radiation. The enclosure structure is insulated and sealed with thermal tape to maintain near-closed system conditions.

References

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