Out of the Blue

eyrise® Dynamic Liquid Crystal Windows

ELEMENTA

eyrise®

CONTENTS

INTRODUCTION

Façade design is playing a crucial role in building performance as a substantial portion of energy losses and gains in buildings occur due to glazed surfaces[1]. Therefore, optimising façade solutions has become the primary focus in order to mitigate carbon emissions associated with the built environment. Energy efficient and low-carbon building design has developed rapidly in recent years, with cities around the world investing on low or zero emissions buildings as a way of contributing to reduce greenhouse gas emissions in order to tackle climate change.

At the same time, with constant technological innovation, the creation of "digitally-enhanced" built environment is also increasing in popularity. Smart buildings and more specifically smart façade design are considered an essential part of a building's adaptation to environmental and climatic variations.

In today's market, a high performance building is expected not only to minimise emissions and support digitalisation, but also to promote health and well-being for its occupants. With people spending almost 90% of their day inside buildings[2], research has shown that the quality of the built environment is significantly impacting human health, driving building design to a more human centric approach. Recently developed building standards, such as the WELL Building Standard™, Fitwel, and The Living Building Standard™, are promoting human centric design putting occupant's health and well-being at the forefront of building design, construction and operation.

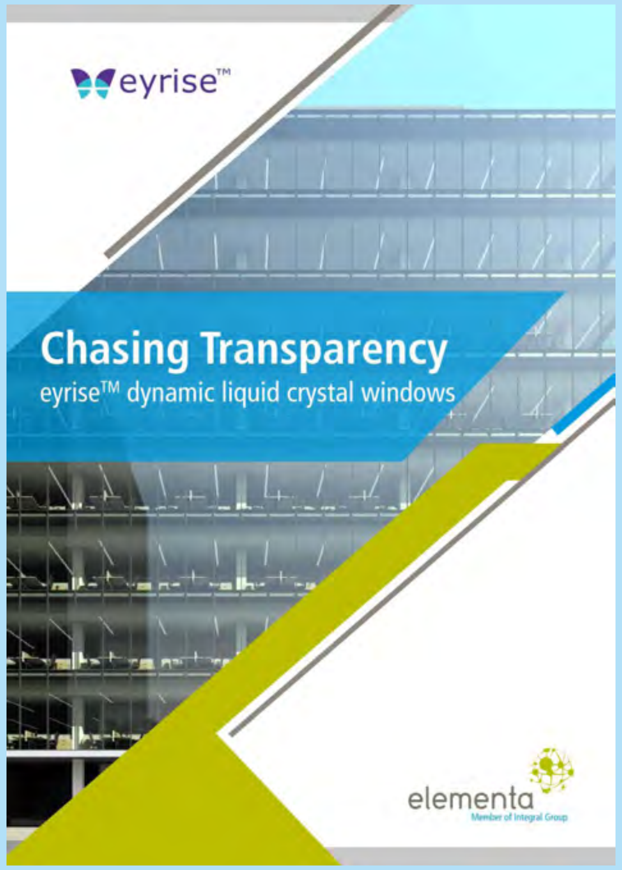
"Dynamic" or "smart" glazing has increased in popularity in recent years, due to the flexibility it offers compared to static façade design solutions. The most commonly used type of this façade technology is the electrically switchable dynamic glass, which alters its optical and thermal properties when it is exposed to voltage. Building designers are increasingly considering dynamic glazing as a compact solution that optimises solar control, energy performance and visual comfort, while providing opportunities for increased daylight and external views.

Most electrically switchable dynamic glass products on the market currently use electrochromic technology - details regarding how the technology works are included in the following section. However, this technology has met some resistance due to limitations such as slow switching speeds and a characteristic blue glass appearance in tinted states, which can have a significant impact on the visual quality of the indoor environment, affecting the perceived colour and brightness of illuminated objects.

Merck Window Technologies B.V., an affiliate of Merck KGaA, Darmstadt, Germany, have developed a dynamic glass product, known as eyrise®, which uses an alternative technology of liquid crystal molecules and offers a dynamic glazing that can switch incredibly fast and presents a colour-neutral appearance.

As result of a collaborative research study between Elementa Consulting and Merck Window Technologies B.V., this report aims to provide a comparative study between. eyrise® liquid crystal glass technology and electrochromic glass technology, focusing on the impact they have on occupant's health and well-being.

These technical investigations have been assembled into three sections within this report – Colour Rendering, Switching Speed and Circadian Well-being, and compare the performance of the different technologies against a common aspect.



The first research study "Chasing Transparency" examines the performance of eyrise® Dynamic Liquid Crystal Windows technology compared to typical well established façade design solutions.

Download here

TECHNICAL BACKGROUND

Electrically switched dynamic glass technology has the ability to control the amount of daylight and heat that they transmit in response to external climatic variables or according to occupants' requirements.

Electrochromic windows include materials (thin-films of ceramic metal oxides) that have the capability to change their colour as a result of a chemical reaction which happens when electrical current is applied. This change in colour, from a bright tint to a darker tint, aims at protecting the occupants of the interior spaces from the sun heat and glare. The technology, however, has exhibited some important limitations, most notably its typical blue colour hue in tinted states and its slow transition speed.

More specifically, the first generation electrochromic technologies appear to have a yellow hue in their clear states and blue hues across their darker states, while the transition process can take up to 30 minutes depending on window size. Second generation electrochromic technologies, on the other hand, appear more colour neutral in their bright states and they tend to have a milder blue colouration in their tinted states, while they have improved their transition speed to approximately 3 minutes, again depending on window size.

The alternative electrochromic solutions selected for this study represent two different technological generations of electrochromic glass, currently available in the market.

Table 1 on the right presents the three products under comparison, listing the main attributes of each technology retrieved from the product brochures.

Each dynamic product, including eyrise®, has been simulated using Lawrence Berkeley Laboratory's WINDOW and OPTICS software to create material definitions that accurately depict the spectral variation of light transmittance and reflectance. These material definitions were then used to generate physically-accurate renderings from different view positions, for each of the product alternatives. Figure 1 on the right illustrates the optical properties of the three products under comparison at their bright state, as they appear in OPTICS software. The part highlighted in yellow within the graphs indicates the visible light spectrum range of wavelenghts between 380nm to 740nm.

Table 2 on the right, summarises the optical performance of the products at their bright and tinted state. Mixtures B and E referenced for eyrise® constitute the liquid crystal mixtures that form the two different glazing units examined in the study. These two mixtures were selected to make accurate comparison possible between the different products and to examine the three different technologies under similar transmittance levels.

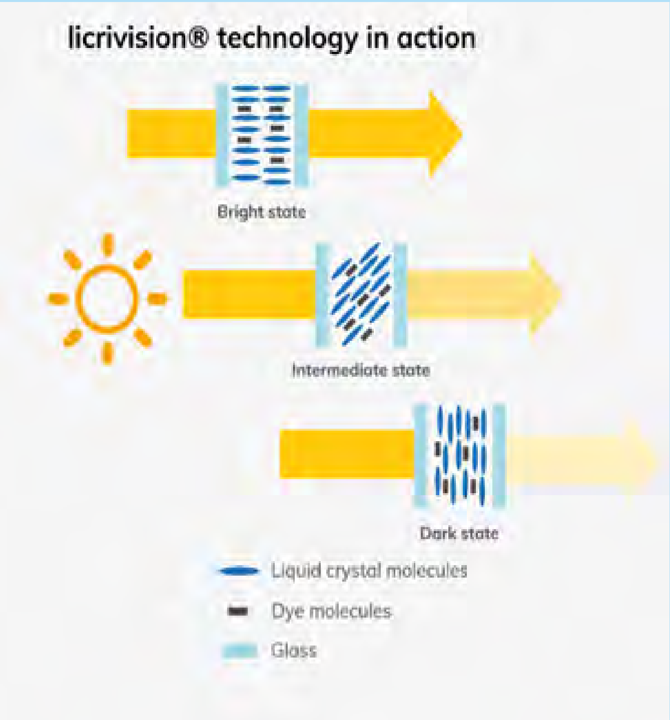


Figure 2: licrivision® technology - The heart of eyrise® windows

eyrise® is an innovative technology which answers customers' needs and overcomes the limitations of typical electrochromic glass technologies. The product uses an alternative technology based on liquid crystal molecules known as licrivision®.

licrivision® is a transparent material comprising a mixture of dyes and liquid crystals and is applied between two panes of glass that have an invisible conductive coating. As a low voltage is applied to the licrivision® layer, the crystals alter their orientation, thereby changing the position of the colour molecules (Fig. 2). The position of these molecules determines the tint of the system, which affects whether the glazing is perceived as bright or tinted.

eyrise® window is able to transition between tinted and bright states in less than a second, with continuous control for intermediate shading states Additionally, the product offers an identical neutral colouration from bright to dark states.

Table 1: Main attributes of products under comparison

	eyrise® Liquid Crystal Glass	Electrochromic Generation II	Electrochromic Generation I
Product Launch	2018	2016	2005
Composition	Solution of liquid crystals	Improved ceramic materials	5 layers of ceramic materials
Switching Speed	1 second	3 minutes*	15 minutes**
Colouration	Neutral	Mild blue	Heavy blue

*depending on panel size (brochure statement)
** for a medium size panel to reach 90% of its tint range at room temperature (brochure statement)

Figure 1: Optical properties of products under comparison

eyrise® Liquid Crystal Glass | **Electrochromic Generation II** | **Electrochromic Generation I**

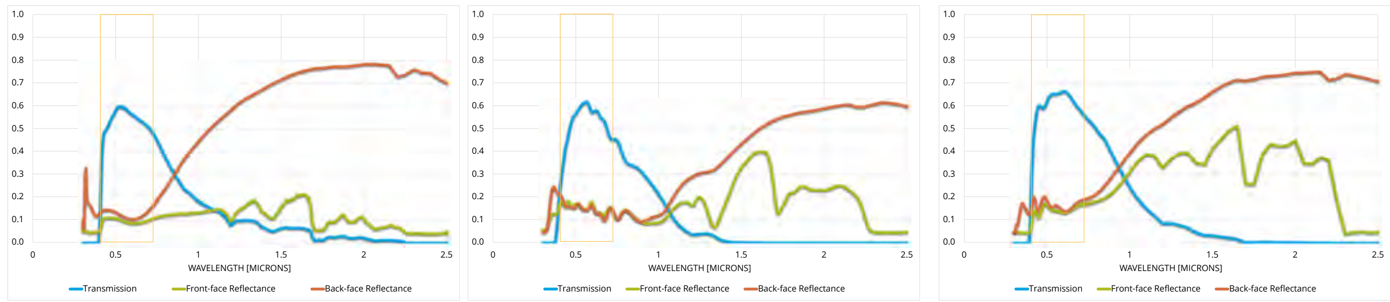
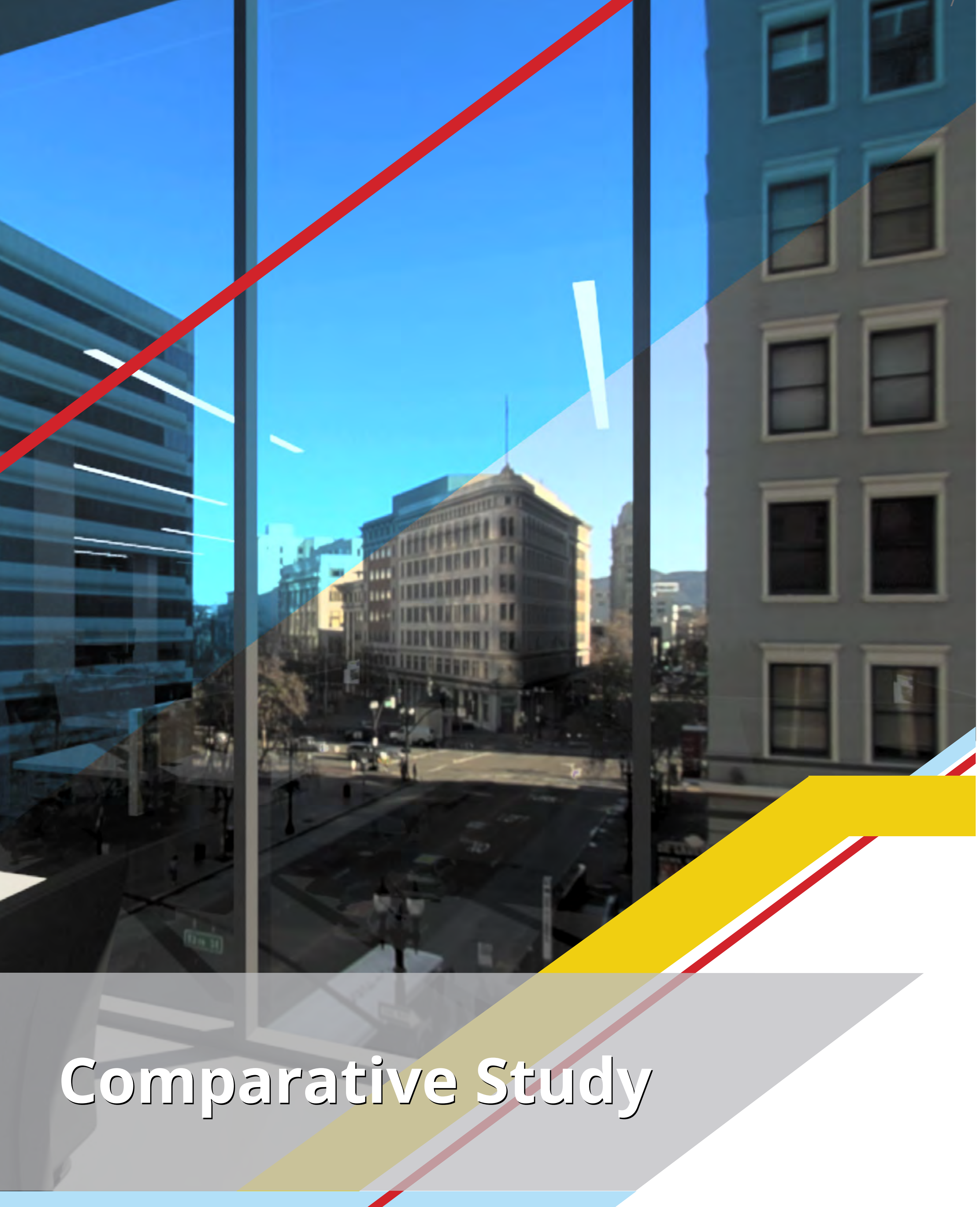


Table 2: Performance data of products under comparison, calculated in accordance with EN410

		eyrise® Liquid Crystal Glass 21.4-16-6		Electrochromic Generation II 10.8-15-4		Electrochromic Generation I 7-12-4	
		Bright State (Mixture B)	Tinted State (Mixture E)	Bright State	Tinted State	Bright State	Tinted State
Visible Light	Transmittance, T(%)	57	2	65	2	60	0.9
	Front Reflectance, Rf(%)	10	6	14 (15)	6	16	11
	Back Reflectance, Rb(%)	12	9	16	12	15 (14)	10 (9)
Solar Energy	Transmittance, T(%)	35	10	40 (41)	0.9 (1)	34 (33)	0.4
	Front Reflectance, Rf(%)	11	9	20 (21)	13 (11)	15	11
	Back Reflectance, Rb(%)	29	28	28	27	19	17
	g-value (%)	39	15	44	7 (5)	40 (41)	7 (9)

The values within the table have been derived from OPTICS software (the values within the parenthesis indicate the values stated in the product brochure).



STUDY METHODOLOGY

This study compares two different electrically switchable dynamic glass technologies currently available in the market, the electrochromic glass technology and the recently developed eyrise® liquid crystal glass technology for solar control. The focus of this comparative study is not on energy savings and building performance but on the impact of the technology on human experience, health and well-being.

The main emphasis has been given on the two aspects that mostly differentiate the two technologies, the colour rendering and the switching speed across the tint range. eyrise® has achieved colour neutrality across all tint states, maintaining a neutral gray colour tone while it also offers the capability to switch between the different states in less than a second. On the other hand, electrochromic technology often recieves negative feedback due to the blue colour rendering when in its tinted state and slow response times which can vary from 5 to 30 minutes.

More specifically, eyrise® technology is compared with two different electrochromic glazing products currently available in the market. One utilises what is known as “Generation I” electrochromic technology, while the other uses “Generation II” electrochromic technology. More details on the different products chosen for this study were presented in the previous section.

For this study, a series of visualisations and daylight analysis has been performed using best practise lighting simulation tools. The report is presented in three main chapters – Colour Rendering, Switching Speed and Circadian Well-being.

Colour Rendering

This section of the report explores the colour rendering performance of the different dynamic glass technologies in various tint states. In order to compare the three products, an accurate representation of each product has been established, using technical data that describe how the optical properties of each glass surface vary across the visible spectrum. This has allowed for physically accurate visualisations to be generated for different tint states of the products, which were then used as a basis of comparison.

The simulations have been conducted using Radiance in its native Unix form, a research grade simulation tool based on the physics of light and material properties. The simulation outputs are High Dynamic Range (HDR) images, with data-rich pixel information containing both luminance (brightness) and colour data. These images have been processed with a tone mapping algorithm that uses HDR data to produce a rendered image which strongly correlates with human vision.

Switching Speed

In this section the impact that transition time of the two different technologies – liquid crystal glass and electrochromic glass - has on glare control is examined, focusing on aspects such as maintaining a comfortable working environment that supports productivity, ability to focus and visual comfort.

For the comparison to be conducted, fisheye renders from an occupant’s point of view have been generated, using the same software and methodology as the renders of chapter “Colour Rendering”.

Circadian Well-being

The WELL Building Standard adopts a metric known as Equivalent Melanopic Lux (EML), which weights an occupant’s exposure to light based on the response of the eye’s non-image forming photoreceptors that have the ability to regulate various body functions.

The purpose of this section is to explore the impact on EML of both the eyrise® product and the two electrochromic alternatives to identify which provides better support for circadian body functions.

The analysis has been conducted using a new circadian lighting design software, Alfa. Alfa is a plugin to the 3D modelling software Rhino, and uses Radiance to perform raytracing calculations based on spectral material and sky information.

01 COLOUR RENDERING

This section aims to investigate and compare the visual appearance of eyrise® dynamic liquid crystal window and the two electrochromic glass alternatives, when applied in an office building.

More specifically, the section looks at the appearance of the three products under different tinted states focusing on the colouration effect and how this impacts the surrounding environment. The appearance of the products is examined in their bright state and their lower tinted state, as well as two mid-state levels.

Two sub-sections are presented in the following pages, one examining the impact of colour rendering on exterior views and the other on the interior environment.

Impact on exterior views

One of the key benefits of dynamic glass is its ability to provide solar protection without obstructing the occupant's view of the external environment. Studies have shown that access to natural light and views of the outdoors not only have a positive impact on occupant health and well-being[3], linking to the relief of boredom, anxiety, and stress, but they are considered by the employees as the number one office perk[4].

But what if the external view is distorted by a blue colouration? How would that impact occupants perception of the external environment and their overall well-being?

This section investigates and compares the appearance of eyrise® with that of the two electrochromic alternatives regarding colour rendering and its impact on exterior views.

Physically accurate renders using the spectral optical data for each product have been created in four different states and the impact that colour rendering has on the occupant's perception of the outside environment is discussed.

The physically accurate renders have been created from an ocucpant's point of view, looking from inside the office to the outside. For the exterior view, a real urban landscape photograph of an office view has been used to assess the colouration of the scene at different tinted states of the products under comparison.

Impact on interiors

The quality of the interior workspace environment plays a key role on occupants' mood and productivity[5]. More specifically, the illumination of the interior environment, the intensity and colour of light, affects the behavioural, psychological and health conditions and overall well-being of occupants[6]. Additionally, studies have revealed that presenting food under coloured light affects appetite[7,8].

Apart from occupant mood and productivity, substandard illumination of the indoor environment can have a significant impact on spaces such as exhibition halls, museums and art galleries where the accurate appearance of the objects under exposition is very important.

This study, using physically accurate renders, explores the occupant's perception of their interior environment during different tinting states of eyrise® glass and the two alternative electrochromic glazing products.

The renders capture a typical internal office environment where specific objects have been intentionally located in the scene, in order to be used as reference for the comparison of the colouration effect.

More specifically, an apple and a banana have been positioned in the scene in order to assess the impact of blue colouration on the appearance of food. Additionally, a ColourChecker chart can be seen. The ColourChecker chart is a rectangular colour chart that presents 24 different colour patches, mimicking those of natural objects such as human skin, sky, and flowers. This chart is often used as a reference tool for spectrophotometric measurements and colour calibration purposes. Similarly, the purpose of the ColourChecker chart in the internal office renders is to be used as a reference tool to assess the degree of colouration. A famous art painting has been also positioned at the office wall, as a way to examine how blue colouration can distort the appearance of art objects, such as in galleries. Finally, the scene includes various coloured objects, i.e. purple planter boxes, which contribute to the overall comparison.

COLOUR RENDERING

IMPACT ON EXTERIOR VIEWS

This sub-section focuses on the appearance of an office exterior view, under clear sky conditions, looking through the different dynamic glass products under comparison.

The images to the right show a perspective view of someone standing inside the case study office building, and looking outside.

The first column illustrates the eyrise® product in different states from bright to fully tinted. The images indicate a very neutral colour rendering throughout the different states, in accordance with the product's Colour Rendering Index (CRI) of 96 at the bright state (visible light transmittance 57%) and 74 at the fully tinted state (visible light transmittance 2%).

The second column illustrates the second generation electrochromic product, which features less colour neutrality, especially at the darker states, where a blue hue is more noticeable. From the renders, the colour distortion of the appearance of the external environment can be perceived, when comparing the colours of the external objects (opposite building wall) through eyrise® and through the Generation II electrochromic products.

The third column illustrates the first generation electrochromic product at similar transmission states. A yellow hue is noticeable at the bright state, when comparing with the other two products. Additionally, the blue colouration is noticeable through all the different tint levels, with the darker ones being the more intense.

In conclusion, the renders presented in this section clearly illustrate the colour neutrality of the eyrise® product across its different states. Blue colouration can be perceived during the darker states of all electrochromic alternatives, which is distorting occupant's exterior views.

Larger images have been included in the Appendix.

Basis of assessment

Time: 2pm

Date: June 21st

Sky condition: Clear, sunny sky

View: Outside

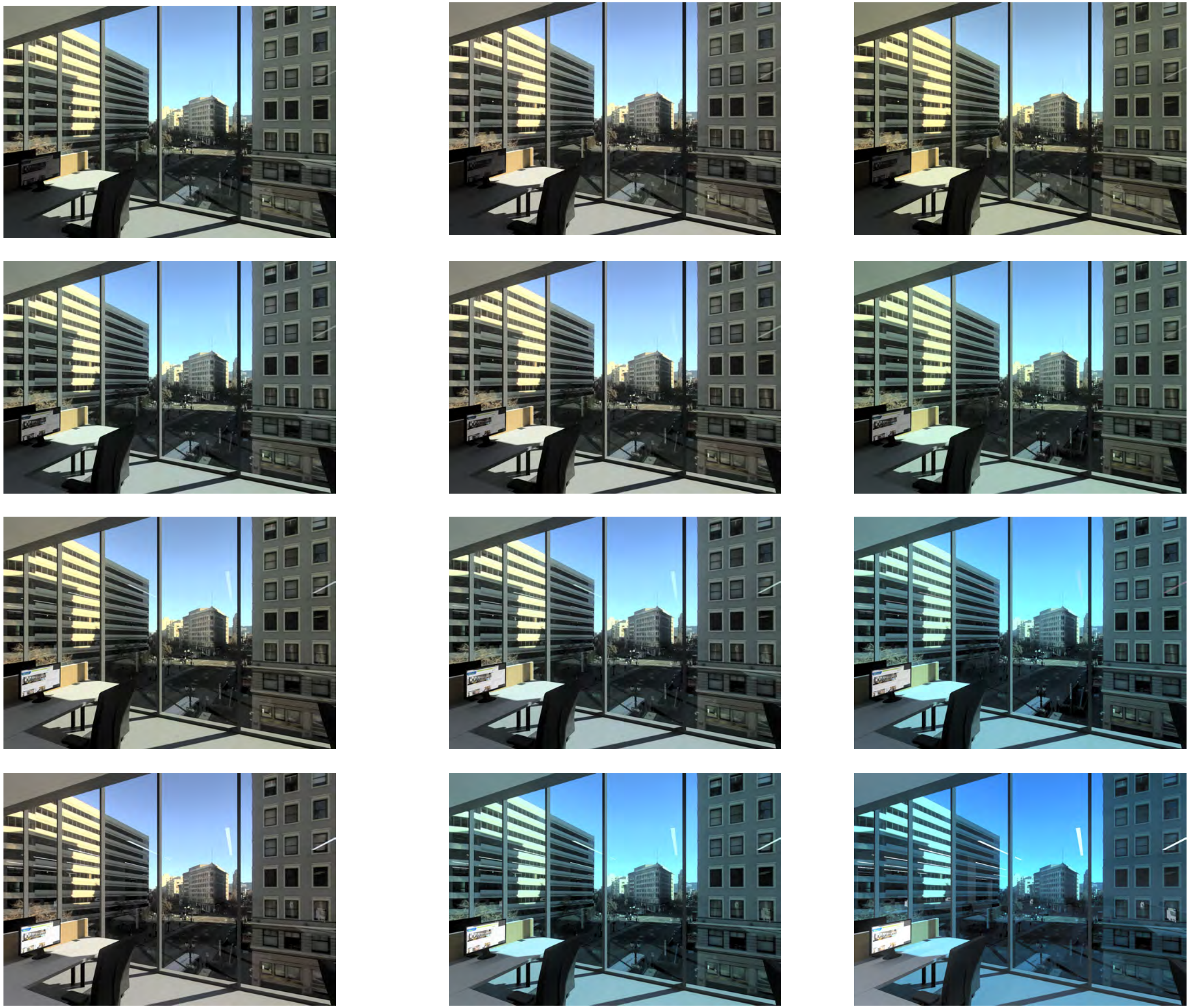
eyrise® | Electrochromic Generation II | Electrochromic Generation I

Bright State

Mid-State I

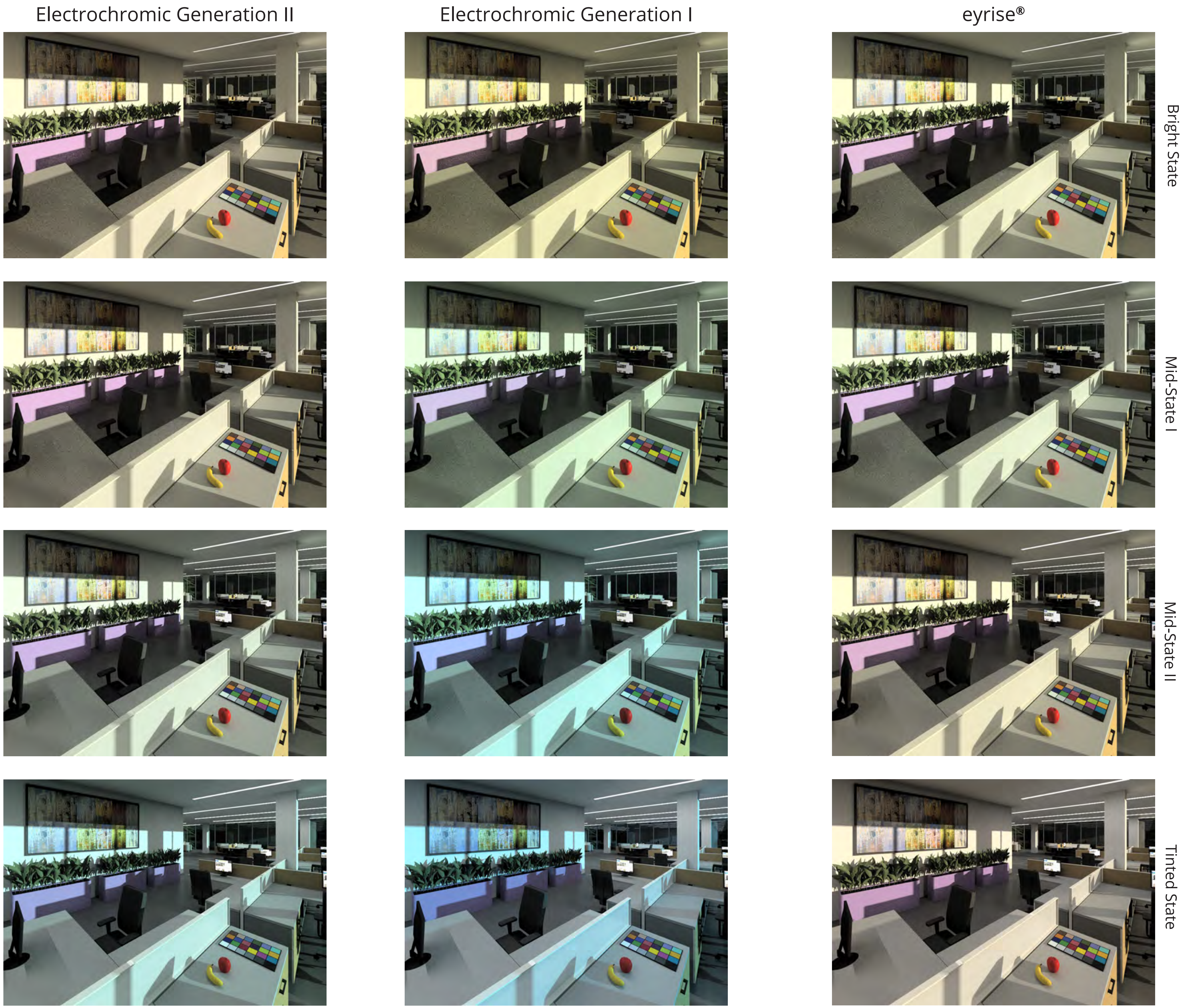
Mid-State II

Tinted State



COLOUR RENDERING

IMPACT ON INTERIORS



This sub-section illustrates the visual appearance of an internal environment where the different dynamic glass products are applied.

The images to the left show a perspective view of someone standing inside the case study office building, this time looking inside. The setting of this assessment is a winter morning condition, where low angle sunlight enters the office space and the dynamic glass products need to be tinted.

In the scene, apart from the usual office furniture, a selection of objects have been positioned in order to be used as a reference to the comparison between the three alternatives. By focusing on the objects within the images, it is possible to assess the impact of blue colouration that is a result of the alternative electrochromic products.

The images in the second and third column illustrate a similar level of blue colouration appearing at the tinted states of the electrochromic products, while the scene maintains a neutral colour through all the states of eyrise®.

These comparisons are easier to make when looking closer to the reference objects. The following pages show a closer view of these objects, making it easier to perceive the impact of the blue colouration across the scene.

As in the previous section, the renders presented in this section demonstrate that the blue hue appearing in the darker states of the electrochromic alternatives have a significant impact on the perceived colouration of the surrounding objects within the office environment. On the other hand, eyrise® maintains a neutral colour across its different states, thus not distorting the appearance of the objects.

Larger images have been included in the Appendix.

Basis of assessment

Time: 10am

Date: December 21st

Sky condition: Clear, sunny sky

View: Inside

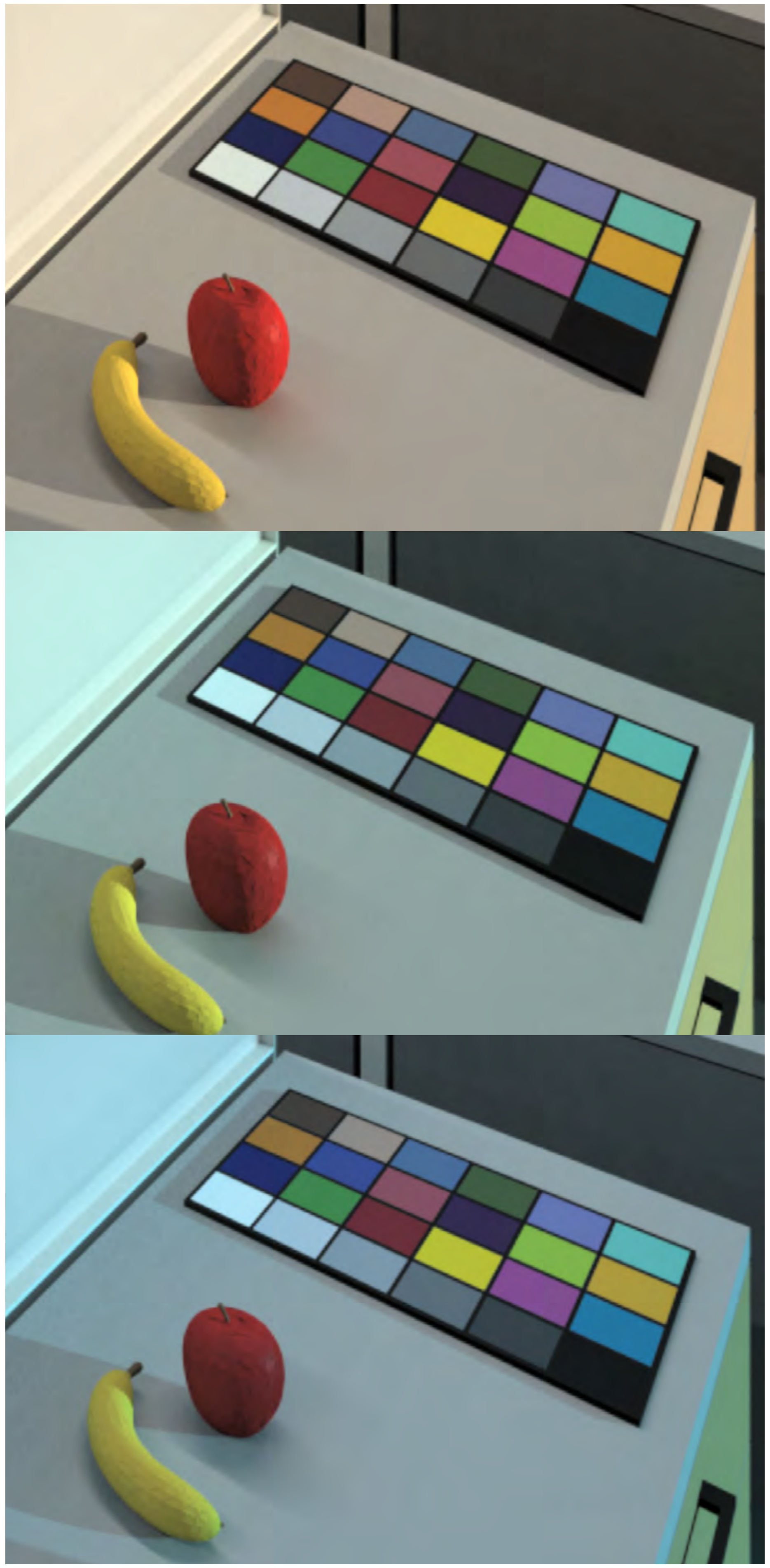
COLOUR RENDERING

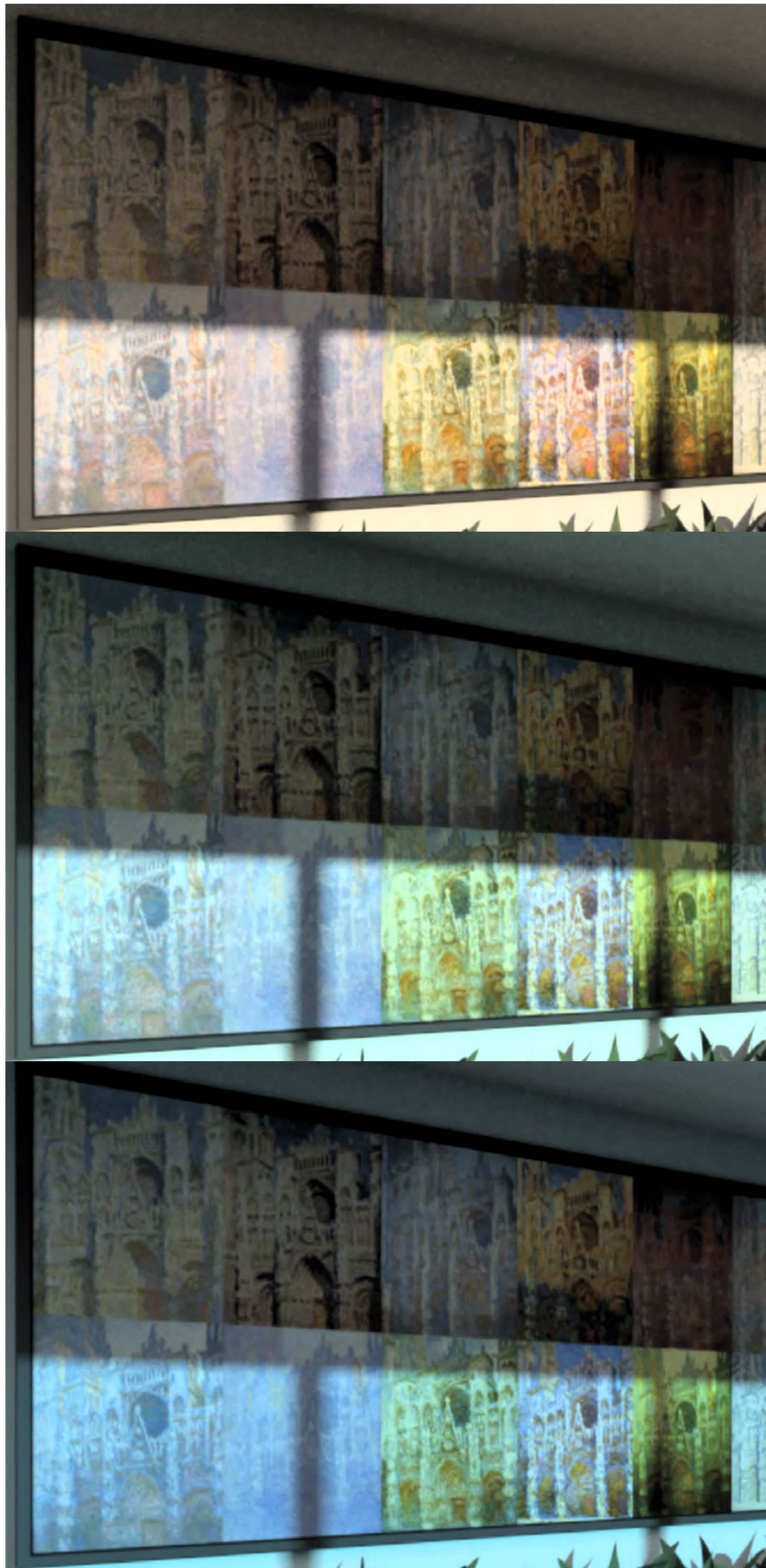
IMPACT ON INTERIORS

eyrise® Tinted State

Electrochromic Gen II Tinted State

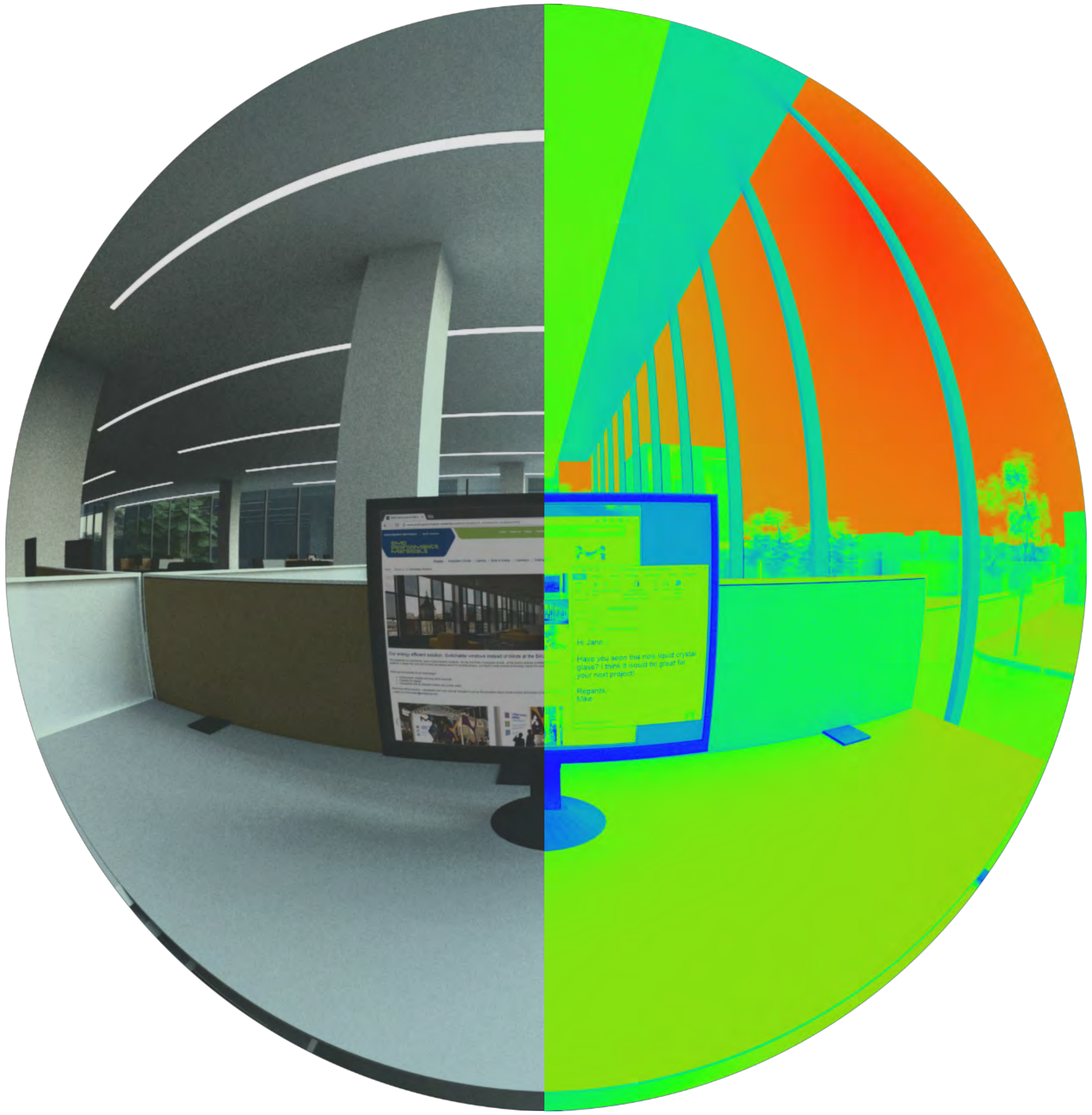
Electrochromic Gen I Tinted State





02

SWITCHING SPEED



Excessive and uncontrolled sunlight penetration is a common issue in highly glazed buildings and can often cause discomfort in the form of glare. Glare occuring in the workplace creates "visual stress" which may have a negative impact on occupants' health and productivity.

Dynamic glazing products offer the capability of controlling glare by tinting their appearance, while at the same time maintaining good levels of daylight and keeping views to the outside unobstracted.

However, the speed of transition between bright and tinted states is an important factor that is often overlooked. This becomes more important when trying to maintain internal visual comfort in an intermittent sky environment, where clouds move quickly.

Studies regarding response times and human interaction with technological systems suggest that 10 seconds is the limit for keeping the user's attention focused, and any time longer than this is associated with users being disrupted, potentially leading to impatience while waiting for the system to complete its task. On the other hand, 1 second is considered the limit for the user's flow of thought to remain uninterrupted, while 0.1 second is approximately the limit for having the user feel that the system is reacting instantaneously[9].

Generation I electrochromic glass needs at least 10 to 15 minutes to transition from clear to tinted state depending on panel size and ambient temperature; the above number relates to transitioning a medium size window panel from clear to 90% of its tinted state under room temperature conditions. On the other hand, eyrise® window has a transition speed of less than 1 second, which significantly outperforms the alternative electrochromic products.

The study presented in this section aims to examine the impact of switching speed on maintaining occupants' comfort and productivity.

The study illustrates the predicted internal visual environment of the three different dynamic glass alternatives, focusing on how options perform in relation to glare reduction.

More specifically, the analysis includes renders of fisheye views of an occupant working near the façade and looking toward the computer screen, using the same software and methodology as the renders of the previous section. For the purpose of this study, a simulated environment to represent a "cloudy day" scenario has been created.

The fisheye renders have been post-processed with a falsecolour luminance map, which indicates the brightness of the surfaces within the field of view. Red and orange colours represent areas that appear very bright to the occupant, while green and blue colours indicate less brightness.

The falsecolour luminance map enables the calculation of a glare metric, known as Daylight Glare Probability (DGP) metric, which was used in the analysis to compare glare risk related to the transition speed of the different products.

HOW IS GLARE RISK QUANTIFIED?

Glare risk has been quantified using the Daylight Glare Probability (DGP) metric, which was developed in 2006 based on empirical studies of subjects within a perimeter office space, and is considered to be a reasonably reliable method for assessing discomfort glare.

The metric predicts the probability that an occupant will be dissatisfied with their visual environment, based on the overall brightness of their field of view as well as the position and intensity of bright sources within it. The "evalglare" module within Radiance provides an opportunity to calculate DGP based on a fisheye render from an occupant's perspective.

DGP values can be correlated to subjective glare ratings as follows:

DGP < 0.35	Imperceptible glare
DGP 0.35 to 0.40	Perceptible glare
DGP 0.40 to 0.45	Disturbing glare
DGP > 0.45	Intolerable glare

SWITCHING SPEED

IMPACT ON VISUAL COMFORT

The images in this section present rendered fisheye views, post-processed with a falsecolour filter that show the brightness of surfaces within the rendered scene.

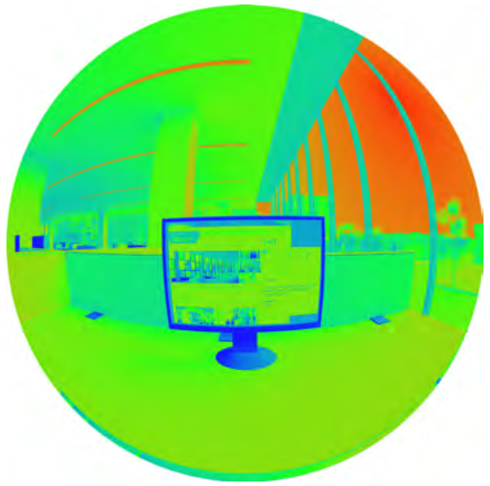
The first row of images below depict the renders when the eyrise® product is installed while the second row depicts the renders when the alternative electrochromic product is installed.

The analysis examines visual comfort levels on a day with passing clouds and compares potential glare risk associated with the transition speed of the two products.

Both products, when clouds cover the sun, are able to maintain their bright state with the occupant likely to experience “imperceptible glare”. When the clouds pass and the sun becomes visible, the glare risk increases and the occupant is likely to experience “intolerable glare”.

eyrise® IMPACT ON VISUAL COMFORT

CLOUDY SKY
BRIGHT STATE - DGP 0.33
IMPERCEPTIBLE GLARE

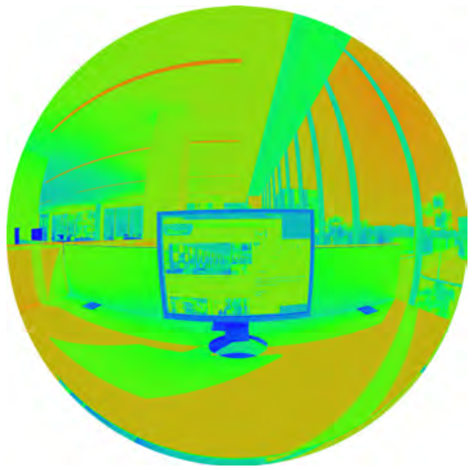


VISUAL COMFORT OK

CHANGE IN WEATHER

1 SECOND

SUNNY SKY - 1 SECOND LATER
TINTED STATE - DGP 0.28
IMPERCEPTIBLE GLARE

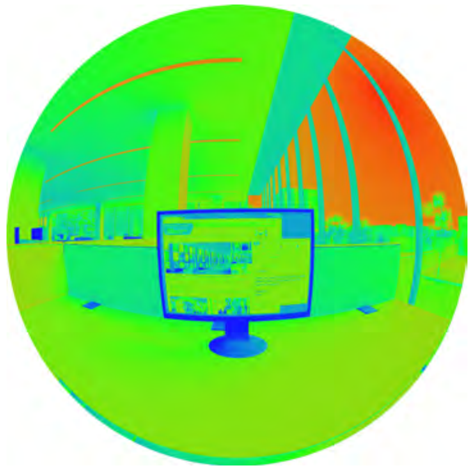


VISUAL COMFORT OK

COMFORT REMAINS CONTINUOUS, SO THE USERS’ FLOW OF THOUGHT REMAINS UNINTERRUPTED[9].

ELECTROCHROMIC GENERATION I IMPACT ON VISUAL COMFORT

CLOUDY SKY
BRIGHT STATE - DGP 0.33
IMPERCEPTIBLE GLARE

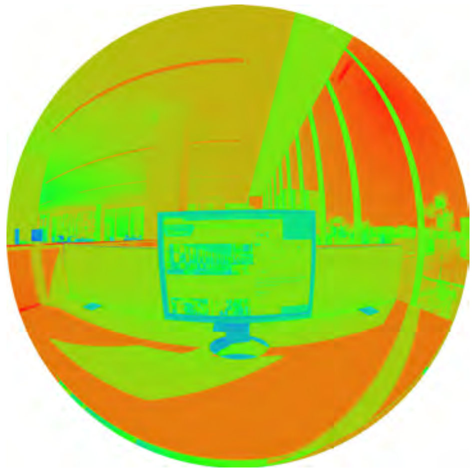


VISUAL COMFORT OK

CHANGE IN WEATHER

1 SECOND

SUNNY SKY
BRIGHT STATE - DGP 0.52
INTOLERABLE GLARE



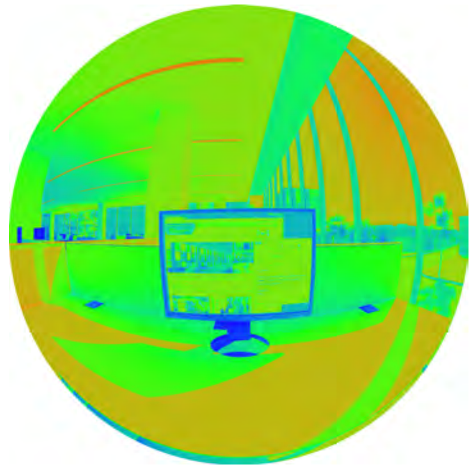
VISUAL COMFORT NOT OK

VISUAL COMFORT NOT OK

15 MINUTES

OVER 10 SECONDS OF DISCOMFORT - USERS ARE LIKELY TO FEEL DISRUPTED AND POSSIBLY IMPATIENT.

SUNNY SKY - 15 MINS LATER
TINTED STATE - DGP 0.27
IMPERCEPTIBLE GLARE



VISUAL COMFORT OK

eyrise® product has the capability to transition between opposite ends of its range in less than a second, therefore reducing the glare risk to imperceptible again, as shown in page 18.

On the other hand, Generation I electrochromic product requires at least 15 minutes to transition to the tinted state in order to bring the visual environment back to comfortable levels. During the transition period, occupants are exposed to high levels of visual discomfort which can have a negative impact on their focus and productivity; fisheye renders captured along the 15 minutes during the transition period indicate high levels of glare risk and are presented in the Appendix.

Additionally, considering the fact that any time longer than 10 seconds is associated with disrupted flow of thought[9], it is likely that during the transition period occupants would be disturbed and would try to find alternative ways to restore their visual comfort.

In conclusion, eyrise® can switch in less than a second maintaining acceptable comfort levels and enhancing occupants’ productivity and focus, while alternative electrochromic products need at least 15 minutes to restore visual comfort levels. During this transition period, occupants can experience high levels of glare risk, while their concentration could be disrupted as they seek for alternative ways to protect themselves from sunlight, having a negative impact on their performance and productivity.

Basis of assessment

Time: 10am

Date: September 8th

Sky condition: Intermittent cloudy sky

Electrochromic product: Generation I

03 CIRCADIAN WELL-BEING

With people spending more than 90% of their time indoors[2], there is an increasing body of research examining the impact of the built environment on human health.

Research indicates that an important component of indoor health and well-being is occupant access to appropriate quantities and quality of light, in particular the provision of light that aligns with the body's circadian rhythm control[10]. There is emerging research revealing considerable health risks related to the disruption of the circadian rhythms as a result of inadequate exposure to daylight, or exposure to spectral wavelengths that affect the human body clock[11,12, 13].

Quantities of light, both artificial and natural, have long been the focus of lighting standards for building design, aiming to optimise illumination levels based on different space and activity types. The WELL Building Standard®, a performance-based standard which explores features of the built environment that advance human health and well-being, adopts a metric which examines occupant exposure to light and if it aligns with their circardian clock.

The metric is called Equivalent Melanopic Lux (EML), and it weighs an occupant's exposure to light based on the response of the eye's non-image forming photoreceptor, melanopsin. Melanopsin, which contains intrinsically photosensitive retinal ganglion cells (ipRGCs), has the ability to regulate various physiological processes, including those relating to alertness, digestion and sleep, through the secretion of a hormone known as melatonin. Through ipRGCs, light of high frequency and intensity promotes alertness, while the lack of this stimulus signals the body to reduce energy expenditure and prepare for rest.

The purpose of this section is to explore the impact of both the eyrise® product and the two electrochromic alternatives on light exposure to identify which provides better support for circadian body functions.

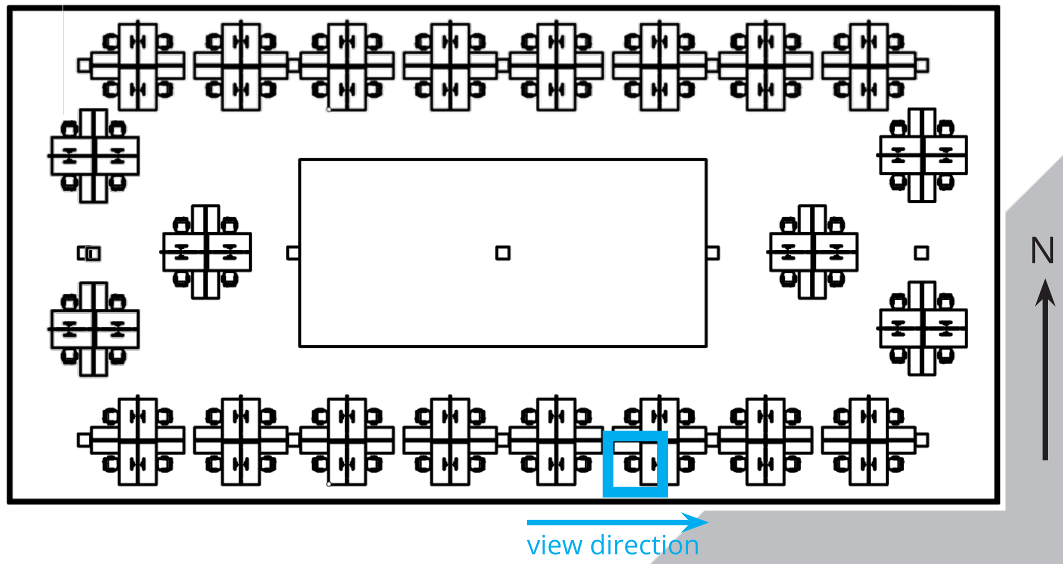
The EML metric is used, which can be affected by the spectral response of building materials, including both opaque and transparent surfaces, and is measured on the vertical plane at eye level of the occupant.

Additionally, minimum illuminance levels are examined within the study in order to assess the impact of the different products on meeting the minimum required levels of light exposure. Photopic Lux (PL) is the metric adopted for this assessment and it has been examined on the horizontal plane at workstation level.

Finally, the Melanopic over Photopic (M/P) ratio metric is adopted, which represents the impact on melanopsin response (equivalent melanopic lux) compared to the amount of perceived brightness (photopic lux). A higher ratio indicates a lighting environment that raises alertness by suppressing melatonin levels.

The analysis assesses each glazing product within different tint states, at a representative time of the year. Figure 3 below illustrates the open plan office space used for the analysis, indicating the occupant position and view direction used for the study.

Figure 3: Open plan office space



CIRCADIAN WELL-BEING

IMPACT ON BODY CLOCK

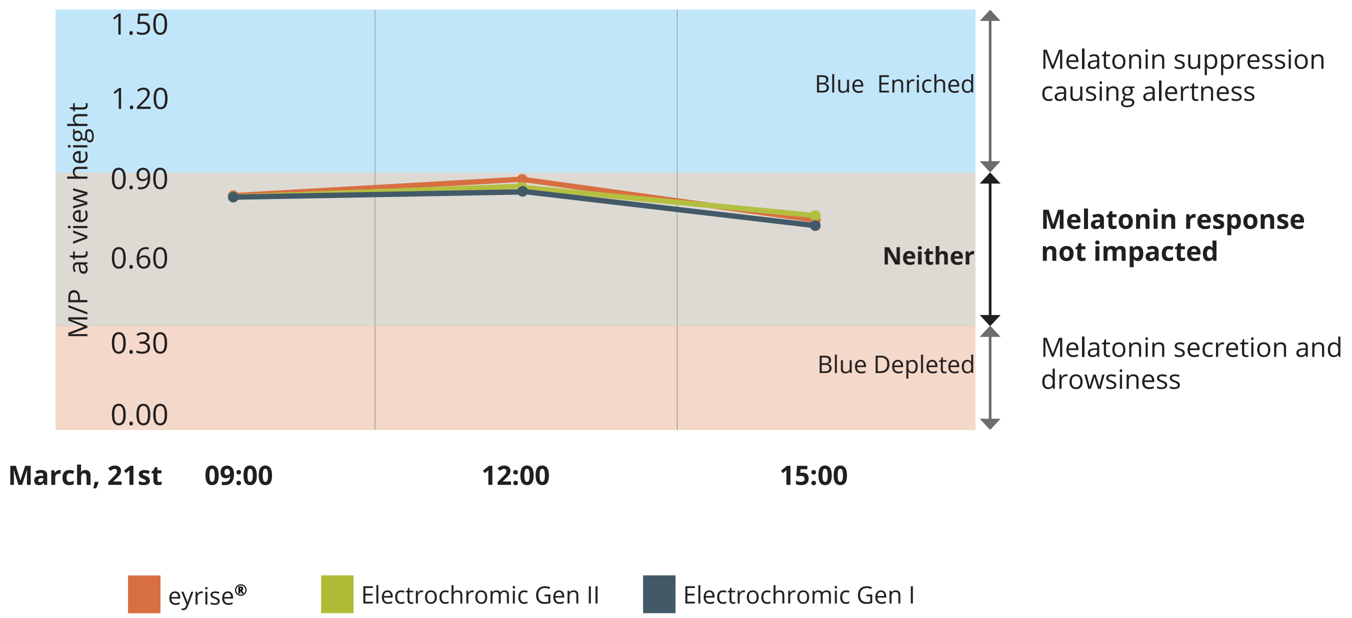
This section examines the impact of the three dynamic glass products on light exposure, using three metrics:

- Photopic Lux (PL), which examines if minimum illuminance requirements are met in order to ensure that occupants are able to carry out office activities. The minimum requirement for desk-based activities is 300 lux, measured at workstation level.
- Equivalent Melanopic Lux (EML), which examines if minimum requirements for melanopic light intensity are met in order to minimise disruption to the occupant circadian system. The minimum requirement proposed by the WELL Building Standard is 200 EML, between 9am and 1pm, measured on the vertical plane at view height.
- Melanopic to Photopic ratio (M/P), which compares the equivalent melanopic lux levels to the amount of photopic lux.

For ratios between 0 to 0.35, the lit environment is perceived “blue depleted”, causing melatonin secretion and drowsiness, typically matching the circadian clock towards the time when people prepare for rest or sleep. Ratios between 0.35 and 0.90 indicate no impact on melatonin response, which corresponds to moments when people are awake and active in a comfortable manner. Ratios higher than 0.9 indicate a “blue enriched” environment which results in melatonin suppression, causing alertness, which at the wrong time, can cause stress, sleep disorders and further anxiety.

eyrise® and the two electrochromic alternatives have been assessed both in their bright and tinted state, at a representative time of the year, March 21st, for three different times within the day - 9am, 12pm, and 3pm. For each time of the day, the minimum requirements for photopic lux and equivalent melanopic lux are examined, as well as the equivalent M/P ratio. For simplicity, the analysis excludes electric lighting and focuses only on the levels and impact of natural light.

Graph 1 - Impact of glazing in **bright** state on M/P ratio



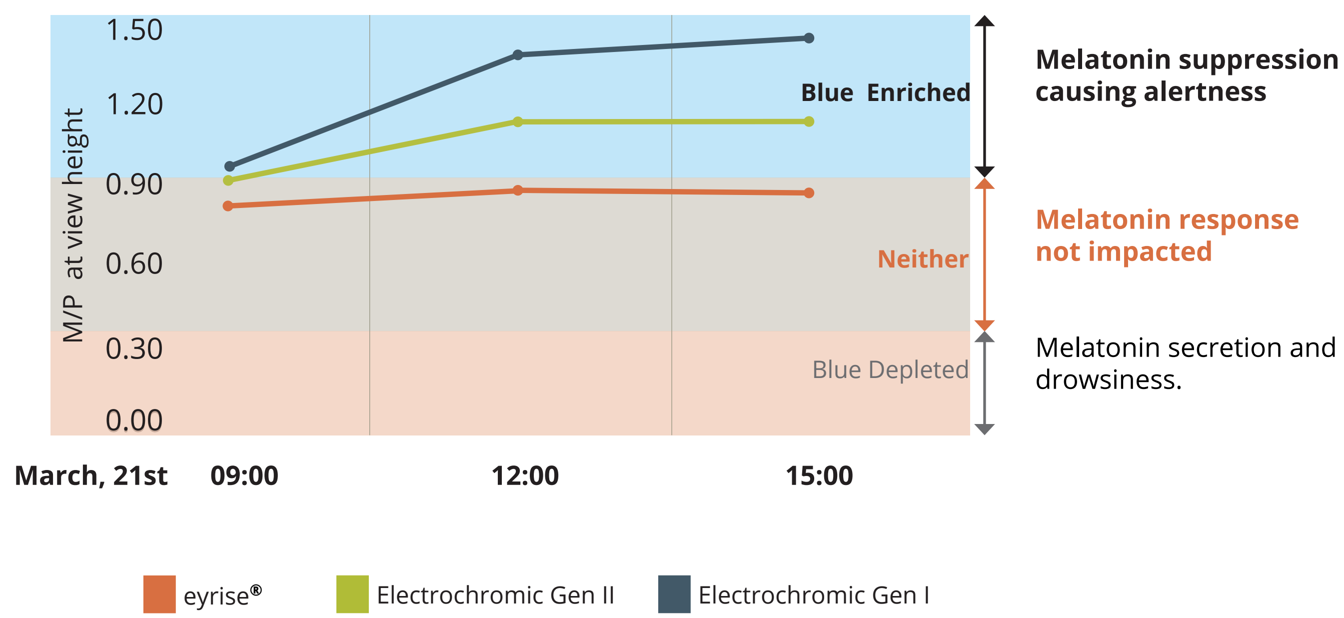
A shown in Graph 1 on the left, the equivalent M/P ratio remains relatively stable for all three products at their bright state at all three times of the day, indicating an environment that doesn’t affect, either positively or negatively, the melatonin levels in occupants’ bodies.

However, at tinted state shown in Graph 2 below, eyrise® maintains a stable equivalent M/P ratio, while both electrochromic products indicate an increase in the ratio during afternoon hours, due to the blue colouration at their tinted state. As melanopsin response is sensitive to the blue part of the visible spectrum, the spectral response of the two electrochromic products creating a more blue enriched environment raises alertness by suppressing melatonin levels. This can lead them towards feeling stressed and nervous.

Finally, the results regarding photopic and equivalent melanopic levels indicated that all three alternatives meet the minimum criteria for both photopic and melanopic illuminance at all three times of the day at both their bright and their tinted state.This indicates that comfortable illuminance levels are provided closer to the facade, which are also aligned with the occupants body clocks.

Overall, it can be concluded that while all three products meet the minimum criteria for photopic and melanopic illuminance when in both their bright and tinted state, they can have a significantly different impact on occupants’ body clock. When tinted, eyrise® product maintains a neutral environment that doesn’t affect melatonin response, contributing positively to occupants’ health and well-being throughout the day. On the other hand, both electrochromic products in their tinted state create an environment that is perceived as “blue enriched” resulting in melatonin suppression, causing alertness during afternoon hours and consequenlty disturbing occupant’s circadian rhythm, health and well-being.

Graph 2 - Impact of glazing in **tinted** state on M/P ratio



CONCLUSION

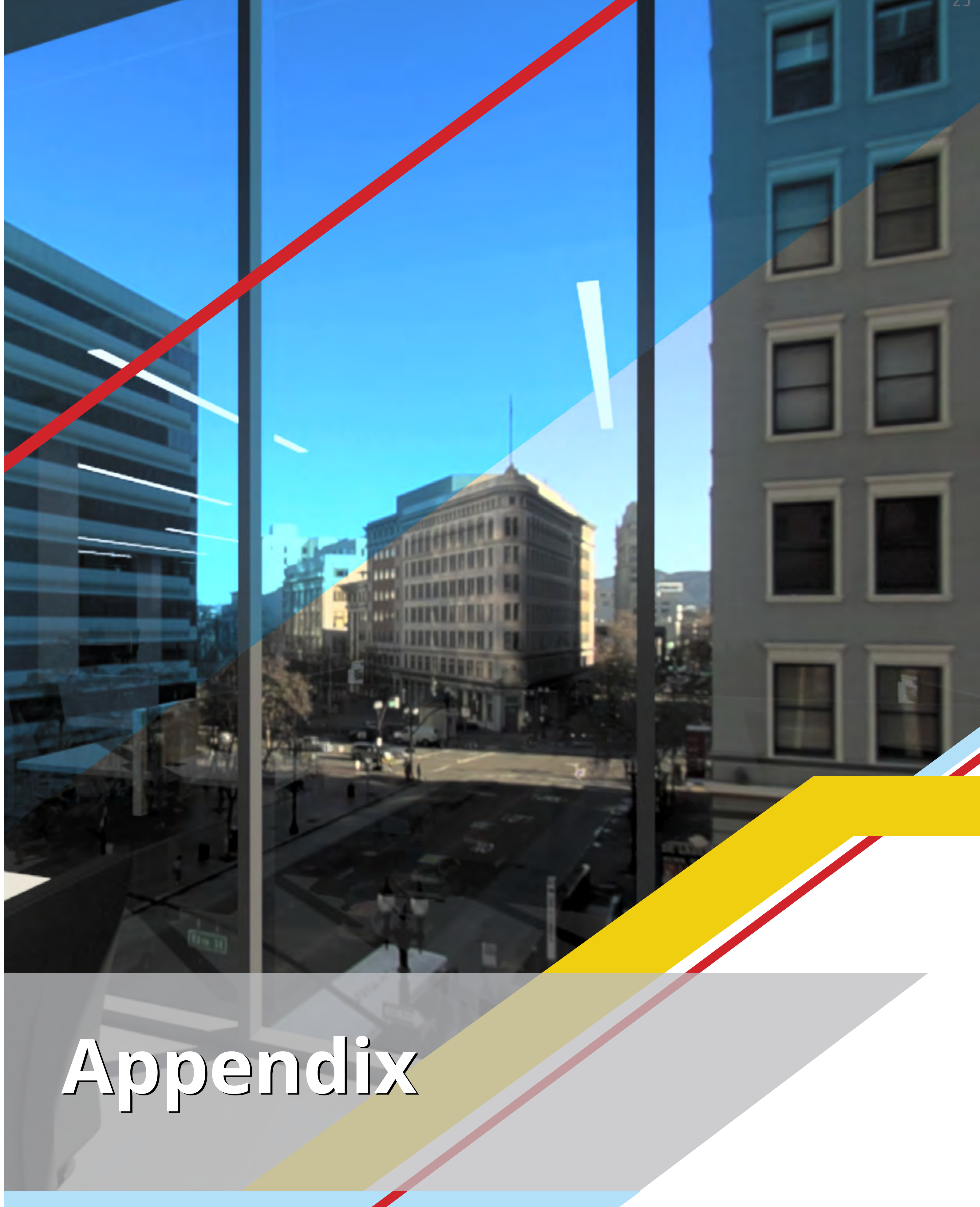
This study compared the impact of **eyrise® dynamic** liquid crystal glass technology and two electrochromic alternatives **on an occupant's health and well-being.** The study was presented in three main chapters, each of them examining a different aspect.

In the first chapter, the study focused on the colour rendering aspect and its impact on exterior views and the interior environment. Physically accurate renders across different tint states of the three products **demonstrated the colour neutrality of the eyrise® product, compared to the blue colouration shown at the darker states of the electrochromic alternatives.** The renders indicated the impact of the blue colouration on occupant's perception of the surrounding environment, as both the exterior views and the colouration of objects shown in the interior office views were distorted. **This distortion of the colouration of the surrounding environment can have a significant negative impact on occupants' mood, productivity and satisfaction in the workplace, while it would also be detrimental in applications such as exhibition halls or art galleries where true colour rendering is critical.**

The second chapter looked to the switching speed of the different technologies and the impact on visual comfort. While eyrise® can switch in less than a second and maintain acceptable comfort levels enhancing occupants' productivity and focus, **alternative electrochromic products need at least 15 minutes to restore visual comfort levels.** During this transition period, occupants are likely to experience high levels of glare risk, while their concentration could be disrupted as they seek for alternative ways to protect themselves from sunlight, having **a negative impact on their performance and productivity.**

The third chapter examined the impact of the different dynamic glass products in occupants' health, focusing on the alignment with their body clock. All three products met the minimum requirements for photopic and melanopic illuminance levels during their bright and dark states. However both **electrochromic products in their dark state created a "blue enriched" environment** during afternoon hours, **causing melatonin suppression and alertness.** Increasing alertness in afternoon periods may seem like a productivity benefit, but is likely to oppose the natural body response to the warmer-coloured sky, therefore **disrupting occupants' circadian rhythms**. On the contrary, eyrise® product maintained a neutral environment supporting occupants' health and well being throughout the day.

In conclusion, **eyrise® product clearly supports occupant health and well-being,** by maintaining a neutral colour across its tinting range and by the capacity to maintain high levels of visual comfort due to its significantly faster transition time.



Appendix

APPENDIX A - RENDERS

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: eyrise®
STATE: BRIGHT

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: eyrise®
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: eyrise®
STATE: MID II

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: eyrise®
STATE: TINTED

APPENDIX A - RENDERS

DATE: 21^{ST} JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: BRIGHT

DATE: 21^{ST} JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: MID II

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: TINTED

APPENDIX A - RENDERS

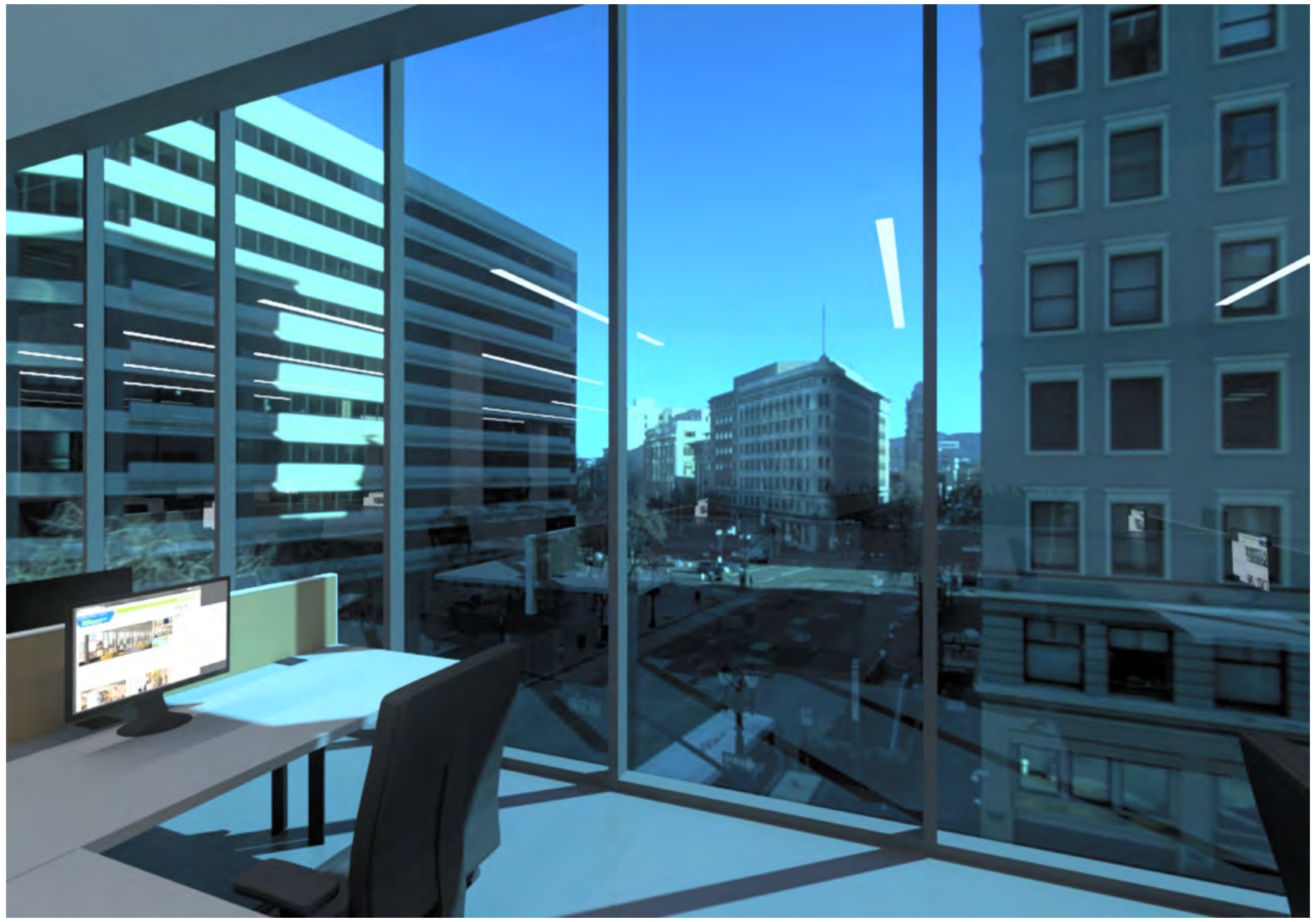
DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: BRIGHT

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: MID II

DATE: 21ST JUNE
TIME: 2PM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: OUTSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: TINTED



APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: eyrise®
STATE: BRIGHT

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: eyrise®
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: eyrise®
STATE: MID II

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: eyrise®
STATE: TINTED

APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: BRIGHT

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: MID II

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION II
STATE: TINTED

APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: BRIGHT

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: MID I

APPENDIX A - RENDERS

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: MID II

DATE: 21ST DECEMBER
TIME: 10AM
SKY CONDITION: CLEAR, SUNNY SKY
VIEW: INSIDE
PRODUCT: ELECTROCHROMIC GENERATION I
STATE: TINTED

APPENDIX B - SWITCHING SPEED OF ELECTROCHROMIC GENERATION I

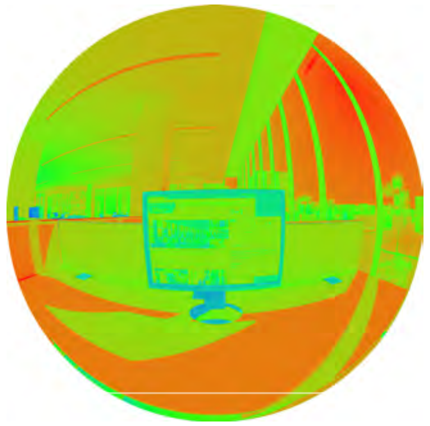
Following up from chapter “Switching Speed”, the renders presented in this section capture the glare risk that an occupant working next to the façade is exposed to, during the transition time of a typical electrochromic glass technology. Generation I electrochromic products need at least 15 minutes to restore visual comfort levels and during this period, occupants are likely to experience high levels of glare risk.

More specifically, the fisheye renders on the right illustrate the brightness of the surfaces within the rendered scene, reporting the Daylight Glare Probability (DGP) levels after 1 second, 5 minutes and 10 minutes of the start of the transition process.

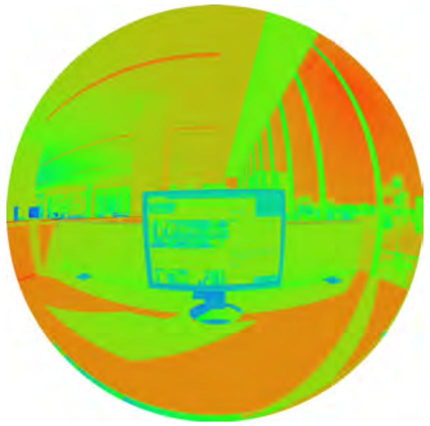
DGP values can be correlated to subjective glare ratings as follows:

DGP < 0.35	Imperceptible glare
DGP 0.35 to 0.40	Perceptible glare
DGP 0.40 to 0.45	Disturbing glare
DGP > 0.45	Intolerable glare

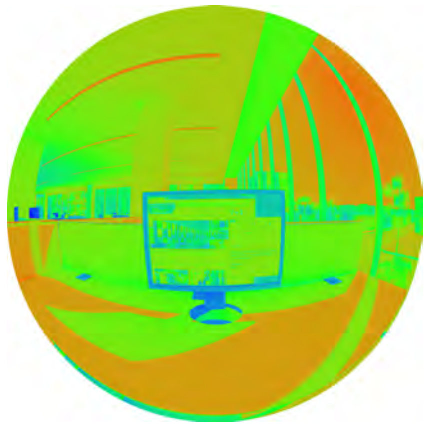
ELECTROCHROMIC GENERATION I



SUNNY SKY
1 SECOND AFTER TRANSITION STARTS
DGP 0.52
INTOLERABLE GLARE



SUNNY SKY
5 MINUTES AFTER TRANSITION STARTS
DGP 0.44
DISTURBING GLARE



SUNNY SKY
10 MINUTES AFTER TRANSITION STARTS
DGP 0.36
PERCEPTIBLE GLARE

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