Laidlaw Scholars Undergraduate Leadership and Research Programme
Research Proposal

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

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Abstract

The proposed research explores the integration of dynamic optical elements within glass façades, aided by an AI-driven energy control system, to prototype an autonomous "perfect window." Traditional static façades fail to regulate radiant energy—solar gain, reflection, daylighting, glare, and blackout—leading to up to 40% energy loss in buildings. This project addresses these challenges by combining advanced spectrally selective coatings with a responsive energy management circuit and segmented daylighting lamellas. An AI algorithm will continuously adapt the façade's behavior based on real-time sensor input and external weather data, ensuring optimal indoor thermal and lighting conditions.

Unlike conventional systems, this solution emphasizes autonomous responsiveness and modularity. A Bluetooth-enabled user app will allow for further personalization. Conducted at AP^2D Laboratories[1], this interdisciplinary research bridges photonics, electrical engineering, and AI to develop a scalable solution for ultra-energy-efficient buildings.

Introduction

During the last few decades, the use of glazed glass façades in buildings has surged dramatically, driven by architectural trends and the desire to maximize natural lighting. However, these predominantly 'static and monolithic' glazed façades cannot actively control the flow of radiant energy, notably, solar gain, solar reflection, daylighting, glare control and blackout – which are critical functionalities vis-à-vis occupant comfort as well as energy efficiency of buildings considering that windows can account for up to 40% loss in building energy[1]. There is a need to constantly vary these parameters with respect to the changing weather conditions, seasonal variations, geographical location, and thermal comfort and daylighting preferences of the occupant, underpinned by optimizing building energy efficiency. This need has sparked the development of "smart coatings" such as electrochromics, thermochromics and photochromics that can be controlled with electrical stimulation. AP^2D Laboratories[2] at the University of Toronto has been at the forefront of such research pioneering several landmark papers and patents in the field of 'dynamic energy control glazing'.

The overarching goal of the proposed project is to advance buildings toward net-zero energy standards. Buildings account for approximately a third of the global energy consumption, much of which is due to heating and cooling systems with the weakest thermal link being the glass façade. I intend to develop a "Perfect Window" by designing an energy control circuit that combines the glazed glass pane technology and state-of-the-art daylighting lamellas with an AI-based algorithm that optimizes the system to harness the natural sunlight in relation to maximizing occupant comfort, lighting needs and minimizing building energy consumption.

[1] Advanced Photonics-Photovoltaics & Devices

Research Objectives & Questions

The primary objective of the proposed research is to undertake the design and demonstration of an 'autonomous perfect window system'. The chief characteristics of a perfect window are the following: clear natural view of the external world, high thermal resistance, high acoustic insulation, maximal solar gain in the winter, maximal solar reflection in the summer, sectional daylighting control permitting daylighting and glare control, and black out.

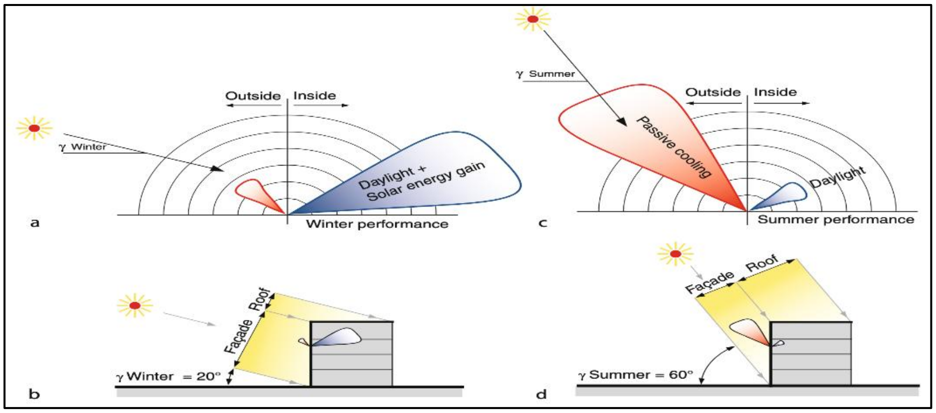

Fig.1 Flows of Radiant Energy[2]

Methodology

The proposed research involves prototyping and refining a radiant energy control circuit integrated with advanced façade glazing technologies developed at AP^{2}D Labs. Specifically, applying the concept of 'radiant energy veil system' through utilization of 'sapphire-like spectrally selective coatings' and RetroSolar's contoured ultra-thin aluminum solar-daylighting lamellas [3-6].

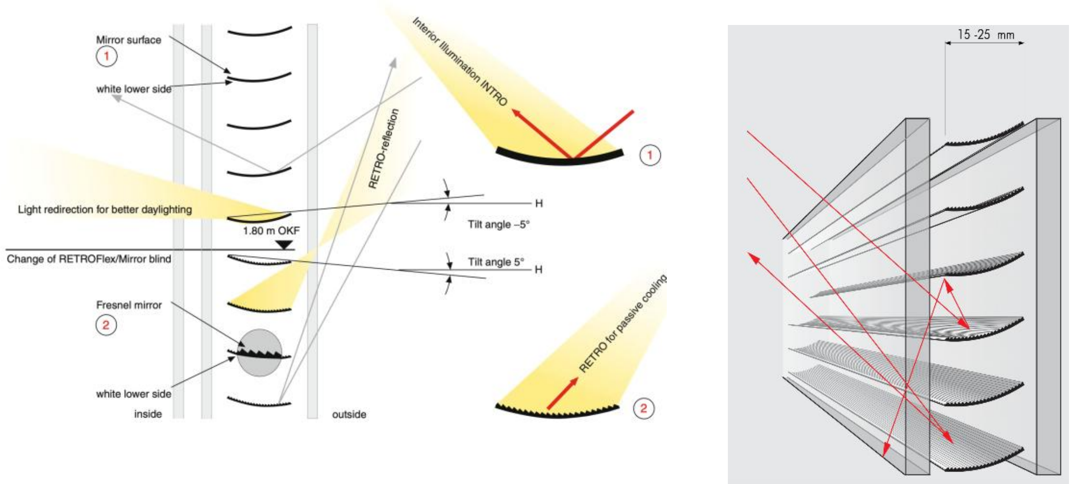

Fig.2 Radiant Energy Veil System and Daylighting Lamellas[2]

The research plan is structured as follows:

i. **Circuit Prototyping**
An initial energy control circuit will be designed using a microcontroller (likely the ESP32), relays, solid-state switches, and a sensing module. This circuit will interface with the glazing system to modulate its thermal and optical properties via electrical impulses.

ii. **Development of a Sensing System**
A sensing module will be developed, incorporating infrared sensors for heat signatures, light intensity sensors for UV rays, and a thermistor for temperature monitoring. The sensing system will be augmented with external meteorological data via the 'Weatherbit API' to create a comprehensive dataset of real-time environmental conditions.

iii. **AI-Driven Control Algorithm**
Collected sensor and weather data will be used to train a custom-designed AI algorithm. The algorithm will optimize the façade's thermal and optical characteristics in real-time to balance energy efficiency with user comfort and lighting preferences, as well as building energy efficiency.

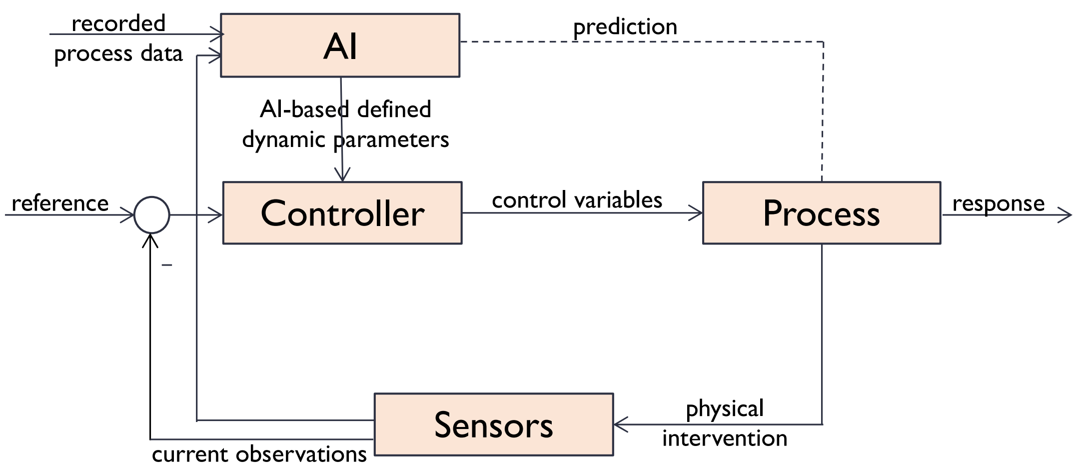

Fig 3. Flow Chart of the Control Algorithm

iv. **PCB Design and Fabrication**
Once the prototype circuit meets functional requirements, a printed circuit board (PCB) will be designed and fabricated using the equipment (oscilloscopes, compound microscopes, waveform generator, soldering station etc.) available within AP^{2}D Labs. A custom 3D printed chassis will be designed for the system.

v. Development of a Control Application

A Bluetooth-based interface application will be developed in C++ to enable manual control and customization of the system's settings.

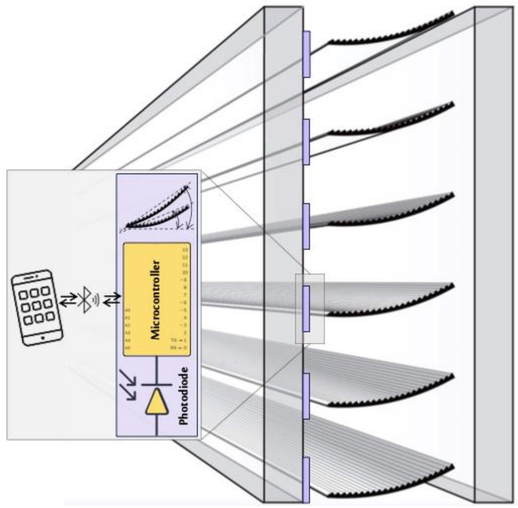

Fig 4. Bluetooth Application[2]

Training and Certifications Needed

I will complete the following training and certification for access to the laboratory:

- **EHS101**: WHMIS and Lab Safety
- **EHS002**: Basic Health and Safety Awareness

This research requires a strong foundation in C++, PCB design (Altium), elementary SolidWorks, 3D printing, and prior experience with microcontroller units. Before beginning, I will review these subjects to ensure proficiency.

Research Location

The project will not require any travel as all the research will be conducted at AP^{2}D Labs in the Galbraith Building at the University of Toronto, Canada.

Research Ethics Board

Research Ethics Board approval is not required.

Timeline

Week 1	Prototype the microcontroller circuit
Week 2	Interface the circuit with the glazed façade and design a PCB
Week 3	Development of the sensing system and AI control algorithm
Week 4	Fabrication of PCB and app development
Week 5	Assembly of the entire 'Perfect Window System'
Week 6	Testing and Optimization

Table 1: An outline of the weekly milestones leading to the realization of the radiant energy control circuit

Resources & Support Needed

Dr. Nazir Kherani's expertise in thin-film semiconductors, optical coatings, and energy materials (230+ publications, 8 patents) will guide the project, ensuring effective design and prototyping. Dr. Kherani will provide access to the AP^{2}D Lab facilities, fabrication tools and equipment, with weekly meetings to track progress. A PhD student will work closely with me, providing detailed guidance. I will complete regulatory health and safety training as well as receive specific laboratory training to ensure proficiency with operation of various characterization systems.

Potential Impact

My proposed research has the potential to usher a new era in AI-assisted ultra-energy-efficient window systems. By the end of six weeks, the project will deliver a tangible prototype of the dynamic control system of the "perfect window" and thus a comprehensive dataset to support further advancements in dynamic façade glazing technologies. On a broader scale, this work aligns with the United Nations Sustainable Development Goals related to energy conservation, sustainable cities, and climate action. My research will serve as an instrumental piece in the puzzle of realizing net/near-zero emission-energy buildings.

References

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