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EVALUATING THE IMPACT OF SMART GLAZING ON THE VISUAL PERFORMANCE OF OCCUPANTS IN OFFICE BUILDINGS IN OKLAHOMA

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EVALUATING THE IMPACT OF SMART GLAZING ON THE VISUAL PERFORMANCE OF OCCUPANTS IN OFFICE BUILDINGS IN OKLAHOMA

A THESIS APPROVED FOR THE
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Dedication

To God, whose grace has sustained me throughout this journey and who has continually answered my prayers.

To my older brother, a resilient sickle cell warrior, whose strength and perseverance have been a constant source of inspiration and motivation to my siblings and me. May his gentle soul continue to rest in the bosom of the lord

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Abstract

The design of office spaces increasingly prioritizes visual comfort, occupant well-being, and energy efficiency, with glazing systems playing an important role in balancing daylight access and glare reduction. While dynamic glazing systems, particularly electrochromic (EC) systems, have been extensively researched for their energy benefits, there is still a lack of understanding about how individual tint states of commercially available EC glazing compare to conventional glazing in terms of visual comfort. This study compares and assesses the performance of conventional clear glazing to different tint states of electrochromic glass (e.g., SageGlass) in a simulated office environment in Oklahoma City. The analysis uses a simulation process that includes Revit, Rhinoceros 3D, and ClimateStudio to evaluate key daylighting and visual comfort metrics such as Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP). The findings show substantial variation in visual performance between EC tint states, emphasizing the trade-offs between daylight availability and glare mitigation. Intermediate tint levels often provide a more balanced performance, however severe tint levels either increase glare risk or diminish daylight sufficiency. By connecting these findings with LEED Standard criteria, this study provides evidence-based guidance for selecting glazing systems and optimum tint levels that improve visual comfort and enable high-performance office design in solar-heavy zones like Oklahoma.

Keywords: Smart glazing, Electrochromic Glazing Systems, Useful Daylight Illuminance (UDI), Daylight glare probability (DGP), Visible Light Transmittance (VLT)

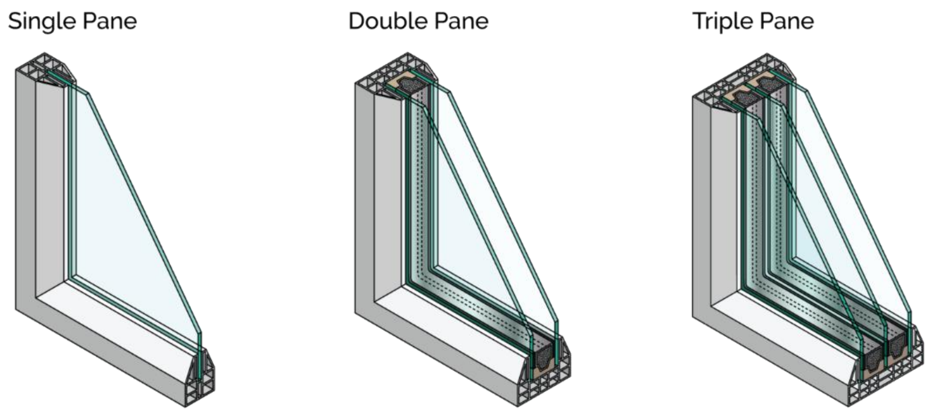
Chapter 1: Introduction

Background

Daylighting is well known for its ability to improve visual performance and occupant well-being in addition to its potential to lower energy use (Budaiwi & Abdul Fasi, 2023). Studies have shown that people who are exposed to natural sunlight have better moods, are more alert and have better circadian rhythms, all of which can increase workplace productivity (Tibermacine & Daich, 2024). Although energy savings are frequently the focus of daylighting, the visual comfort benefits are equally important in developing human-centric office settings. Glazing systems are critical to daylight control in buildings, serving as the interface through which external daylight is managed for interior usage (Tällberg et al., 2019). Conventional glazing, on the other hand, frequently fails to balance competing demands: provide adequate lighting, preserve views, and reduce glare or heat gain. Static glazing techniques might provide excessively bright hotspots or inadequate light deeper within the area (Michael et al., 2023). To address these limitations, researchers and designers have turned to smart systems that respond dynamically to environmental changes. Advanced Glazing systems, such as electrochromic (EC), photochromic (PC), and thermochromic (TC) glazing systems, are under rapid development because of their ability to vary their optical qualities (for example, tint or transmittance) in response to the climate or the user's needs (Attia et al., 2018).

Although previous research has carefully looked at the energy and daylighting performance of dynamic glazing systems, significant gaps remain in understanding how individual tint states of commercially available electrochromic (EC) glazing, such as those manufactured by SageGlass, perform in comparison to conventional glazing, particularly in terms of visual comfort in accordance with LEED Building standards. Existing research frequently evaluates electrochromic glazing as a single, static system, neglecting the variation in visual performance across its different tint levels. This limitation is especially important in areas like Oklahoma City, where high sun intensity can drastically alter daylight distribution and glare conditions. Furthermore, this study aims at addressing this gap using simulation-based analysis to provide designers with clear, performance-driven insights that will help them make faster and more educated decisions when choosing optimal smart glazing conditions during the design process.

Figure 1. Image showing common conventional glazing systems



Problem Statement

Since most individuals spend 80% of their time indoors, daylight is a vital component that affects people's health and well-being (He et al., 2025). Windows are essential for letting in natural light and offering views, but striking the correct balance between enough lighting and visual comfort is still quite difficult (Jamrozik et al., 2019). Various studies have noted how technological advancements have led to the development of smart glazing systems, including photochromic, electrochromic, and thermochromic glazing systems, which are creative solutions that dynamically control light transmission in response to external factors. However, few studies have explicitly compared the different tint states of commercially available electrochromic glazing systems in a region such as Oklahoma, where weather patterns and solar intensity vary substantially.

Purpose of Study

The purpose of the study is to assess and compare the visual performance of conventional glazing and various tint states of commercially available electrochromic (EC) glazing systems in an office setting. The study uses a simulation-based approach to investigate how each glazing condition affects important visual comfort metrics such as useful daylight illumination (UDI) and daylight glare probability (DGP). This study will discover the states that give the best balance between daylight access and glare control by systematically analyzing the performance of various EC tint states. The study also aims to integrate these findings with recognized building performance standards like LEED Building Standard, ensuring that they are relevant to both sustainability and occupant well-being goals. The study intends to provide evidence-based suggestions to help designers make informed decisions about glazing states that fit with occupant preferences, especially in areas with high solar exposure, like Oklahoma City.

Based on the observed gaps and the purpose of this study, the following research questions are proposed:

1. How does each electrochromic (EC) tint state affect key daylighting and visual comfort metrics like Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP)
2. Which EC tint state achieves the best balance of daylight availability and glare control in accordance with LEED Building Standard criteria in Oklahoma's solar conditions?
3. How do variable tint states of EC glazing systems affect spatial functionality in office settings by altering daylight distribution, glare conditions, and visual comfort metrics?

Significance of the Study

This study is significant because it contributes to daylighting research and design practice by offering a granular, performance-based evaluation of specific tint states of electrochromic (EC) glass, rather than treating dynamic glazing as a uniform system. By comparing different tint states of commercially available systems like as Sage Glass, against traditional glazing, the study fills a fundamental gap in understanding how dynamic façade behavior translates into meaningful visual comfort results.

Furthermore, by setting the analysis within the meteorological context of Oklahoma City, the study offers region-specific insights into the relationship of solar intensity, daylight distribution, and glare, an area that is frequently under-represented in previous work. This makes the research more relevant to designers working in similar high solar exposure climates.

Limitations

This study has various limitations that should be noted when evaluating the findings. First, the analysis is limited by the presence of a single electrochromic glazing system SageGlass in the simulation environment, limiting the generalizability of findings to other EC technologies and manufacturers. The study uses simulation-based methods, which, while reliable, cannot fully reproduce real-world conditions such as occupant behavior, adaptive controls, and individual comfort preferences.

Furthermore, the study is based on a specific office arrangement, orientation, and material setup, which may affect daylight distribution differently in other spatial contexts. The use of a single climatic dataset for Oklahoma City further limits the results' generalizability to places with varying solar and sky conditions. Also, the study focuses primarily on visual comfort metrics (UDI and DGP), leaving out other performance considerations, including thermal comfort, energy consumption, and long-term occupant adaptation.

Collectively, these limitations imply that, while the study provides substantial and context-specific insights, its findings should be understood in light of the defined simulation parameters and environmental variables.

Chapter II: Literature Review

Facade

The French term facade literally translates to "frontage" or "face." A building's facade is crucial from an engineering standpoint due to its influence on environmental and energy efficiency.(Lai & Hokoi, 2015). The facade of the building is one of its most important features (Halawa et al., 2018), they are a part of the building envelope and provide support for the external architectural features of buildings; they have evolved through history from clay, stone, wood, and brick to steel and glass to meet various functional and climatic needs (Moghtadernejad et al., 2019). The facades of buildings are the first view of the outside world and give the initial reflection of the building, and they are the first thing to look at and express the taste and personality of the designer (Tantawy, 2023)

Advanced/high performance facades

New facade technologies that adjust to the environment are essential for glazing design because they strike a balance between visible transmittance, energy efficiency, and circadian lighting requirements, emphasizing the intricate connection between daylight performance, energy savings, and non-visual light considerations (Ghaeili Ardabili et al., 2025). Notwithstanding advances in technology and the introduction of new high-performance façade systems, their expected role has been extended (Moghtadernejad et al., 2019). Adaptive facades are building envelopes that can adapt to changing boundary conditions in the form of short-term weather fluctuations, diurnal cycles or seasonal patterns (Attia et al., 2018).

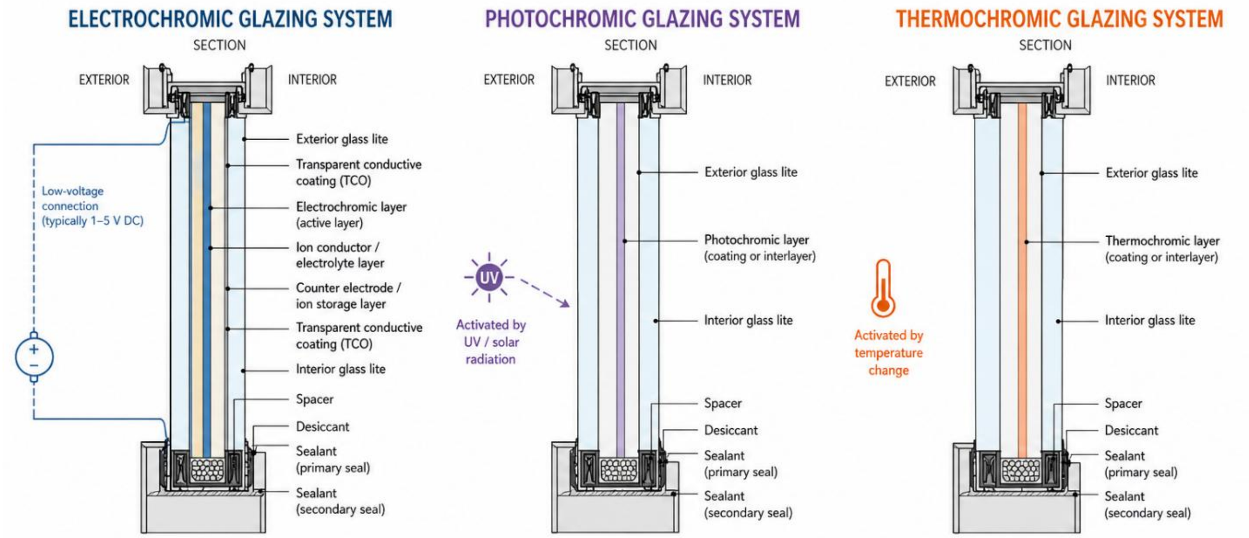
Application of Smart materials in building facades

With its ability to respond dynamically to environmental cues and greatly increase energy efficiency, smart materials have become a game-changer in building facade design. Conventional facades are usually static and need a lot of energy to keep interiors comfortable. On the other hand, smart materials that can instantly adjust to variations in temperature, light, and humidity, including shape memory alloys, thermochromic coatings, and electrochromic glass, might lessen the need for mechanical systems and enhance building performance (Al-Obaidi et al., 2017).

Types of smart glazing

Research on smart glazing systems demonstrates an increasing emphasis on adaptive façades that combine daylighting, energy efficiency, and occupant comfort. According to studies, electrochromic glazing provides accurate, user-controlled modulation of visible light and solar heat gain by electrical voltage, making it one of the most mature and commercially feasible dynamic systems (Tällberg et al., 2019). Thermochromic glazing, especially that based on Vanadium dioxide (VO_2) coatings, responds passively to temperature changes and shows great promise for lowering cooling loads without sacrificing transparency. However, issues with transition temperature tuning and long-term durability still exist (Jiang et al., 2024; Zhang et al., 2023). Photochromic glass responds to sun intensity, automatically darkening under high irradiance, and has been found to increase visual comfort and reduce glare without requiring external control devices (Heidari Matin et al., 2022; Meng et al., 2024). Collectively, these three technologies represent the transition of smart façades from passive (photochromic and thermochromic) to active (electrochromic) control systems. Each makes a distinct contribution to balancing daylight quality, thermal performance, and visual comfort, reinforcing dynamic glazing's position as a crucial method for sustainable building design in varying climates.

Figure 2. Image showing the common smart glazing systems



Application of smart glazing in buildings

Smart glazing integration into building facades has emerged as a fundamental method for increasing daylight quality, visual comfort, and energy efficiency. Subsequent implementations in office buildings demonstrate that Electrochromic glazing (EC) windows may preserve outdoor vistas while lowering glare and energy consumption, particularly when integrated into automated façade systems (Tällberg et al., 2019; Villa et al., 2024). The beneficial effects of EC glazing on occupant well-being were also shown by field studies like (Woo et al., 2021), which found that office spaces with EC façades in place of static shade systems experienced increased comfort and satisfaction. Applications in commercial and educational buildings show that Thermochromic glazing TC glazing, especially when oriented toward sun-exposed façades, reduces indoor cooling loads while preserving adequate daylight levels (Aburas et al., 2019; Zhang et al., 2023). Nevertheless, studies also highlight difficulties in reaching optimal transition temperatures and preserving clarity throughout intermediate phases (Wu et al., 2023). As a passive daylighting and glare management technique, photochromic glass (PC) has been used in buildings, primarily in façade regions that receive changeable sunlight. When used without external controls, it has demonstrated encouraging results in increasing visual comfort and decreasing the likelihood of glare (Heidari Matin et al., 2022). PC-coated glass can adaptively balance daylight penetration and visibility, as shown by case studies in office and educational buildings. However, performance may be limited by slower reaction times in dynamic weather circumstances when compared to electrochromic alternatives (Meng et al., 2024). These studies all show that smart glazing technologies are regularly used in façade systems to improve building performance by lowering the need for artificial lighting and mechanical shading. When appropriately integrated with façade orientation, climate conditions, and control systems, these glazing systems contribute to both energy savings and occupant well-being, representing a significant improvement in responsive building envelope design (Teixeira et al., 2025).

Visual performance of facades and its importance for occupants

The visual performance of the façade, including the delivery of appropriate lighting, controlled glare, and high-quality vistas, has a direct impact on how people feel and function in interior spaces. Systematic evidence suggests that places with access to daylight and window views produce higher visual comfort, better mood, and subjective well-being than visually deprived situations (Vasquez et al., 2022; Woo et al., 2021). The performance importance of façade-mediated visual connection was highlighted in controlled tests where having a window with a view enhanced emotional states and cognitive function in comparison to rooms without a view (Ko et al., 2020). Better daylight performance and less glare are also linked to increased visual satisfaction in field tests conducted in green workplaces, confirming that façade solutions should balance views, glare control, and illumination rather than maximizing any one of these factors (Lim et al., 2017). When considered collectively, the research confirms that façades that provide enough natural light without glare and with good views promote comfort, contentment, and task performance all of which are essential components of wholesome, effective buildings (Ko et al., 2020; Vasquez et al., 2022; Wienold & Christoffersen, 2006)

Visual comfort and their metrics

Visual comfort in constructed spaces is an important component of occupant well-being, influencing subjective satisfaction, performance, and the requirement for shade or artificial illumination. Researchers use a set of quantitative criteria to objectively evaluate visual comfort. These metrics cover three important components: daylight availability, glare risk, and luminance/illuminance distribution.

Metrics of daylight availability, such as useful daylight illuminance (UDI), and spatial daylight autonomy (sDA), have been used to measure how much daylight a location receives and how well it provides usable light without being overly bright. For instance, (Carlucci et al., 2015) describes how UDI informs trade-offs in visual comfort design by capturing both over-lit (> 3000 lux) and under-lit (< 100 lux) circumstances (Carlucci et al., 2015). Likewise, simulation-based research uses sDA and ASE to assess if a façade satisfies the visual comfort requirements of occupants throughout the year (Nourkojouri et al., 2021).

Glare measures are also essential since high contrast or bright sources in the field of view reduce comfort and visual performance. The Daylight Glare Probability (DGP) is a widely used measurement that assesses the percentage of occupants likely to experience discomfort from daylight glare (Wienold & Christoffersen, 2006). Field experiments in tropical regions indicated that threshold values for acceptable DGP are lower than previously proposed. For instance, DGP < 0.35 was found to correlate with comfortable circumstances in Thailand offices (Chaloeytoy et al., 2020)

Luminance/Illuminance distribution measures show how evenly distributed and balanced the light levels are throughout the workplace and in the visual field. Comfort has been demonstrated to be impacted by luminance ratios, such as the proportion of bright to dark regions in the field of view: According a study by (Shi et al., 2021), a comfortable visual environment should have a brightness contrast ratio of no more than 40:1 (Shi et al., 2021).

Impact of smart glazing on visual aspects of light

By adjusting sunshine levels, lowering glare, and stabilizing illumination, smart glazing technologies including electrochromic (EC), thermochromic (TC), and photochromic (PC) systems have been demonstrated to enhance visual performance in buildings.

Photochromic (PC) glazing

Photochromic (PC) glazing systems, which darken in response to ultraviolet (UV) radiation under bright sunshine, are an effective way to reduce glare without requiring electrical control. (Heidari Matin et al., 2022) found that using colored photochromic coatings in office façades increased Useful Daylight Illuminance (UDI) and decreased DGP relative to normal glass in various sky circumstances, (Khaled & Berardi, 2023) conducted a cross-climate simulation of flexible photochromic films and found that they lower interior illuminance peaks and glare risk, but their responsiveness varies depending on orientation and solar exposure.

Electrochromic (EC) Glazing

Electrochromic (EC) glazing systems have been extensively researched for their capacity to dynamically modulate daylight levels and increase occupant visual comfort in office settings. Simulation and field research conducted by (Fernandes et al., 2013) found that split-pane electrochromic windows controlled for daylight and visual comfort achieved substantial lighting energy savings while maintaining acceptable glare conditions in a south-facing private office. Similarly, (Costa et al., 2024) showed through Radiance simulations that well-designed EC glazing control significantly improves occupant visual comfort and luminance balance in office interiors.

Thermochromic (TC) glazing

Thermochromic (TC) glazing systems regulate light transmittance based on temperature changes, darkening under higher solar loads to minimize over-illumination. (Teixeira et al., 2022) evaluated a TC glazing system in a simulated office setting and found that it achieved better luminance balance and reduced glare hours compared with clear glass, especially during summer months. (Zeng et al., 2024) further reported that gel-based thermochromic glazing effectively decreased the frequency of glare events and improved overall daylight uniformity, offering enhanced occupant visual comfort across varying temperature conditions. Together, these studies demonstrate that TC glazing serves as a passive but climate-responsive strategy for glare control, offering substantial visual benefits in warm, high-irradiance environments such as Oklahoma City.

Impact of smart glazing on non-visual aspects of light

In addition to visual comfort, smart glazing affects light's non-visual impacts, such as regulating circadian rhythms, promoting attentiveness, and improving general wellbeing.

Photochromic (PC) glazing

Photochromic glass, which changes color in response to solar UV radiation, can passively control light levels, influencing circadian rhythms. Cross-climate examinations of photochromic window films reveal that their variable transmittance changes melanopic-equivalent daylight illuminance (mel-EDI) across varied sky and orientation circumstances, hence modifying potential circadian stimuli (Khaled & Berardi, 2023). In a broader perspective, Ardabili, Azari, De Zoysa, and Wang noted that glazing spectrum and transmission are significant determinants of indoor circadian health, underlining the need of spectral design in adaptive glazing systems such as PCs (Ghaeili Ardabili et al., 2023)

Electrochromic (EC) Glazing

Electrochromic glazing systems can have a major impact on occupants' circadian health by controlling daytime light exposure, which impacts sleep, attentiveness, and overall well-being. Field studies have demonstrated that apartments outfitted with EC windows deliver higher levels of circadian-effective daylight exposure, improving sleep timing and well-being compared to traditional blinds (Nagare et al., 2021). Simulation research reveals that EC glazing can balance glare reduction with enough melanopic exposure, assisting in maintaining both visual and non-visual illumination requirements throughout the day (Costa et al., 2024).

Thermochromic (TC) glazing

Thermochromic glazing's transmittance varies with temperature, altering both visual and non-visual sunshine exposure in warm climes. Simulation studies have demonstrated that optimal thermochromic glazing can improve the Circadian Stimulus (CS) and melanopic daylight exposure while maintaining acceptable illuminance and lowering energy usage (Fan et al., 2024). Zeng et al. (2024) found that gel-based thermochromic systems reduced excessive light during midday hours, resulting in more stable melanopic exposure patterns throughout the day (Zeng et al., 2024) Similarly, (Salamati et al., 2020) reported that VO_2-based thermochromic coatings filtered high-intensity daylight and minimized circadian overstimulation while still allowing sufficient morning light for healthy entrainment. Overall, TC glazing offers a passive, temperature-responsive strategy to reducing circadian illumination exposure, making it appropriate for climates like Oklahoma's, where summer sun intensity can be high.

Table 1. Literature Review Summary

Author & Year	Method	Independent Variable(s)	Dependent Variable(s)	Key Findings	Relevance
Aburas et al. (2019)	Literature review	Thermochromic properties, temperature	Energy use, daylight (VLT)	Demonstrates that thermochromic glazing passively reduces solar heat gain and cooling loads, but often compromises daylight availability due to limited visible transmittance control	Establishes the core trade-off between daylight and energy, which underpins evaluation of UDI vs glare across glazing types
Al-Obaidi et al. (2017)	Literature review	Adaptive façade strategies	Energy, daylight, comfort	Shows that biomimetic/adaptive façades dynamically respond to environmental changes, improving overall building performance but requiring complex integration	Positions smart glazing as part of adaptive façade systems, supporting the study's focus on dynamic performance
Attia et al. (2018)	Literature review	Façade types, control strategies	Energy, daylight, comfort	Identifies lack of standardized frameworks for evaluating adaptive façades and emphasizes need for integrated, multi-	Justifies use of multiple daylight and glare metrics (UDI, sDA, ASE, DGP) for comprehensive evaluation

				domain performance assessment	
Carlucci et al. (2015)	Literature review	Visual comfort indices	Glare, illuminance	Compares visual comfort metrics and highlights that no single index captures all aspects of comfort; climate-based metrics are more reliable	Provides methodological justification for selecting DGP and UDI
Chaloeytoy et al. (2020)	Field + simulation	Daylight conditions, DGPs	Glare perception	Establishes validated DGPs thresholds that correlate strongly with occupant glare perception in office environments	Strengthens credibility of glare analysis and supports interpretation of DGP results
Costa et al. (2024)	Simulation	EC tint states, control	UDI, sDA, glare	Finds that electrochromic glazing dynamically reduces glare while maintaining useful daylight, achieving a balance between visual comfort and daylight autonomy	Directly supports comparison of EC tint states vs baseline glazing using similar metrics
Fan et al. (2024)	Simulation + optimization	Thermochromic VLT	UDI, circadian, energy	Demonstrates that optimal glazing design requires balancing daylight, circadian stimulus, and energy, revealing inherent performance trade-offs	Supports multi-metric approach and highlights need to balance visual comfort and daylight availability

Fernandes et al. (2013)	Simulation	EC control strategies	Energy, daylight	Shows that EC windows controlled for daylighting significantly reduce lighting energy while maintaining visual comfort conditions	Supports performance advantage of EC glazing over static systems
Ghaeili Ardabili et al. (2025)	Simulation	Glazing type, spectrum	Circadian lighting	Indicates that glazing properties significantly influence circadian-effective light exposure indoors	Extends study by linking daylight performance to occupant health outcomes
Ghaeili Ardabili et al. (2023)	Literature review	Window characteristics	Circadian health	Concludes that window design strongly impacts circadian rhythm, emphasizing importance of daylight quality, not just quantity	Reinforces importance of quality daylight metrics beyond illuminance
Halawa et al. (2018)	Literature review	Façade design strategies	Energy, comfort	Highlights importance of climate-responsive façade design in optimizing building performance in hot climates	Supports climate-based simulation approach (Oklahoma EPW)
Heidari Matin et al. (2022)	Simulation	Smart colored glazing	Visual performance	Finds that smart glazing improves visual comfort by reducing glare and controlling light	Directly supports visual performance benefits of smart glazing systems
Jiang et al. (2024)	Experimental review	VO_2 materials	Optical/thermal performance	Advances in thermochromic materials improve switching efficiency but still	Provides material-level explanation for performance limitations observed in simulations

				face limitations in optical clarity	
Khaled & Berardi (2023)	Simulation	Photochromic films, climate	Energy, daylight	Performance of smart films varies significantly across climates, affecting daylight and energy outcomes	Supports need for climate-specific analysis in your study
Ko et al. (2020)	Field study	Window views	Comfort, cognition	Access to views improves emotional state, thermal comfort, and cognitive performance	Reinforces importance of daylight and window quality for occupant experience
Lai & Hokoi (2015)	Literature review	Solar façade systems	Energy, daylight	Solar-integrated façades enhance building performance through energy generation and daylight control	Positions glazing within broader façade performance systems
Lim et al. (2017)	Field study	Daylight levels	Visual satisfaction	Higher daylight availability improves occupant satisfaction but may introduce glare if uncontrolled	Supports need to balance daylight quantity and glare (UDI vs DGP)
Meng et al. (2024)	Literature review	Photochromic materials	Optical performance	Highlights technological progress in smart glazing materials for improved responsiveness	Provides background on emerging smart glazing technologies
Moghtaderneja d et al. (2019)	Literature review	Façade design stages	Design performance	Emphasizes importance of early-stage façade decisions on overall building performance	Supports simulation-based evaluation in design phase

Nagare et al. (2021)	Field study	Daylight exposure	Sleep, circadian health	Increased daylight exposure improves sleep quality and circadian alignment	Supports broader benefits of daylight beyond visual comfort
Nourkojouri et al. (2021)	Simulation + ML	Daylight variables	Visual comfort	Machine learning can accurately predict daylight and comfort performance in early design stages	Suggests advanced tools for optimizing glazing performance
Salamati et al. (2020)	Simulation	Thermochromic glazing	Daylight, energy	Thermochromic glazing reduces energy demand but may reduce daylight levels in certain states	Reinforces performance trade-offs across glazing states
Shi et al. (2021)	Field + lab	Luminance levels	Visual comfort	Establishes luminance thresholds for visual comfort using subjective and physiological responses	Supports definition of acceptable glare/comfort limits
Tällberg et al. (2019)	Review + simulation	Smart window types	Energy performance	EC glazing offers greater controllability and better overall performance than passive smart glazing	Supports selection of electrochromic glazing in your study
Tantawy (2023)	Analytical study	Building function	Façade design	Building function influences façade design strategies and performance priorities	Provides contextual design perspective
Teixeira et al. (2022)	Simulation	Static vs thermochromic	Energy, daylight	Smart glazing improves energy performance but may reduce daylight compared to clear glazing	Directly supports comparison between conventional and smart glazing

Teixeira et al. (2025)	Literature review	Smart glazing technologies	Energy, daylight	Identifies research gaps in performance evaluation of smart glazing systems	Directly supports research gap statement
Vasquez et al. (2022)	Literature review	Daylight, views	Comfort, satisfaction	Occupants strongly prefer daylight and views, influencing satisfaction and wellbeing	Supports human-centered design focus
Villa et al. (2024)	Simulation	EC glazing, climate	Energy, comfort	EC glazing improves performance but effectiveness varies with climate conditions	Supports climate-specific evaluation of EC systems
Wienold & Christoffersen (2006)	Model development	Luminance distribution	Glare (DGP)	Developed the DGP model, a widely accepted glare prediction metric	Provides foundation for glare analysis metric (DGP)
Woo et al. (2021)	Field study	Daylight & views	Wellbeing	Access to daylight and views improves physical and emotional wellbeing	Reinforces importance of daylight in office environments
Wu et al. (2023)	Review	Smart window technologies	Energy, daylight	Smart windows improve building performance but require optimization for best results	Supports integration of smart glazing systems
Zeng et al. (2024)	Simulation	Thermochromic glazing	Energy efficiency	Thermochromic glazing enhances energy efficiency under varying conditions	Supports energy benefits of smart glazing
Zhang et al. (2023)	Literature review	Thermochromic materials	Energy performance	Thermochromic windows show strong potential but require further	Provides future outlook and research direction

	development for widespread adoption

Chapter III: Method

Study Design

The study uses a simulation-based quantitative approach to compare a conventional clear glazing system to a dynamic electrochromic glazing system with variable tint states. The goal is to determine how these glazing characteristics affect daylight availability and visual comfort measures.

The chosen space was modelled, simulated, and analyzed using a digital workflow that included Autodesk Revit, Rhinoceros 3D (Rhino), and ClimateStudio. Simulations were carried out using Oklahoma City's Typical Meteorological Year (TMY) weather file, ensuring that the findings reflect actual climatic circumstances. This methodology enables a controlled and repeatable study of glazing performance while separating the impact of visible light transmittance (VLT) on daylight metrics.

Independent Variable

The type and optical condition of the glazing system are the independent variables in this study, as they have a direct impact on daylight transmission and visual performance in the simulated office setting. Two basic glazing systems were tested: a traditional low-emissivity (low-E) double-pane transparent glazing and a dynamic electrochromic glass system.

low-emissivity (low-E)

The baseline condition is a low-emissivity (low-E) double-pane transparent glazing system with a visible light transmittance (VLT) of 60%. This system consists of two layers of clear glass separated by a sealed hole, usually filled with air or inert gas, and coated with a thin low-emissivity layer to limit infrared heat transfer. Despite its improved thermal performance, the glazing retains a high level of daylight transmission, making it an appropriate standard for comparison. It reflects standard practice in commercial office development and serves as the benchmark against which improved glazing technologies' performance is measured.

Electrochromic Glazing System

The second independent variable is an electrochromic glazing system, specifically one manufactured by Sage Glass, which can dynamically change its tint in response to electrical input. This glazing system comprises of numerous thin-film layers embedded within the glazing assembly, allowing for reversible variations in light transmission. Unlike static glazing, electrochromic glass offers adaptive control over daylight penetration, glare, and solar heat gain without the use of mechanical shading systems.

To assess its performance, the electrochromic glazing was tested in four discrete tint states: EC State 0 (clear, VLT 60%), EC State 1 (light tint, VLT 17%), EC State 2 (moderate tint, VLT 5%), and EC State 3 (dark tint, VLT 0.9%). In addition, a dynamic mode was studied, in which the glazing's tint level is continuously adjusted in reaction to changing daylight circumstances over time. The study compares various glazing conditions to determine the impact of both static and adaptive light transmission qualities on daylight metrics such as Useful Daylight Illuminance and Daylight Glare Probability (DGP).

Dependent Variable

The dependent variables in this study are quantitative daylight performance metrics used to assess visual and luminous conditions in the office. These measurements are Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP).

Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) is the percentage of occupied time during which indoor illuminance levels are within a "useful" range, which is commonly between 100 and 3000 lux (≈ 9–280 fc). Values less than 100 lux (9 fc) are regarded insufficient for visual tasks, whilst values greater than 3000 (280 fc) lux may cause visual discomfort or glare. LEED building standards encourages maintaining illuminance levels that facilitate visual tasks without creating discomfort. A higher percentage of UDI in the 100-3000 lux (≈ 9–280 fc) range is often regarded as desirable in LEED-compliant environments (*USGBC | U.S. Green Building Council*, n.d.).

Daylight Glare Probability (DGP)

Daylight Glare Probability (DGP) assesses the possibility of visual discomfort produced by glare, taking into account luminance contrast, brightness distribution, and the position of bright sources in the occupant's field of view an this is based on the Daylight Glare Probability (DGP) metric, which Wienold and Christofferen devised. DGP forecasts how likely it is that an observer in a given view position and orientation may suffer uncomfortable glare (Christoffersen & Wienold, n.d.). The metric is commonly derived using a fisheye depiction with a 180-degree opening angle. DGP readings can range from 0% to 100%, grouped into four bands:

- Imperceptible: < 34%
- Perceptible: 34% - 38%
- Disturbing: 38% - 45%
- Intolerable: > 45%

Control Variables

The interior space was purposefully set up as an extreme situation that increases daylight penetration and probable glare conditions in order to thoroughly assess glazing performance under high daylight exposure. In order to maximize internal light redistribution, surface finishes with primarily high Light Reflectance Values (LRVs) were standardized. Matte white paint (LRV 50–70%) was used to finish the walls, and white acoustic ceiling tiles (ACT) with an LRV of 80–85% were used for the ceiling. Both materials were chosen to reflect and diffuse incoming daylight farther into the room. Although a medium-tone carpet (LRV 20–30%) was chosen for the floor in order to preserve some visual balance, the overall reflectance technique favors brightness amplification over attenuation. To maintain a typical working conditions without significantly reducing light levels, furniture features such as a desk (LRV 35–45%), three seats (LRV 25–35%), and a storage unit on the north wall (LRV 30–40%) were also kept within moderate reflectance ranges. The study simulates a most extreme daylighting state by purposefully producing a highly reflecting interior environment, which enables a more critical evaluation of electrochromic glass effectiveness in reducing excessive illuminance and glare. This method guarantees that under demanding visual conditions, fluctuations in Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP) accurately reflect the efficacy of each glazing state.

Case Study Description

The case study is the 50 Penn Place, which is located at 1900 NW Expressway in Oklahoma City, OK 73118. The building has 16 floors, a total floor space of about 324,296 square feet, and serves as a mixed-use office and retail tower.

The building is rectangular in plan with a vertically extruded form, with a north-south facing orientation. The selection of 50 Penn Place as a case study is very aligned with the goals of this research on daylight performance and visual comfort. As seen in Figure 3, the building's glazing-dominant curtain wall façade allows for significant daylight penetration, making it extremely responsive to variations in solar conditions and hence appropriate for assessing the impact of various glazing systems.

As a pre-high-performance office building, it uses conventional static glazing with limited lighting management capabilities. This makes it an appropriate starting point for comparing the performance of advanced systems like electrochromic glazing system. Its façade characteristics and lack of dynamic shading give a clear foundation for evaluating daylight-related changes.

Furthermore, the structure is largely isolated, with few adjacent impediments, allowing for consistent solar exposure across all façades. This constraint lowers external shading variables, ensuring that simulation results are primarily based on the building's envelope performance.

Finally, its position in a sunny climate creates conditions where excessive daylight and glare are regular issues. This makes it ideal for assessing key performance indicators like Useful Daylight Illuminance (UDI), and Daylight Glare Probability (DGP).

Figure 3 Exterior view of 50 Penn place. Source: LoopNet.

Figure 4 Interior view of a south-west facing office in 50 Penn Place. Source: LoopNet.

Test Space and Simulation Zone

A south-west facing office at the perimeter of the building was chosen as the analysis space because it represents one of the most critical and problematic daylight situations in the building. This orientation is subjected to intense afternoon sunlight with low sun angles and high solar radiation, which raises risk of glare and visual discomfort. Unlike north-facing spaces, which receive more diffuse and consistent sunshine, the south-west façade receives direct solar penetration during peak occupancy hours from 8am to 6pm, making it extremely sensitive to glazing performance variations. The modeled zone as seen in Figure 5, includes a single workspace measuring 12ft (3.6m) by 12ft (3.6m) and a ceiling height at 8ft (2.4m) as seen in Figure 6. It is equipped with a desk, 3 chairs, and a computer display, positioned to reflect typical occupant use and view orientation toward the exterior façade. Storage units and shelving are modeled along the north walls to approximate realistic furniture layout and potential light reflection or obstruction. A work plane height of 30 in. (0.76 m) is used to measure horizontal illuminance across the primary desk surface. The interior furnishings, finishes, and layout remain constant across all simulation scenarios to ensure that variations in results are solely attributed to the different glazing systems and daylight conditions being evaluated.

Figure 5 Floor plan of simulated office space

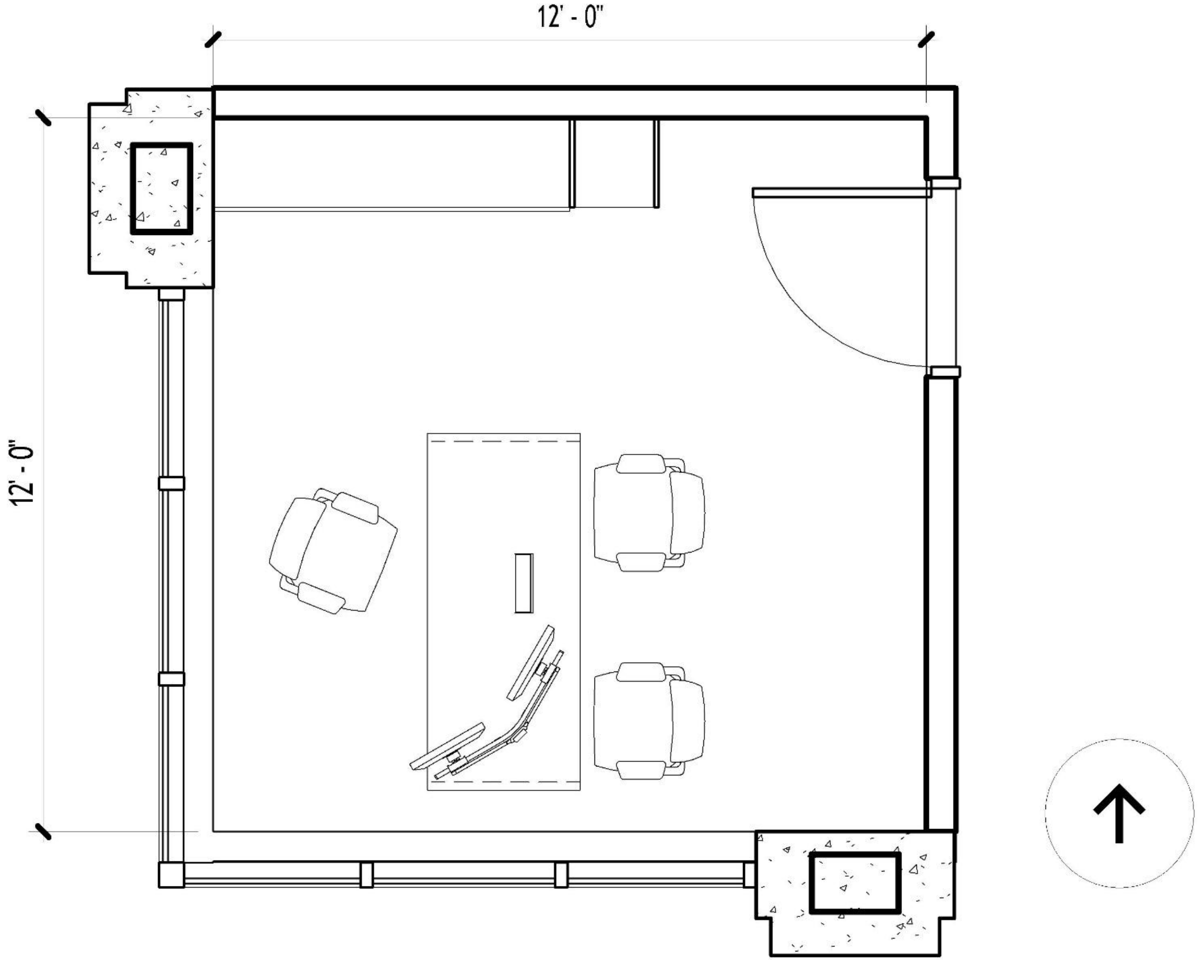


Figure 6 Interior elevation of simulated office space

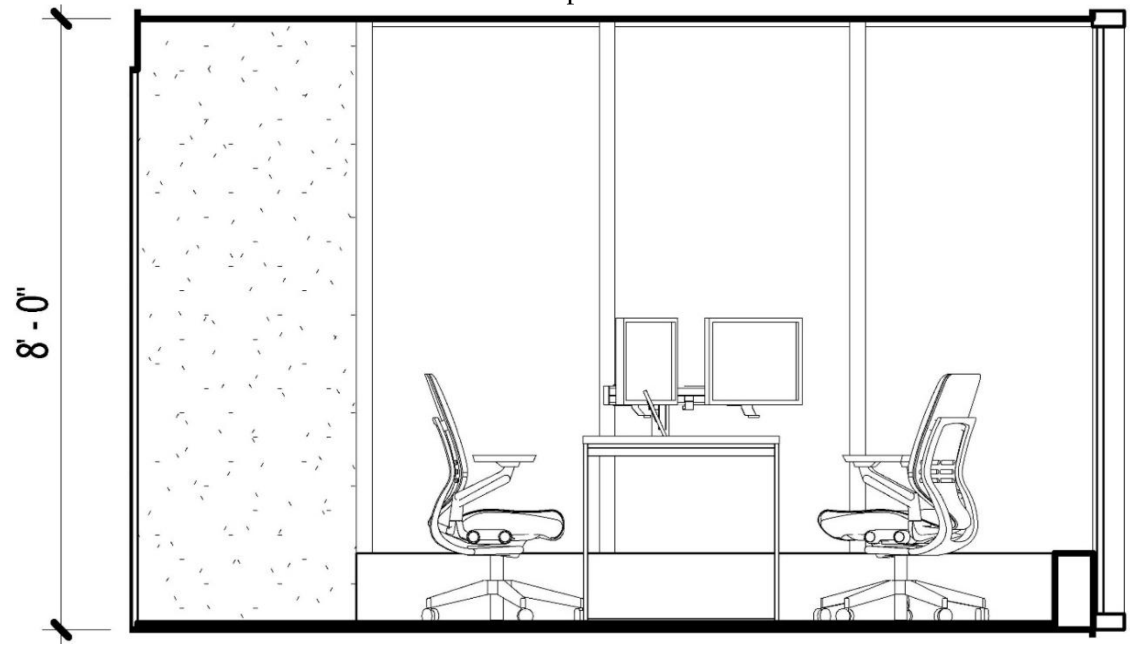
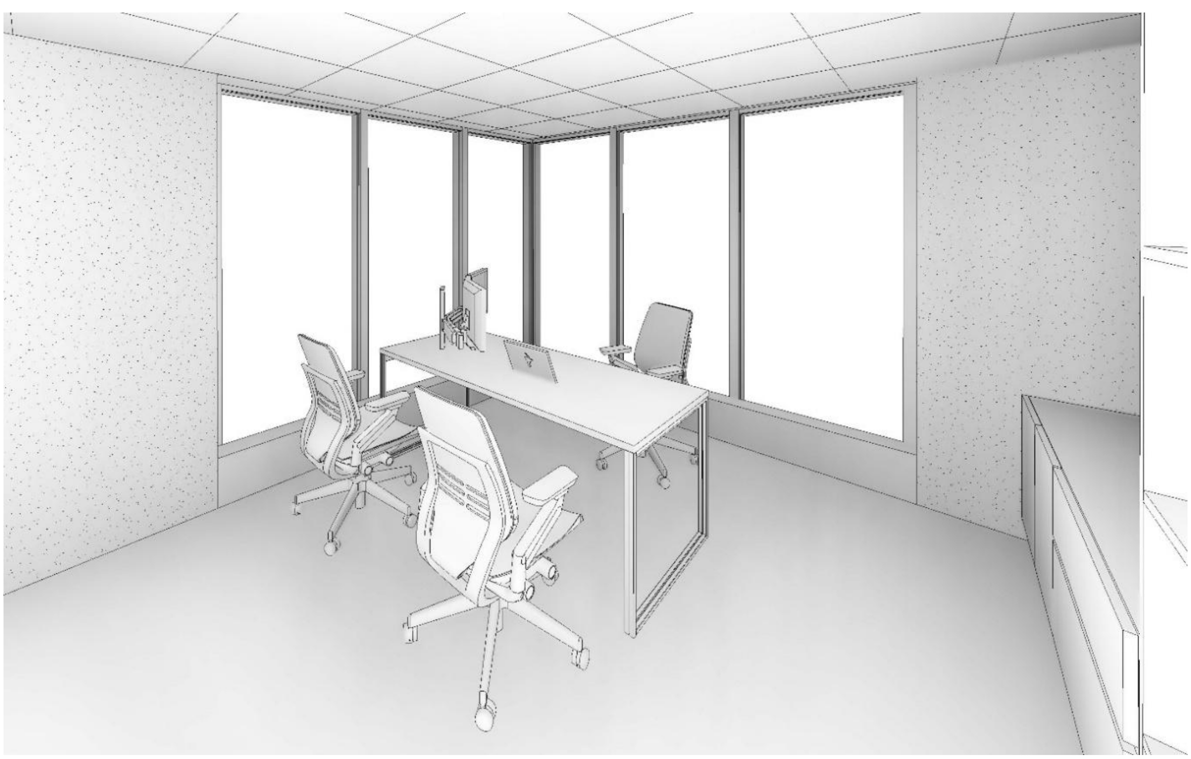


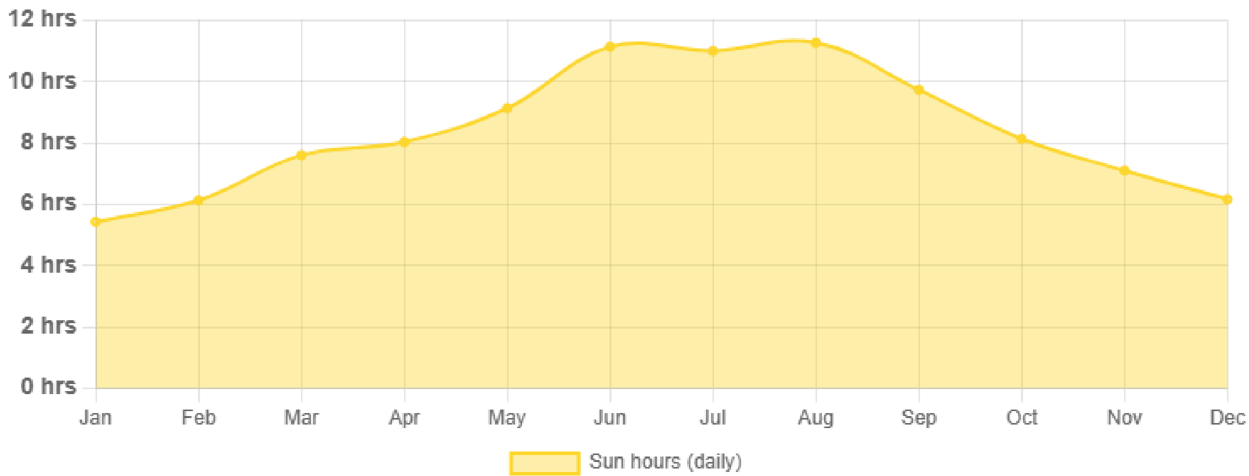
Figure 7 3d interior view of simulated office space



Location and Climate Zone

Oklahoma City has a humid subtropical climate, with hot summers, moderate winters, and significant seasonal change in solar exposure. Because of its relatively low latitude and mostly clear skies, the region receives a lot of solar radiation all year, especially in the summer as shown in Figure 8. This makes daylight an important consideration in building performance and occupant comfort.

Figure 8 Average monthly hours of sunshine in Oklahoma



All simulations were carried out with the EnergyPlus Weather (EPW) file for Oklahoma City, which represents the Typical Meteorological Year (TMY) dataset. This dataset contains hourly climatic information such as solar radiation, sky conditions, and illuminance levels.

Oklahoma City falls in the ASHRAE Climate Zone 3A (warm-humid), which is characterized by:

- High solar radiation levels
- Significant seasonal fluctuation.
- Summers are hot, and the sunlight is intense.

These climatic conditions provide opportunities and problems for daylighting. While high sun exposure can increase daylight availability, it also raises the danger of glare and visual discomfort, making it an excellent setting for testing electrochromic glazing systems.

Glazing Configurations

The baseline glazing is a standard low-emissivity (low-E) double-pane transparent glazing system typically used in office buildings. While the electrochromic glass chosen is SageGlass.

SageGlass was chosen for this study because it is a commercially accessible and frequently used electrochromic glazing system that represents real-world office applications. Its capacity to function in numerous predetermined tint states (60%, 17%, 5%, and 0.9% VLT), as well as a dynamic mode, enables a systematic assessment of how different light transmission levels affect daylight performance and visual comfort.

SageGlass is also available in ClimateStudio's material catalogue and has been tested for optical qualities. This assures correct simulation inputs while also improving analysis reliability and reproducibility.

The major metric used to define glazing performance is Visible Light Transmittance (VLT), which is the proportion of visible light that passes through the glazing. Table 2 shows the different glazing system conditions and their VLT used in the study.

Table 2. Glazing systems conditions and their Visible Light Transmittance (VLT)

Condition	**Description**	**VLT (%)**
Baseline	Low-E double-pane clear glazing	60
EC State 0	Electrochromic (clear state)	60

EC State 1	Electrochromic (light tint)	17
EC State 2	Electrochromic (medium tint)	5
EC State 3	Electrochromic (dark tint)	0.9

Software and Workflow

The daylight simulation workflow integrates three core platforms Autodesk Revit, Rhinoceros 3D (Rhino), and ClimateStudio to create, export, and analyze the model efficiently. These tools have been thoroughly tested in the architectural and building performance research communities for accurate daylight and glare prediction (Amoruso et al., 2019; Costa et al., 2024; Nagare et al., 2021)

Autodesk Revit (BIM Modeling and Documentation)

Revit serves as the primary Building Information Modeling (BIM) environment for developing the buildings geometry. The software defines floor plans, façade openings, glazing types, and materials with precise physical properties.

The Revit model ensures geometric accuracy and parametric control, enabling seamless export to Rhino. Previous studies confirm that Revit-based daylight models can be reliably linked with Radiance/DAYSIM engines for performance simulation (Amoruso et al., 2019)

Rhinoceros 3D (Rhino)

The Revit model is imported into Rhino for simulation refinement and sensor-grid setup. Rhino provides detailed geometric editing, material layering, and parametric control for testing multiple façade configurations.

ClimateStudio (Plug-in for Rhino)

ClimateStudio, developed by Solemma LLC, is the primary simulation tool performing climate-based daylight modeling (CBDM) and glare analysis. Built on validated Radiance and Daysim engines.

ClimateStudio uses the Oklahoma City TMY3 weather file to generate:

- Annual metrics: UDI
- Point-in-time analyses: DGP and illuminance maps
- Visualization outputs: false-color luminance renderings

Radiance-based workflows within ClimateStudio have been validated for architectural daylight and glare research (Katia et al., 2021; Özdemir & Çakmak, 2022)

Together, Revit, Rhino, and ClimateStudio provide an integrated digital ecosystem. Revit for BIM accuracy, Rhino for flexible geometric manipulation, and ClimateStudio for scientifically validated daylight analysis.

Design Scenario.

The building was modelled in Autodesk Revit and then imported into ClimateStudio for daylight and performance analysis. The Oklahoma City EPW (Typical Meteorological Year) weather file was used to mimic site-specific environmental conditions.

Simulation Parameters

The daylight simulation was run on a yearly basis, using full-year climatic data for Oklahoma City. To represent a normal office occupancy pattern, the research was conducted on a daily basis from 8:00 AM to 6:00 PM. The schedule was chosen to capture the times when occupants are most likely to rely on daylight for visual work and encounter potential glare conditions. Point-in-time runs at these hours are paired with annual climate-based calculations to contextualize momentary results against year-round performance.

The simulation was run over a full year to account for seasonal and hourly fluctuations in solar position, daylight availability, and sunlight penetration. This annual approach gives a more comprehensive assessment of glazing performance than analyzing simply certain dates or hours, as it accounts for variations in daylight conditions over different months and times of day.

A continuous work plane height of 30 inches (0.76 m) above the finished floor was utilized to symbolize a normal desk level in an office. The analysis grid was placed across the occupied space of the room to assess illuminance performance under each glass condition. All simulation parameters, including space geometry, orientation, interior arrangement, and non-glazing material qualities, were held constant, allowing variances in outcomes to be attributed only to the glazing system and its tint states.

Data Collection

ClimateStudio simulation outputs were created and extracted for further investigation. UDI and DGP values were obtained for each glazing condition.

To ease interpretation, the data were organized into structured graphs and visualized with comparable bar charts. The analysis is focused on discovering trends and variations amongst glazing states, notably in terms of:

- Daylight availability
- Glare reduction
- Balance between illumination and comfort

A comparative study was undertaken to identify which glazing condition delivers the best visual performance under the specified climatic circumstances.

Chapter IV: Analysis and result

This chapter summarizes the methodology and findings from the daylight simulation study, which was conducted to assess the impact of electrochromic (EC) glass on visual performance in Oklahoma office environments. The simulations were conducted using Climate Studio, assessing different glazing states (Clear baseline, EC States 0-3, and EC Dynamic) across important daylight performance metrics: Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP).

The goal of this chapter is to provide a clear and impartial explanation of the simulation results, backed by tables and diagrams, as well as to connect the findings to the research questions about visual comfort, daylight performance, and adaptive façade behavior.

Low-E Glazing and EC State 0 (VLT 60%)

The UDI result for the low E glazing and electrochromic (EC) glazing at Tint State 0 with visible light transmittance (VLT) of 60% turned out to be at 20.1%, meaning only 20.1% of the floor area falls within the useful illuminance range of 100 – 3000 lux (≈ 9–280 fc) on an annual average. As seen in Figure 9, the space is dominated by excessive illuminance (represented in pink) greater than 3000lux (280fc). This indicates an abundance of daylight, but not effectively controlled. The time of day and annual pattern represented in Figure 10 further reinforces this condition, showing that excessive illuminance dominates for most days of the year, with only intermittent reductions into the acceptable range.

Figure 9 Floor plan showing UDI distribution of the simulated office for baseline low-E glazing/ Sage electrochromic glazing (EC State 0 – clear state) at 60% VLT.

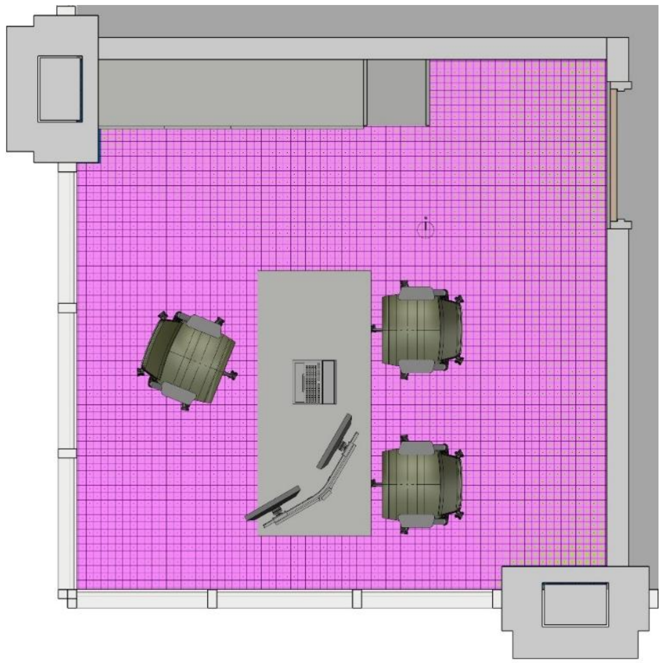
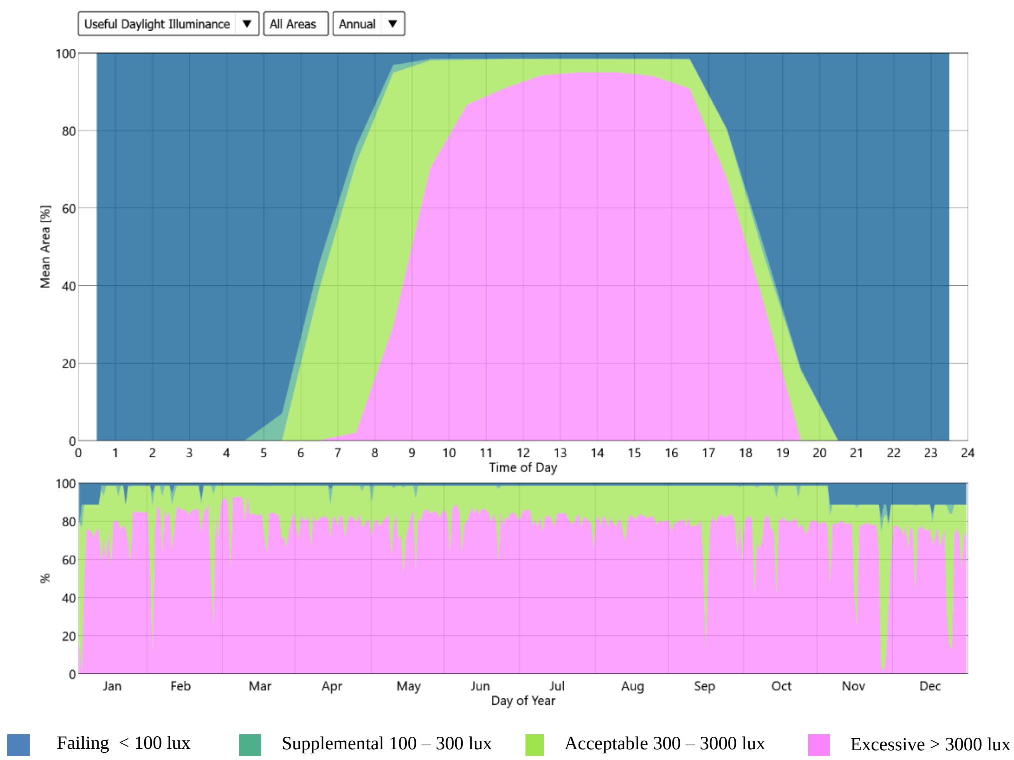


Figure 10 Average daily and annual graph of the UDI distribution for the simulated office floor plan for baseline low-E glazing/ Sage EC glazing (EC state 0 – clear state) at 60% VLT



The impact of Excessive solar exposure is further evident in the Daylight Glare Probability (DGP), with an average DGP occurrence of 99.1%, signifying that glare is present for nearly all occupied hours. As shown in Figure 11, glare spots are dispersed across virtually the whole floor space, indicating that all occupied positions are consistently exposed to high glare levels. The time of day and annual trend in Figure 12 reveal that glare begins to develop approximately 8:00 AM, increases rapidly, and peaks between 12:00 PM and 4:00 PM. During these peak hours, intolerable glare predominates, indicating conditions that are likely to cause significant visual discomfort and impair work performance. Glare levels then decrease around 6:00 p.m., as daylight intensity decreases.

Figure 11. Floor plan showing DGP distribution of the simulated office using low E glazing and Sage electrochromic glazing (EC State 0) at 60% VLT.

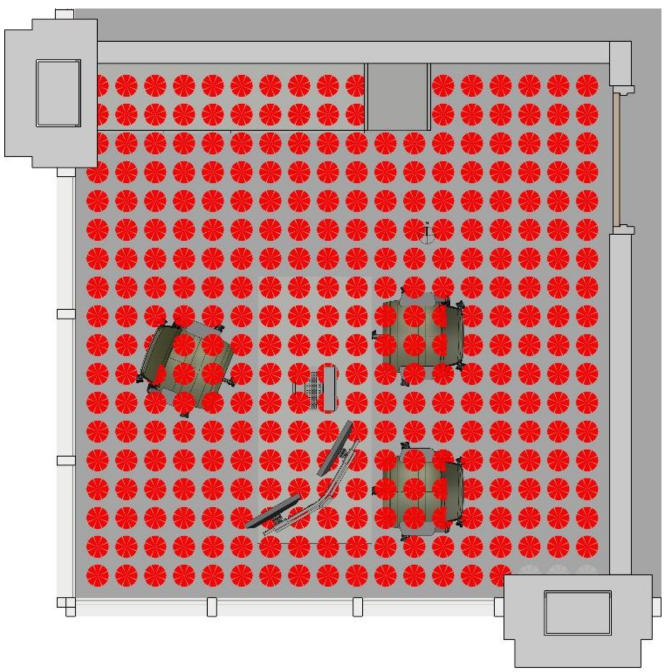
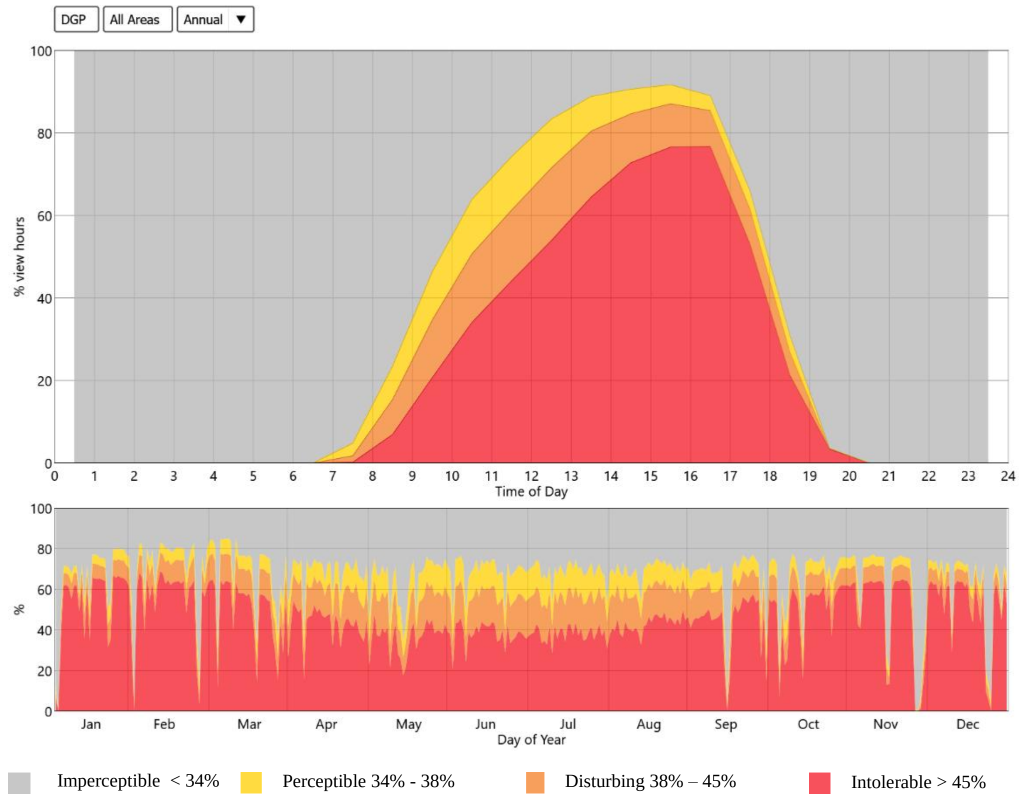


Figure 12. Average daily and annual graph of the DGP distribution for the simulated office floor plan for baseline low-E glazing and Sage EC glazing (EC state 0) at 60% VLT



EC State 1 (Light Tint)

UDI results of 60.1% for the electrochromic (EC) glazing at Tint State 1 (17% VLT) show a significant improvement in daylight usability across the area. As illustrated in Figure 13, the spatial distribution shows that a significant portion of the floor area (green area) falls within the acceptable illuminance range of 100 – 3000 lux (≈ 9–280 fc). The time of day trend in Figure 14 reinforces the spatial observation. The failing area (dark blue) indicates no usable daylight from 8 PM – 6AM. The acceptable area (light green) usually between 100 and 3000lux (≈ 9–280 fc) indicates that quality daylight reaches over 100% of the floor area between 9 AM and 5 PM. Excessive area (Pink) implies possibility of over exposure usually >3,000 lux (280 fc). The peak occurs between 11:00 AM and 5:00 PM, when up to 65% of the area is overexposed to light. This implies that this area will be uncomfortably bright in the afternoon without further tinting or shading. The annual trend indicates a higher percentage of excessive light in the winter from January – March and November to December and this due to the low angle of the sun in the sky, allowing more light penetrate deeper into the room.

Figure 13. Floor plan showing UDI distribution of the simulated office using Sage electrochromic glazing (EC State 1) at 17% VLT.

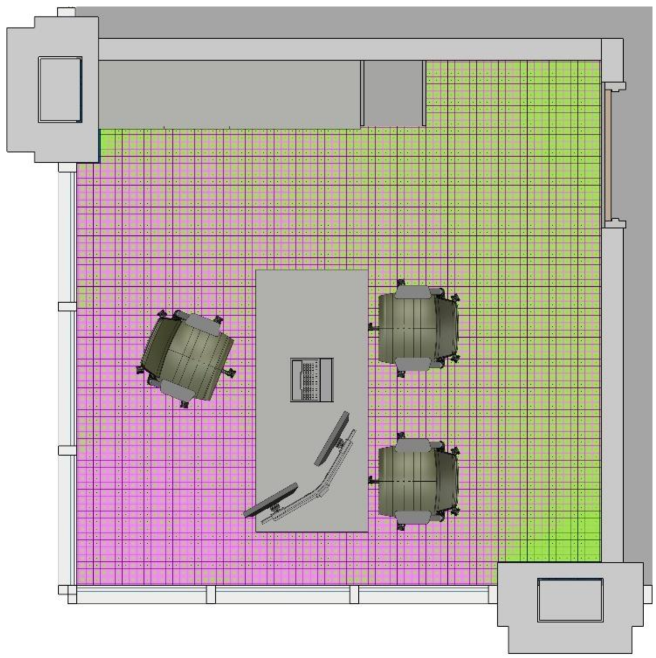
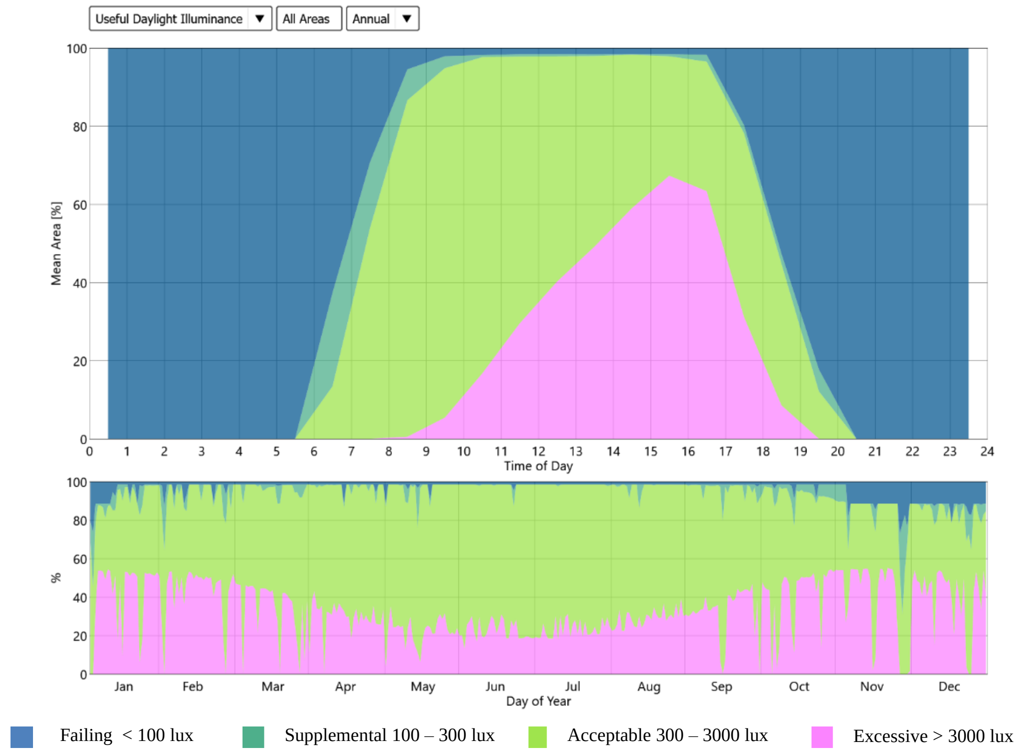


Figure 14. Average daily and annual graph of the UDI distribution for the simulated office using Sage Electrochromic glazing (EC state 1- light tint) at 17% VLT



The DGP has a result of 80% for the electrochromic (EC) glazing at Tint State 1 (17% VLT) meaning 80% of the views in the space experience glare >5% of time. The floor plan as seen in Figure 15 is dominated by intolerable areas (red) across the space. There are only a few isolated spots with somewhat reduced glare levels (orange/yellow area), but they are small and not concentrated in areas that can be used. The time of day trend in Figure 16 indicates that the space is glare free from 8:30 PM – 8:00 AM. However, glare begins to appear around 9 AM, and it steadily increases towards the noon peaking around 4:30 PM with over 30% of view hours falling within the intolerable (red) range, while perceptible (yellow) and disturbing (orange) glare tends towards 45% of view hours. The annual distribution indicates perceptible (yellow), disturbing (orange) and intolerable (red) are significantly more frequent but fluctuate from October through

March. From May through August, the glare probability drops significantly, staying consistent mostly below 15%.

Figure 15. Floor plan showing DGP distribution of the simulated office using Sage electrochromic glazing (EC State 1 – light tint) at 17% VLT.

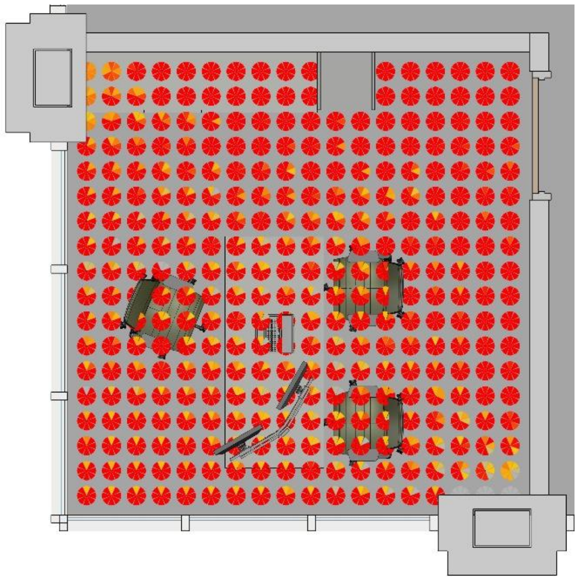
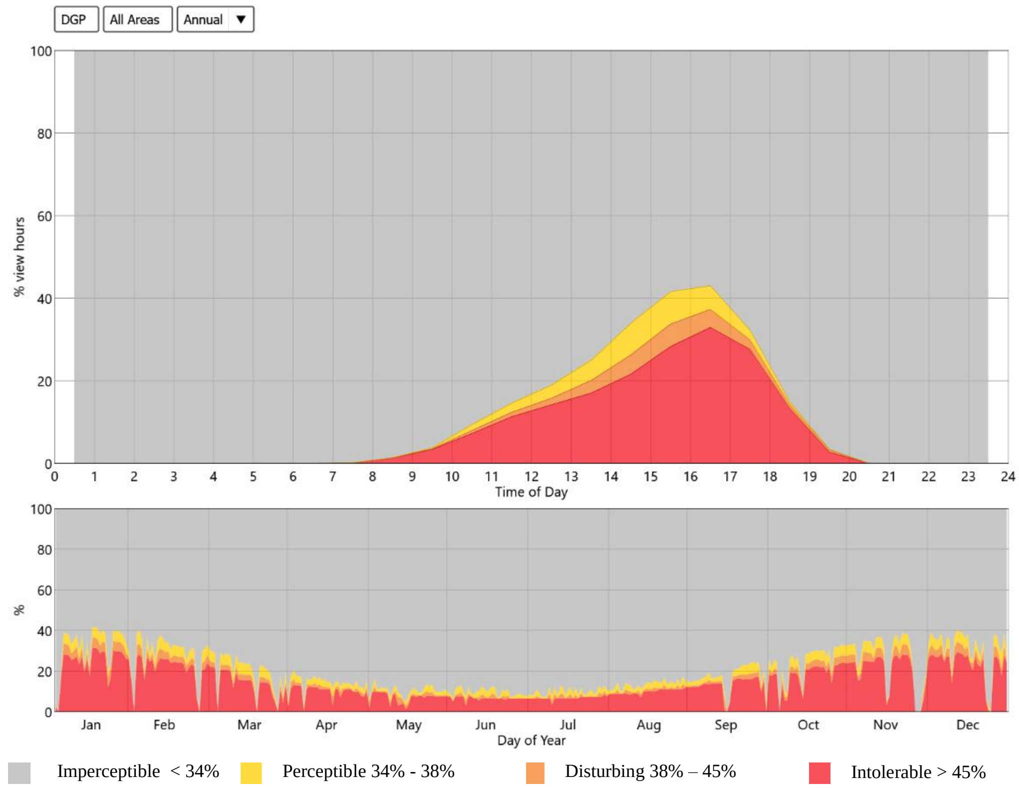


Figure 16. Average daily and annual graph of the DGP distribution for the simulated office using Sage Electrochromic glazing (EC state 1 – light tint) at 17% VLT



EC State 2 (Medium Tint)

The recorded UDI results of 58.8% for the electrochromic (EC) glazing at Tint State 2 with visible light transmittance (VLT) of 5% shows a significant improvement in daylight usability across the area. From the floor plan in Figure 17, the acceptable (light green) becomes more dominant. This indicates that 58.8% of the space falls within the acceptable illuminance range of 100 – 3000 lux (≈ 9–280 fc). The time-of-day trend in Figure 18 reinforces the spatial observation. The failing area (dark blue) indicates no usable daylight from 8:30 PM – 5:30 AM. The acceptable area (light green) usually between 100 and 3000lux (≈ 9–280 fc) indicates that quality daylight reaches over 100% of the floor area between 7:30 AM and 7:30 PM. Excessive area (Pink) from 9:30 AM – 5:30 PM implies possibility of overexposure usually >3,000 lux (280 fc). The peak rises around

2:30 PM, when up to 30% of the area is over lit. The aggressive spikes of excessive light previously seen in winter from January – March and November to December are significantly muted. While winter months still show more "Pink" than summer due to low sun angles

Figure 17. Floor plan showing UDI distribution of the simulated office using Sage electrochromic glazing (EC State 2 – medium tint) at 5% VLT.

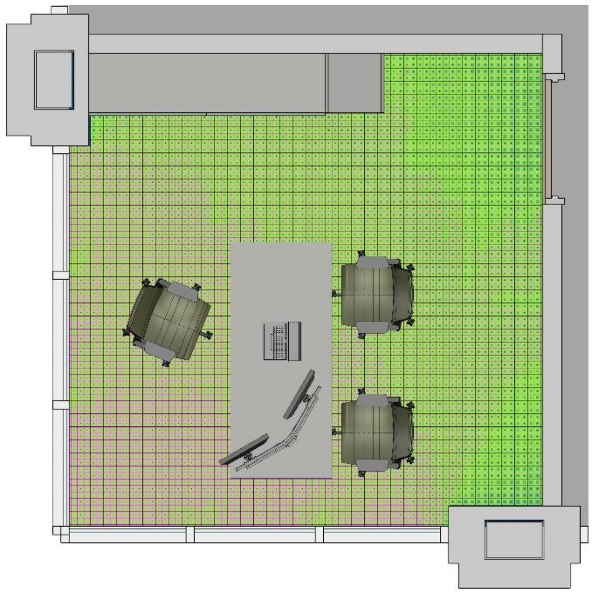
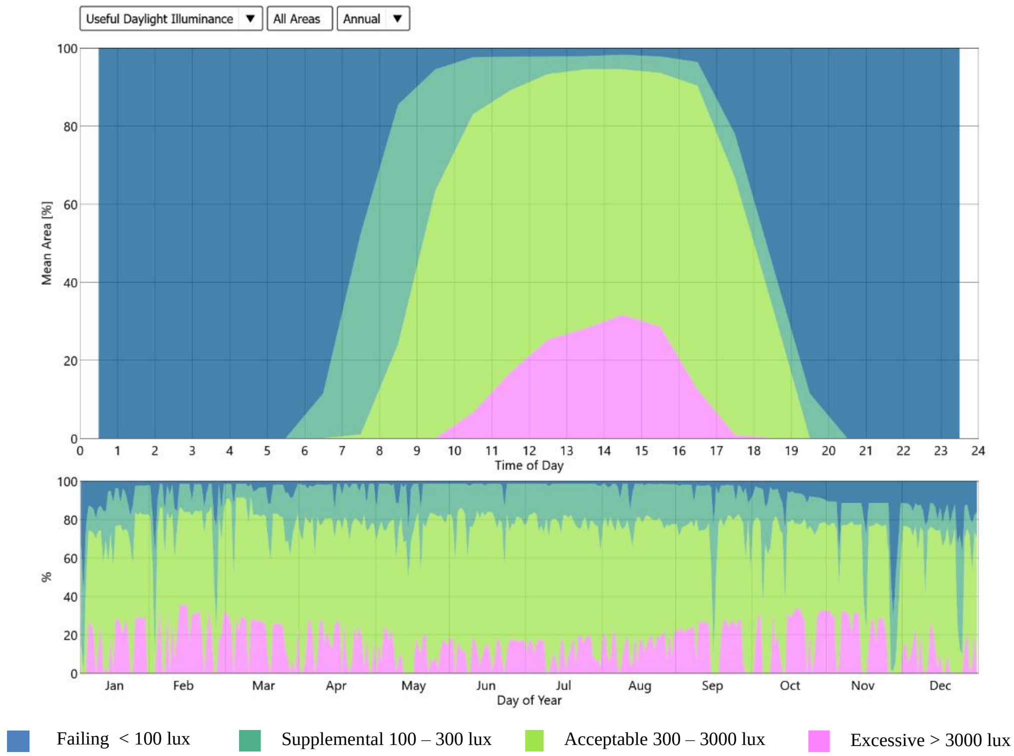


Figure 18. Average daily and annual graph of the UDI distribution for the simulated office floor plan for Sage EC glazing (EC state 2 – medium state) at 5% VLT



The DGP has a result of 68.4% for the electrochromic (EC) glazing at Tint State 2 with visible light transmittance (VLT) of 5% meaning 68.4% of the views in the space experience glare >5% of time. The floor plan as seen in Figure 19 still remains predominated by intolerable areas (red) across the space. However, compared to lighter tint states, there is a visible increase in imperceptible regions (grey), particularly in zones farther from direct façade exposure. The perceptible (yellow) and disturbing (red) glare are more noticeable as transitional zones between intolerable and imperceptible areas. The time of day trend in Figure 20 indicates that the space is glare free from 8:30 PM – 8:00 AM. However, glare begins to appear around 9 AM, and it steadily increases towards the noon peaking around 4:30 PM with about 30% of view hours falling within the intolerable (red) range. The annual distribution indicates perceptible (yellow), disturbing (orange) and intolerable (red) are more frequent but fluctuate from October through March but not as high as lighter tint state. From May through August, the glare probability is significantly low, staying consistent mostly below 10%.

Figure 19. Floor plan showing DGP distribution of the simulated office using Sage electrochromic glazing (EC State 2 – medium tint) at 5% VLT.

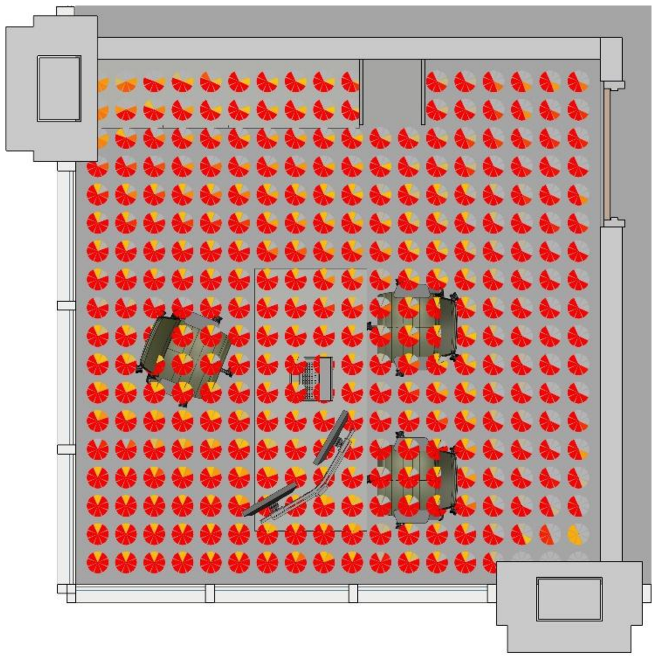
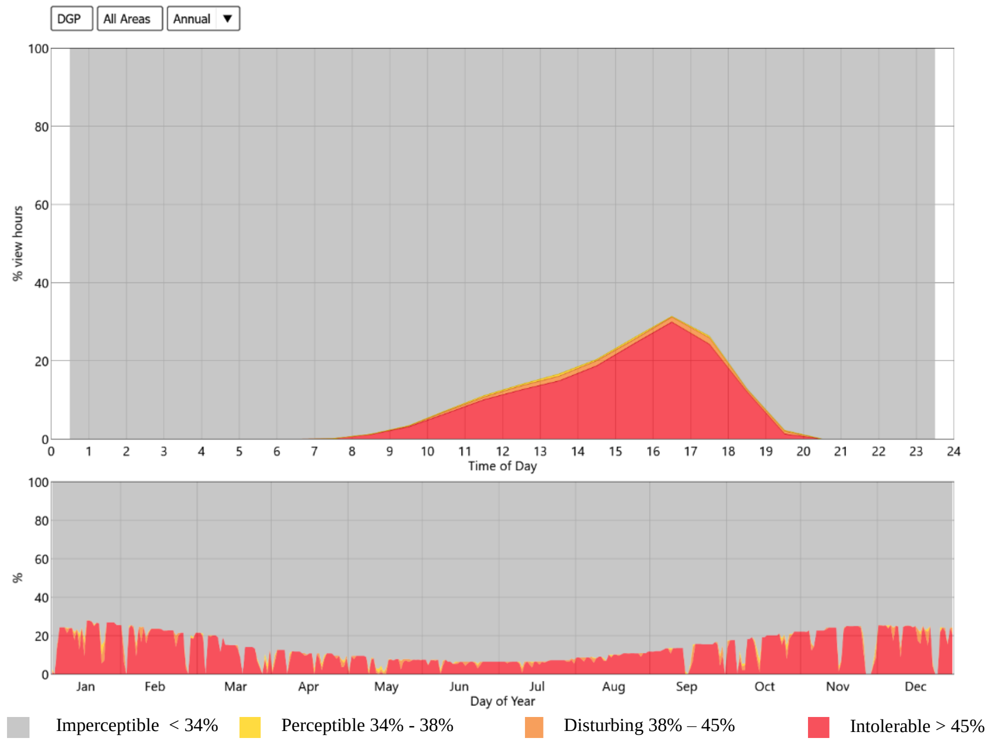


Figure 20. Average daily and annual graph of the DGP distribution for the simulated office using Sage Electrochromic glazing (EC state 2 – medium tint) at 5% VLT



EC State 3 (Dark Tint)

The recorded UDI results of 24% for the electrochromic (EC) glazing at Tint State 3 with visible light transmittance (VLT) of 0.9% shows a significant decline in useful daylight availability resulting in an under lit space. Figure 13 shows that most of the space falls below 100 lux (9fc) with only the perimeter and a small portion of the center achieving acceptable illuminance of 100 – 3000 lux (≈ 9–280 fc), and no area experiencing excessive light. According to the time-of-day analysis in Figure 20, useful daylight is limited to a small window between roughly 10:00 AM and 5:00 PM. During this period, acceptable levels only cover roughly half of the floor space, leaving the remainder underlit. This pattern is consistent throughout the whole year, with relatively little gains from acceptable daylight, even in the winter, and failing conditions predominating for a significant amount of the year. Overall, this tint state overcompensates by lowering daylight availability to insufficient levels.

Figure 21. Floor plan showing UDI distribution of the simulated office using Sage electrochromic glazing (EC State 3 – dark tint) at 0.9% VLT.

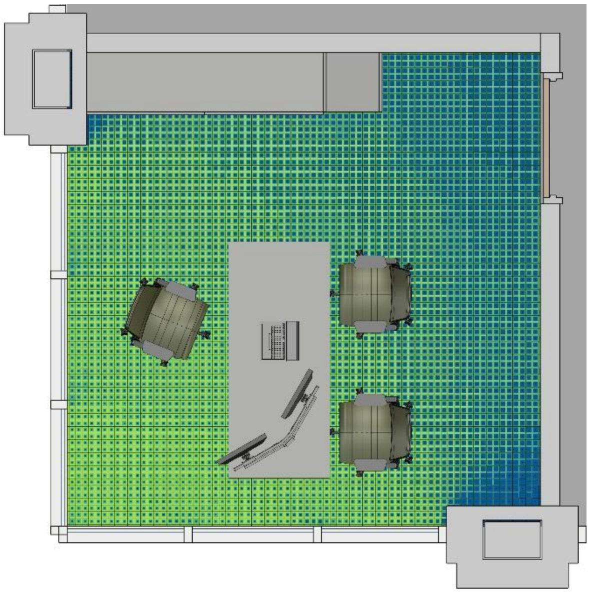


Figure 22. Average daily and annual graph of the UDI distribution for the simulated office floor plan for Sage EC glazing (EC state 3 – dark state) at 0.9% VLT

The DGP has a result of 55.9% for the electrochromic (EC) glazing at Tint State 3 with visible light transmittance (VLT) of 0.9% meaning 55.9% of the views in the space experience glare >5% indicating a significant improvement in glare control compared to higher VLT states. The floor plan as seen in Figure 23 shows that the darker tint successfully lowers brightness contrast and direct solar penetration by showing a noticeable increase in grey regions (imperceptible glare), particularly near the outer and deeper interior zones. Though they are less noticeable than in earlier tint states, red spots (unbearable glare) are nevertheless visible in some places of the workspace, especially in regions that are directly exposed to the façade. The time-of-day analysis represented in Figure 24 reveals that glare occurs within a more limited window, primarily between 10:00 AM and 6:00 PM, with peak conditions around 3:00 PM to 5:00 PM, where intolerable glare reaches approximately 20 – 25% of view hours, which is notably lower than lighter tint conditions. This improvement is further supported by the annual pattern, which shows a decreased frequency of glare throughout the year, with lower intensity in the summer and somewhat higher occurrences in the winter because of lower sun angles.

Figure 23. Floor plan showing DGP distribution of the simulated office using Sage electrochromic glazing (EC State 3 – dark tint) at 0.9%VLT.

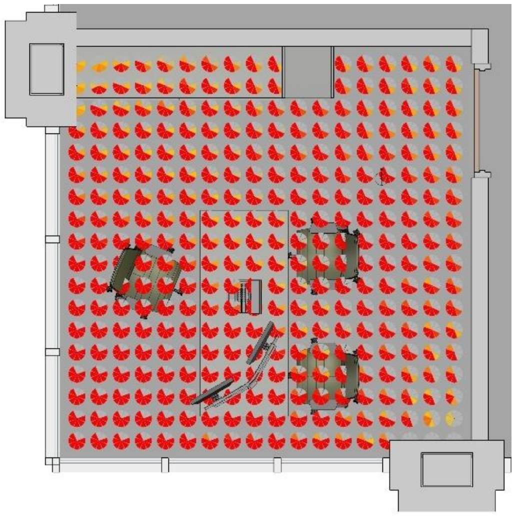
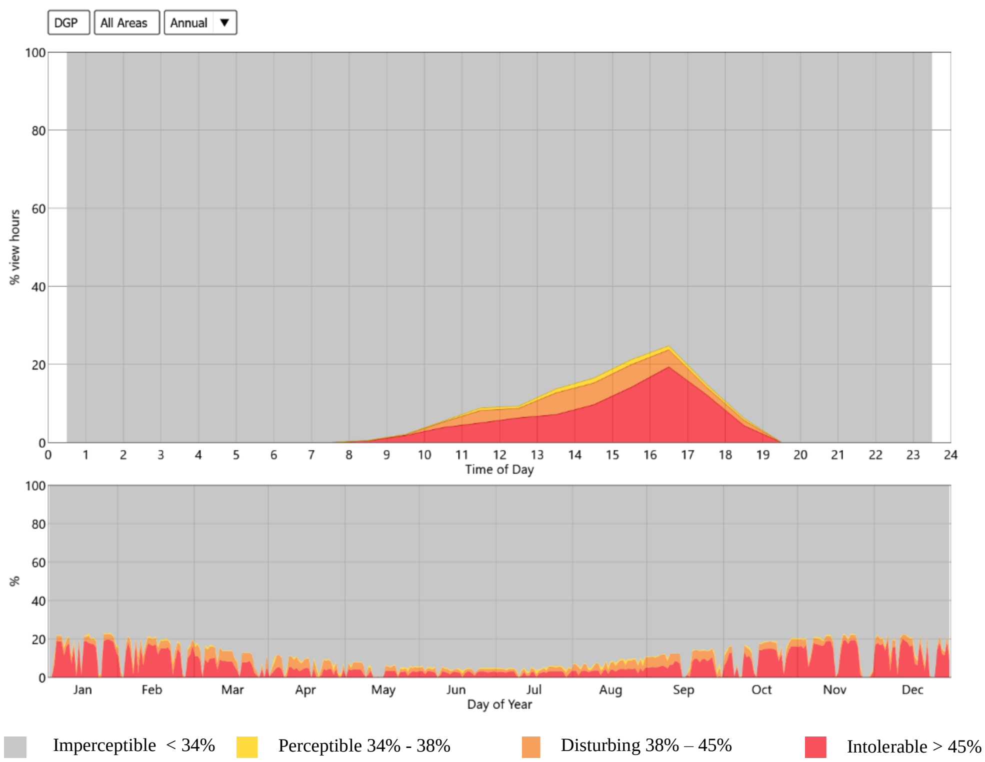


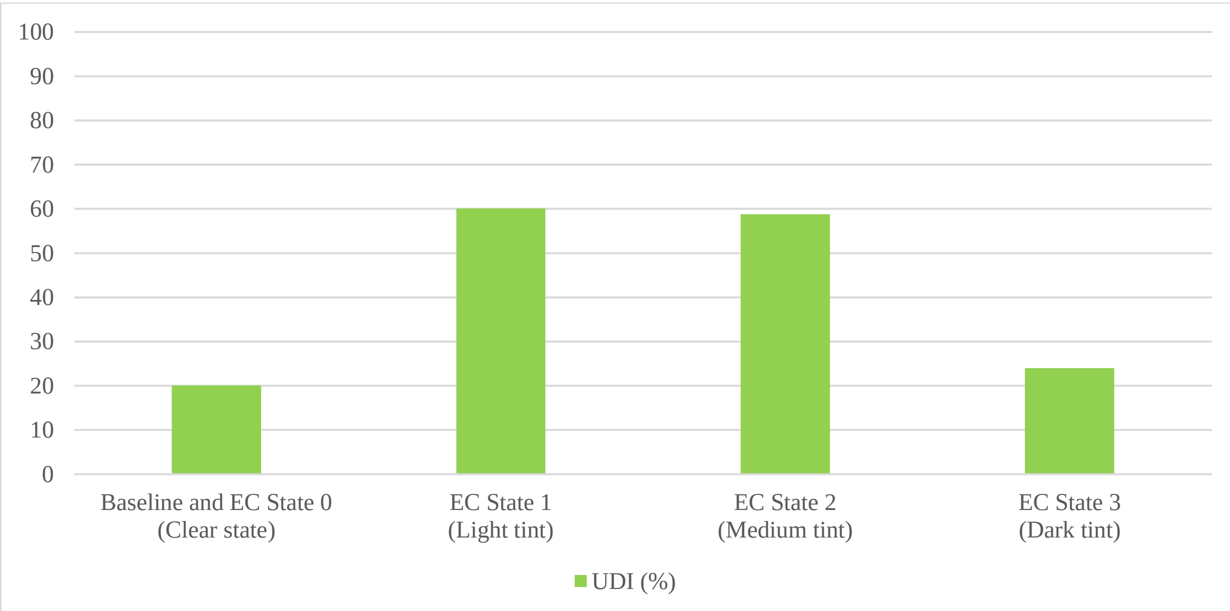
Figure 24. Average daily and annual graph of the DGP distribution for the simulated office using Sage Electrochromic glazing (EC state 3 – dark tint) at 0.9% VLT



Comparison

Figure 25 and Figure 26 shows the comparison between Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP) across the different glazing states. This trade-off is crucial to comprehending the performance of both conventional and electrochromic glazing systems.

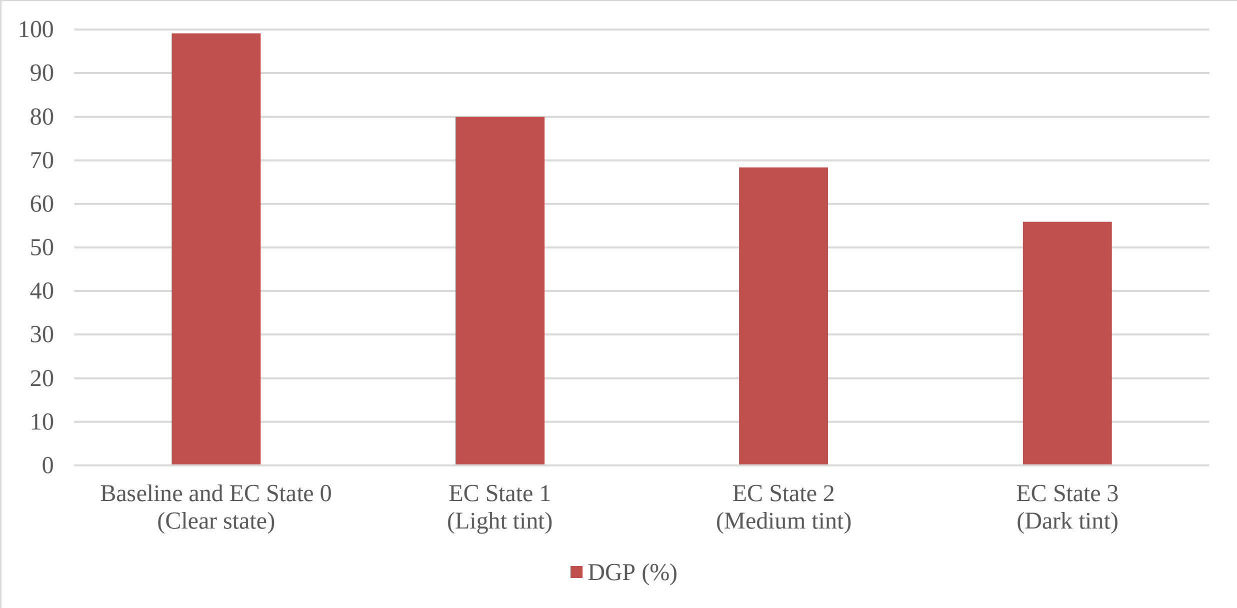
Figure 25. Comparison of UDI metrics across the different glazing states



The space performs poorly in terms of daylight usability in the baseline and EC clear condition (60% VLT), with a low UDI of about 20%, while glare is very strong, approaching 100% DGP. This suggests that although while a lot of daylight enters a space, it is primarily uncontrollable and excessive, which causes extreme visual discomfort. Because glare dominates the occupant experience, the environment in this state is over lit yet unusable.

Daylight performance significantly improves with the switch to EC State 1 (17% VLT), as UDI rises to almost 60%, meaning that more than half of the area is now within the useful illuminance range of 100 – 3000 lux (≈ 9–280 fc).

Figure 26. Comparison of DGP metrics across the different glazing states



From Figure 26 DGP decreases to about 80% at the same moment, indicating some glare reduction. Even though daylight is now more useful, glare levels are still high, indicating that visual discomfort is still a significant problem, especially during winter periods when the sun is at a lower angle.

The two metrics are more favorably balanced in EC State 2 (5% VLT). While DGP further decreases to around 68%, indicating a more pronounced decrease in glare, UDI stays reasonably high at about 59%, suggesting that daylight availability is still beneficial. This condition is a compromise where there is enough daylight and some control over glare. Glare is still present at levels that could compromise occupant comfort, so while the area has been improved, it is still not at its best.

Glare is greatly reduced at the darkest tint, EC State 3 (0.9% VLT), with DGP falling to about 56%, the lowest of all states. This demonstrates that the tint reduces direct sunlight penetration and brightness contrast. The majority of the area becomes underlit and dependent on artificial illumination as a result of this improvement, though, since UDI falls drastically to around 24%.

The benefits of daylighting, such as energy savings and improved visual performance, are diminished in this situation since the area does not receive enough daylight.

Overall, the comparison shows that there isn't a single static glazing state that best meets the needs of glare reduction and daylight availability. While lower VLT values decrease glare but result in insufficient daylight, higher VLT values cause excessive daylight and extreme glare. The mid-tint range (EC States 1 and 2) offers the most balanced performance, however even these don't completely eliminate glare problems. This highlights the significance of dynamic electrochromic operation, in which the glazing can adapt to changing external circumstances to sustain sufficient visual comfort (DGP) and adequate daylight (UDI) throughout the day and year.

Chapter V: Conclusion and Discussion

The results apply to a typical private office under extreme daylight conditions, and based on the results, useful daylight illuminance (UDI) and daylight glare probability (DGP) are directly and inversely affected by the various electrochromic (EC) glazing states. While DGP continuously lowers, UDI first improves and then declines as the glazing moves from clear to darker tint states. The area has very high glare (≈100% DGP) and low useful daylight (≈20% UDI) in the clear state (60% VLT), suggesting that excessive, uncontrolled lighting reduces visual comfort. Although glare is still an issue, adding tint (EC State 1 – 17% VLT) greatly increases daylight usability (≈60% UDI) while lowering glare (≈80% DGP). The best balanced state is achieved by additional tinting (EC State 2 – 5% VLT), which maintains strong UDI (≈59%) and delivers a more apparent decrease in glare (≈68% DGP). Nevertheless, glare is further reduced (≈56% DGP) in the darkest state (EC State 3 – 0.9% VLT), but UDI significantly decreases (≈24%), creating an underlit space. Optimal daylighting should minimize glare and eye discomfort while providing adequate illumination (usually 100–3000 lux/9–280 fc), according to LEED standards. In comparison to lighter states, EC State 2 (5% VLT) preserves a high percentage of practical daylight while lowering glare to a more tolerable level, resulting in the best balance in a typical private office with extreme daylight conditions. While the darkest condition sacrifices too much daylight and the lighter states are unable to effectively reduce glare, it provides the closest alignment with both daylight adequacy and visual comfort criteria, even though it does not totally eliminate glare.

Spatial function

In terms of spatial function, the various tint states not only affect office workspace efficiency but also indicate suitable uses in other building types and zones where their features might be beneficial. The strategic application of different electrochromic glazing tint states based on daylight exposure and spatial function is supported by guidelines from Lawrence Berkeley National Laboratory and the U.S. Department of Energy (*Berkeley Lab | Delivering Science Solutions for the World*, n.d.), (*National Laboratories*, 2026) . In north-facing workplaces, inner zones, circulation areas, and collaborative spaces, when maximizing daylight penetration and visual connection is needed with little glare danger, the clear state (VLT ~60%) works best. For general peripheral offices and task-based work areas where a balance between daylight availability and glare management is needed throughout the day, intermediate tint states (VLT ~17%–5%) are more appropriate. For south and west-facing façades, peripheral workstations exposed to direct sunlight, conference rooms with digital displays, and other glare-sensitive settings, the fully tinted condition (VLT ~0.9%) is ideal because it reduces excessive illuminance and maintains Visual comfort levels. This performance-based application supports the use of various electrochromic tint states based on orientation and space function in accordance with recommendations from the U.S. Green Building Council, which stress striking a balance between glare mitigation and daylight sufficiency (*USGBC | U.S. Green Building Council*, n.d.).

Other design principles supporting visual comfort

Beyond glazing choices, the study argues that efficient office design necessitates a comprehensive daylighting approach that considers a variety of environmental and spatial aspects. Shading systems should be used with electrochromic windows to limit direct solar penetration and increase glare management, while high-reflectance interior surfaces improve daylight distribution deeper into the area without increasing discomfort. Office layouts should be designed to maximize daylight penetration by utilizing shallow floor plates, open formats, and selective workstation placement, ensuring equitable access to natural light. At the same time, regulating the brightness contrast between bright facades and interior surfaces is critical for reducing ocular strain.

Artificial lighting systems should be combined with daylight-responsive control systems to ensure consistent illumination and energy efficiency. The findings also highlight the necessity of keeping external views while minimising glare, as well as zoning spaces based on lighting sensitivity, with high-focus areas necessitating greater control. Finally, giving users more control over environmental variables can improve comfort and happiness. These concepts show that high-performing office settings require a coordinated strategy that matches facade systems, interior materials, spatial layout, and lighting controls to promote visual comfort and occupant well-being.

Limitations

This study has various limitations related to the simulation-based technique, spatial design, climatic data selection, and the scope of performance measurements. First, relying on simulation tools provides implicit assumptions about sky conditions, material qualities, and occupant behavior, which may not properly replicate real-world variation. While proven engines, such as those contained in ClimateStudio, achieve high levels of accuracy, the findings are predictive rather than empirical. Second, the analysis is based on a fixed office layout, including workstation placement, furniture configuration, and viewing direction, and does not take into consideration dynamic occupant behavior or different spatial configurations that may affect daylight distribution and glare perception. Third, the use of a single climatic dataset, specifically, the Typical Meteorological Year (TMY) file for Oklahoma City, limits the findings' applicability to other geographic regions with varied solar profiles and atmospheric circumstances. Finally, the study focuses primarily on visual comfort metrics, namely Useful Daylight Illuminance (UDI) and Daylight Glare Probability (DGP), without taking into account other critical performance indicators such as thermal comfort, energy consumption, or occupant physiological responses, which are required for a more comprehensive evaluation of electrochromic glazing systems.

Future Research

Future studies should address these limitations by combining simulation and empirical methods to give a more comprehensive validation of findings. Field investigations with real occupants in controlled office spaces outfitted with electrochromic windows could help close the gap between predicted and actual performance. Furthermore, future research should look into different office layouts and adaptive workplace setups to better understand how spatial variability affects daylight distribution and glare perception. Expanding the investigation to encompass other climatic contexts outside of Oklahoma City would improve the results' application to a variety of environmental conditions. Furthermore, integrating additional performance metrics such as thermal comfort, energy consumption, and circadian lighting effects would provide a more comprehensive picture of building performance. Future research could also use data-driven approaches, such as machine learning integrated into BIM environments, to predict optimal electrochromic tint states based on occupant preferences, time of day, and environmental conditions, paving the way for more adaptive and occupant-centered façade systems.

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