Energy Efficient Room

Design Team
Nicholas Matook, Rachel Miller, Kendal Smith, Drew Somero, Josef Suwardi

Design Advisor
Prof. Sagar Kamarthi

Abstract
This project evaluates the impact that EC (electrochromic) windows have on the energy efficiency of a room’s HVAC system. A simulation model of an office-like room has been constructed using AnyLogic software. The model includes: heat transfer through the window, heat flow within the room, heating and cooling (HVAC) systems, schedules of occupancy in the room, limits on temperature (based on occupancy comfort values and building limits), and historical data of weather and solar irradiance for Boston in 2011. Using JavaScript, functions and variables in this model interact to realistically mimic the heat transfer, energy use, and temperature changes in and outside a room. The simulation is optimized using tinting logic to either increase or decrease solar radiation through the EC window based on room temperature and weather data. In other words, the model significantly reduces the burden on the HVAC system by determining when to tint the window, and to what level. This modulation of tint therefore reduces the total energy consumption of the room while maintaining the comfortable ambiance in the room. The remainder of the project focuses on running the simulation model for more scenarios and analyzing the output information to determine specifications on how/when/where EC windows are significantly efficient and cost-effective.

For more information, please contact sagar@coe.neu.edu.
The Need for Project

True implementation of green energy is still years away, so economically feasible technologies need to be developed to minimize energy consumption without drastically compromising on the way humans live.

Global warming, along with decreasing energy supplies, is creating a market for clean technologies that reduce energy consumption. Global warming is threatening the Earth’s natural balance and is a current hot button issue that must be addressed for sustainability of future generations. True implementation of green energy is still years away, so technologies that minimize energy consumption, without drastically compromising on a comfortable lifestyle, need to be developed. These technologies also need to be economically viable for general and widespread use. This project develops a simulation model of EC (electrochromic) windows that minimize the energy being consumed in a room without needing direct human action or interaction. This project proves the economic value of the EC windows.

The Design Project Objectives and Requirements

Design and build a simulation model of EC smart windows to analyze energy savings, while keeping the room comfortable for end users.

Design Objectives

The objective of this project is to design and build a simulation model of an EC window that can adapt its tint level to achieve a balance between human comfort preferences and energy consumption. By running the simulation model at different settings and analyzing the results, the group will determine how cost-effective the EC window technology is.

Design Requirements

The simulation model considers a $12 \times 10 \times 10$ ft office room with the EC window size of $10 \times 12$. Co-variables such as cloud cover, building material, tilt angle, and building direction are included in the model to accurately simulate energy flow in and out of the room. Table 1 is a list of key parameters that can be used to describe the EC window performance (SHGC= Solar Heat Gain Coefficient).
Table 1: EC window tinting data from Sage electrochromics;

Although this table shows only four levels of tint, the simulation model considers the windows’ full potential: a continuous range of tint possibilities between the extremes.

Another input to the simulation model is the hourly weather data of Boston in 2011. Room temperature is highly dependent on the outside temperature and associated solar radiation.

Design Concepts considered

Multiple inputs were considered in order to optimize energy efficiency and comfort level. The inputs include lighting comfort, temperature comfort, energy savings, and irradiance into the room.

The project team considered three methods—Arena, AnyLogic, and Thermodynamic Models—for building the simulation model. After assessing the pros and cons of each method, the team selected AnyLogic as a perfect tool to build the simulation model. AnyLogic’s dynamic software allows different parts of the model to interact. In this project, user preferences and schedules must be able to interact with the physical characteristics of the simulated room (Rep 4).

For user preferences, the initial model included both temperature and lighting comfort limits when occupied. Theoretical mathematic models were developed with constraints to match this logic. As the model progressed, lighting comfort preferences were determined to be inconsequential. The focus of this project is to evaluate the thermal efficiency of the EC windows; this has nothing to do with lighting. Also, upon the observation of a functioning EC window, the fully tinted window appeared to be more similar to very darkly shaded sunglasses, than the black wall once envisioned. Thus the tinting of the window is much less disruptive to the room.
occupant than originally thought (Rep 4.2).

The tinting logic of this model is the most crucial piece of the simulation model. This logic allows an EC window to function at its highest possible level of energy efficiency. Initially, the design of the tinting used sensor data to react to indoor and outdoor temperatures, as well as the indoor lighting comfort. When the project team’s understanding of AnyLogic and the problem matured, this design was changed to be based solely on the indoor variables. The team realized that indoor temperature is what needed to be optimized and tinting logic could be based only on the temperature inside the room. The key to the success of this logic was the development of the variable Delta_RoomTemp; this took into account the change in room temperature due to all factors besides the tint and the HVAC effect. The tint level is determined by reading this variable and working to keep it at zero. This will be described further in the following section.

**Recommended Design Concept**

The final design minimizes the total energy consumed by the room by using tinting logic that assist the HVAC systems in keeping the room within an ergonomically comfortable temperature range.

**Design Description**

The final model is set up to simulate a room of any size with any size EC window(s) in the Boston area and compare the HVAC energy consumption of that room against the same room, but with a Low-E window(s), i.e. low-emissivity, standard window(s). The model considers Boston’s historical temperature and solar irradiance data for computing energy demands of the rooms. This comparison derives the energy savings made possible by the EC window(s) within the user preference system. This design allows the users to change their comfortable temperature range as well.
Analytical Investigations

The model accounts for solar irradiance that the window allows through (affected by tint level), heat transfer through the window, walls, floor, and ceiling, heat transfer from the actual user (person) as well as their computer, and the HVAC system (Rep 7.4). These equations, along with their outputs in multiple test scenarios, have been validated against not only theoretical equations, but also with the physical prototype built by the mechanical engineering (ME) team. Many iterations of this process were undertaken in order to create as realistic of a model as possible.

Experimental Design

In the final phase of design, the team realized that the extreme levels of tinting were not being achieved as often as would be optimal. Temperature limits for the HVAC system were identical to those designated for the tinting system; thus, the heating and cooling were immediately bringing the room temperature back within the comfort range before the extremes of the window tint could have an effect. The development and use of the Delta_RoomTemp variable, described earlier, changed this. This way, the logic works to keep the indoor temperature within the comfort limits as often as possible, reverting to the most extreme levels of tint when outside this range. The HVAC system then only switches on or off when the temperature exceeds these limits and the room is occupied; tinting logic is independent of the room occupancy. In the final design of the model, this advanced tinting logic was implemented.

Key Advantages of Recommended Concept (Results)

This tinting logic allows for the most optimal amount of solar radiation into the room regardless of the season and time
of the day. Results from one of the most realistic tests (large office- 1600 ft$^3$, half window- 60ft$^2$) yielded energy savings nearing 34%.

A more clear demonstration of the EC window’s effect on the room is the solar irradiance data, shown in Figure 1. This graph shows the total radiation let into the room due to the weather (sun intensity) and the tint level applied to the window via the optimized tinting logic.

Financial Issues

Although EC windows currently have high initial costs ($80/ft^2$) than low-e windows ($10-15/ft^2$). But, improvements in the manufacturing process already being implemented by the company Soladigm, are expected to drop the price of EC windows to as low as $20/ft^2$ in the near future. Combining that price reduction (in future) with a reduction of HVAC energy consumption as high as 25%, EC windows are a worthy investment (Rep. 3.2).
Recommended Improvements

Develop system to integrate control of all building systems affecting energy consumption, including EC window tint, HVAC usage, and lighting.

The energy efficient room simulation can be easily adjusted by changing parameters to mimic rooms and buildings of any type. However, as every building is unique, enhanced algorithms could be added to account for odd shaped buildings and variations in sunlight based on local climate conditions. Ideally the model could be transferred to an independent program for easy distribution to potential end users.