YAŞAR UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

THE ENERGY PERFORMANCE COMPARISON OF THE INTEGRATION OF ELECTROCHROMIC GLAZING TO AN OFFICE BUILDING WITH DIFFERENT GLAZING TYPES IN HOT-HUMID CLIMATIC REGION

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ABSTRACT

THE ENERGY PERFORMANCE COMPARISON OF THE INTEGRATION OF ELECTROCHROMIC GLAZING TO AN OFFICE BUILDING WITH DIFFERENT GLAZING TYPES IN HOT-HUMID CLIMATIC REGION

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JANUARY 13TH

Windows, as one of the least energy-efficient components of a building, are responsible for up to 40% of the total energy cost, including heating, cooling and lighting, and more. 30% of this energy is lost to because of inefficient building components (DOE)., 2006). Electrochromic glass (EC) is one of the leading technologies and can significantly reduce the energy consumption of buildings (View Glass, 2013). Unlike traditional glass, EC glass dynamically changes its shadow states according to the needs of the occupants. When the tint level of the glass changes, the properties of the glass change accordingly. Previous studies have been conducted on energy simulations of electrochromic glass. However, most existing software does not have the ability to add the four staining states to the EC glass or to apply a specific staining program, making the simulation result inaccurate and unreliable. Simulation workflows in DIVA which take multiple main factors three tinting states, solar load impacts, glass tinting schedule into consideration seem to indicating improved reliabilities.

For building envelopes, conventional glasses offer only fixed properties and unique control of the light passing through them. EC glass offers a better solution given a wider range of visible light transmission. Due to the dynamic nature, the EC glass needs a specific control algorithm to check the state of the glass at a certain time of the day, and therefore the coloring program varies. A lot of research has been carried out on the study of property, energy performance and the visual comfort of EC glass, but thermal comfort is an area that has been little studied. More attention needs to be paid to thermal comfort as it affects labor productivity and human health, which could be the most compelling market driver in the future.

The main objective is to minimize unwanted increases in solar heat during the cooling season and to maximize them during the heating season and also to optimize daytime lighting performance without glare.

Keywords: Electrochromic Glass, EC glass tinting states, tinting schedule, solar radiation impacts, software simulation, DIVA software RHINO plug-in.

ÖZ

ELEKTROKROMİK CAMLILIĞIN SICAK NEMLİ İKLİM BÖLGESİNDE FARKLI CAM TİPLERİ İLE OFİS BİNASI ENTEGRASYONUNUN ENERJİ PERFORMANS KARŞILAŞTIRMASI

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Bir binanın en az enerji tasarruflu bileşenlerinden biri olan Windows, ısıtma, soğutma ve aydınlatma ve daha fazlası dahil olmak üzere toplam enerji maliyetinin% 40'ından sorumludur. Bu enerjinin% 30'u verimsiz bina bileşenleri nedeniyle kaybedilir (DOE)., 2006). Elektrokromik cam (EC) önde gelen teknolojilerden biridir ve binaların enerji tüketimini önemli ölçüde azaltabilir (View Glass, 2013). Geleneksel camdan farklı olarak, EC cam gölge durumlarını yolcuların ihtiyaçlarına göre dinamik olarak değiştirir. Camın renk tonu seviyesi değiştiğinde, camın özellikleri de buna göre değişir. Elektrokromik camın enerji simülasyonları hakkında daha önce çalışmalar yapılmıştır. Bununla birlikte, mevcut yazılımların çoğu dört boyama durumunu EC camına ekleyemez veya belirli bir boyama programına başvuramaz, bu da simülasyon sonucunu yanlış ve güvenilmez hale getirir. DIVA'da üç renklendirme durumu, güneş yükü etkileri, cam renklendirme programı göz önünde bulundurularak birden fazla ana faktörü alan simülasyon iş akışları, gelişmiş güvenilirlikleri göstermektedir.

Bina zarfları için, geleneksel camlar sadece sabit özellikler ve içinden geçen ışığın benzersiz kontrolünü sunar. EC cam, daha geniş bir ışık geçirgenliği yelpazesi göz önüne alındığında daha iyi bir çözüm sunar. Dinamik doğası nedeniyle, EC camı, camın durumunu günün belirli bir saatinde kontrol etmek için özel bir kontrol algoritmasına ihtiyaç duyar ve bu nedenle renklendirme programı değişir. EC camın özelliği, enerji performansı ve görsel konforu üzerine bir çok araştırma yapılmıştır, ancak termal konfor az çalışılan bir alandır. Gelecekte en cazip piyasa sürücüsü olabilecek işgücü verimliliğini ve insan sağlığını etkilediğinden termal konfor için daha fazla dikkat gösterilmelidir.

Ana hedef, soğutma mevsiminde güneş ısısında istenmeyen artışları en aza indirmek ve ısıtma mevsiminde bunları en üst düzeye çıkarmak ve ayrıca parlama olmadan gündüz aydınlatma performansını optimize etmektir.

Anahtar Kelimeler: Elektrokromik Cam, EC cam renklendirme durumları, renklendirme programı, güneş radyasyonu etkileri, yazılım simülasyonu, DIVA yazılımı RHINO eklentisi.

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor Prof. Dr. Başak Kundakçı Koyunbaba for her guidance and patience during this study.

I would like to express my enduring love to my parents, who are always supportive, loving and caring to me in every possible way in my life.

Geli Ibrahim geli mohamed

İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled “THE ENERGY PERFORMANCE COMPARISON OF THE INTEGRATION OF ELECTROCHROMIC GLAZING TO AN OFFICE BUILDING WITH DIFFERENT GLAZING TYPES IN HOT-HUMID CLIMATIC REGION” and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Geli Ibrahim geli mohamed

Signature

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

(ASE)	Annual Sunlight Exposure
(A)	Annual-based Metrics
(DA)	Daylight Autonomy
(DF)	Daylight Factor
(DGP)	Discomfort Glare Probability
(P)	Point-in-time Metrics
(sDA)	Spatial Daylight Autonomy
(UDI)	Useful Daylight Illuminance

CHAPTER 1
INTRODUCTION

EC glass can block the solar radiation near the infrared which crosses the summer and allows the light to penetrate in winter, which considerably making the energy consumption more beneficial.

Although EC glass has been on the market and developed for decades, it is not yet widely used in the construction of enclosures. EC glass has many unique components compared to conventional glass. This chapter explains the basic concepts and terminology of EC glass, to better understand how glass works and potential problems. Knowing the main advantages and disadvantages of EC glass is also important for the decision-making process regarding the application of the product. There are certain types of electrochromic lenses on the market, including SageGlass, View Inc, Smartglass, Polytronix, etc. SageGass and View Inc. are manufacturers specializing in the development of printable electrochromic glass for use in building windows.

1.1 Context

One of the energy efficient components of a building, Windows represents 40% of the total cost of energy, including heating, cooling and lighting, and more than 30% of this energy is lost due to the lack of building components (DOE, 2016) Electrochromic glass (EC) in It is one of the advanced technologies and can significantly reduce the energy consumption of buildings.

1.2 Statement of problem

The process of rehabilitation of buildings is often very limited, especially with regard to morphological changes, in the case of historic or listed buildings. Therefore, this section examines the technology of electrochromic (EC) windows that emerge using the building's energy simulation to assess the building's impact on energy efficiency. Cases related to the current state of EC device technology are explained and possible future trends are discussed. Validation of control procedures for commercially available EC windows, a case study for rehabilitation using the ESP-r simulator (University of Coimbra, University of Coimbra), impact analysis of energy efficiency and thermal comfort.

The renovation of old buildings is necessary for the general improvement of the energy indicators of the buildings. In this context, the document focuses on the energy savings that can occur when using electrochromic (EC) windows, a new and interesting alternative to protection devices to control solar gain in buildings under Mediterranean climates. Windows EC technology is presented briefly and the optical properties of the lens configuration are analyzed according to the operating range. The dynamic behavior of the EC window and the different control strategies are modeled. The effect of the EC window on the heating and cooling energy requirements was examined considering different environmental parameters (external dry thermometer temperature, internal dry thermometer temperature and event radiation) and the reference point for the control of the EC. A comparison between different window solutions (single, double, triple glazing and EC windows).

1.3 Research Questions

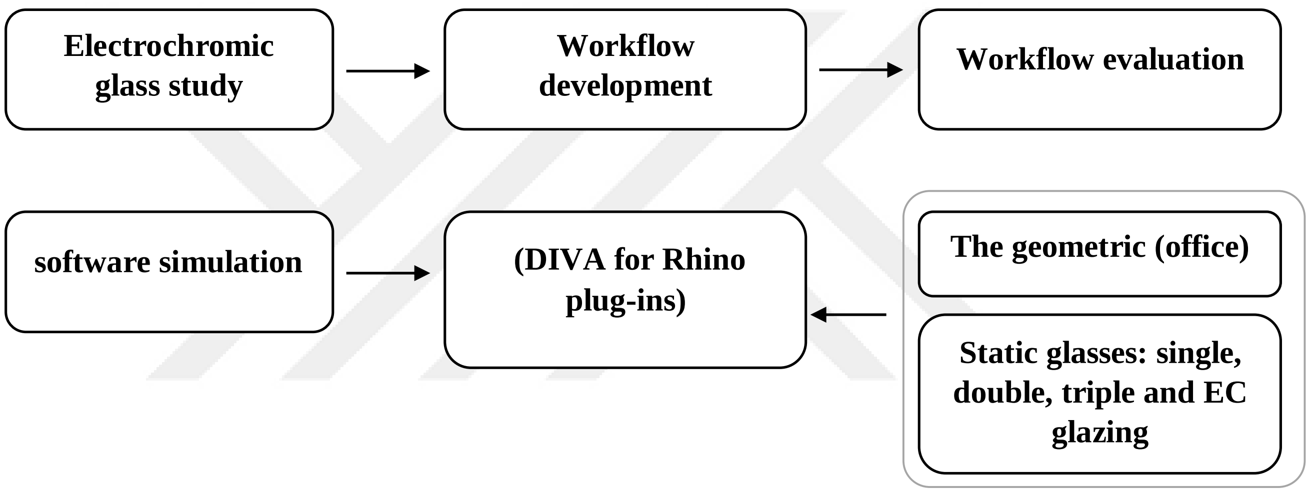
The real question which is very challenging here is how can the EC electrochromic behave as a glazing material for daylight and illuminance comfort better than the other materials, Form the single pane, (1) double pane glazing (2) and the triple pane glazing (3) comparing to the electrochromic glazing. And to see how far it can go as an adaptive material.

1.4 Research Objective

The goal of the research is to find a better way to make comfort simulations in daylight for EC glass windows. It also minimizes unwanted solar heat gains during the cooling season and maximizes during the heating season and also optimizes daylight performance without glare on the work plane.

1.5 Data Gathering Technique

The workflow for this study is as simple as collecting light (lux) data from simulations as much as possible; Make an evaluation between these types of glass.



CHAPTER 2

PREVIOUS STUDY: BACKGROUND AND LITERATURE ANALYSIS

The relevant electrochromic glass work is summarized in this section. Research has been conducted to examine energy efficiency and visual comfort in buildings mounted on electrochromic glass (EC), but thermal comfort is a poorly studied area. On the other hand, the thermal comfort simulation methods for conventional static glazed buildings are summarized, which is crucial to define the limitations for EC glass work. In addition, as a background study, to learn about the manufacturing process Arcadia Inc. A physical model was created in the store.

2.1 General work history of Electrochromic glass

In 1969, the first replaceable electrochromic device was exhibited in the laboratory (Deb, 1969). Lee et al. In the following years and in the late 1990s, some developers in the United States gradually improved the size, switching range and stability of the CE glass cycle. They were chosen by the Ministry of Energy (DOE) and, therefore, were invited to collaborate. He collaborated with DOE National Laboratories to develop the glass market (Lee et al., 2012). The National Renewable Energy Laboratory conducted a series of tests to evaluate the durability of EG glass. At Lawrence Berkeley National Laboratory, large EG prototypes have been combined with automatic control and dimmable light control. The technical potential was assessed, such as low energy consumption, maximum load requirements and greater user comfort. However, some subjects were assessed in a short time to measure large-scale data under real conditions. Therefore, more work is needed after the occupation to better evaluate the acceptance and satisfaction of users of EC windows (Lee et al., 2012).

2.2 Previous studies on the energy performance of electrochromic glass.

Although this thesis aims to study the thermal comfort and illuminance of EC glass, the previous studies on energy efficiency on EC glass are summarized because the simulation process and the input data of thermal comfort and energy efficiency are similar.

2.2.1 Energy simulation in BEopt

Possible energy savings of EC windows in residential buildings Sullivan et al. A single family home in Atlanta was modeled on the BEopt software and it was assumed that EC windows would automatically function based on the incident sunlight during the cooling season. EC windows are expected to reduce 9.1% of all household energy consumption and 13.5% of all domestic electricity demand and 10.3% in 50% of American house construction (Sullivan et al. 1994).

2.2.2 Energy simulation in eQuest

Several parametric modeling simulations have been completed for an eight-story standard office building using eQuest v3.63 based on ASHRAE 90.1-2007 (Pease et al., 2010). Each type of window is modeled to compare the energy efficiency of Sage EC windows and other conventional static glass. The simulation was carried out for three climates: Minneapolis, Phoenix and Washington. According to ASHRAE 90.1-2007, a certain static glass is selected for the climatic zone.

		SHGC	U-Value	VLT
Phoenix, AZ		0.25	0.75	40%
Washington, DC		0.4	0.55	40%
Minneapolis, MN		0.4	0.55	40%
SageGlass Double Pane (Argon)	Clear	0.48	0.29	62%
	Tinted	0.09	0.29	3.5%
SageGlass Triple Pane (Argon)	Clear	0.38	0.14	52%
	Tinted	0.05	0.14	2.9%

Table 1: *Glazing characteristics (Pease et al, 2010)*

The minimum annual energy savings of EG double and triple panels for the three climatic zones were compared to single glazed static glass or ASHRAE 90.1-2007 base glass and commercial triple glass. This study confirmed that EC glass can save a certain amount of energy, but EC glass only takes into account two states of coloring. The parameter of the reference case is not a constant variable, since the properties of static glass differ according to the individual climatic regions, which makes the results complex and incomparable.

	Static Single Pane (no daylighting controls)	ASHRAE 90.1-2007	Commercial Triple
SageGlass Double	45%	20%	NA
SageGlass Triple	53%	34%	14%

***Table 2**: Glazing characteristics (Pease et al, 2010)*

2.2.3 Energy simulation in EnergyPlus

In a study by Lee et al., Another energy uses of the air conditioning and lighting system was determined by the EnergyPlus simulation (Lee et al., 2013). A west-facing conference room with an automatic EC window is modeled in Washington DC. While EC windows are replaced using the same control algorithm as the actual product, except that the window is activated by external vertical radiation, the physical EC window is activated by the level of external vertical lighting that is not found in EnergyPlus. The equivalent switching thresholds were calibrated using data measured in clear sky conditions. The reduction of energy uses in frames and lighting, with a total annual energy consumption decreased by 39-48% and the maximum demand for electricity decreased by 22-35% according to current conditions, and in the harvest of sun and winter in summer and the reduction of thermal conduction in the window. The estimated percentage of those dissatisfied with the thermal environment was also calculated in the EnergyPlus simulation. This number decreased from 18% in the single glazing window to 13% with transparent and colored double glazed EC windows filled with argon. In this study, the EC windows were automatically controlled in full open mode or in full color, again the four coloring states were not taken into account.

2.2.4 Energy Efficiency Assessment with Monitored Data

LBNL has reported results from large-area electrochromic windows (Lee et al., 2000). Two offices in Oakland, California were exposed to almost the same indoor and outdoor environment at the same time to compare the two rooms. The window / wall ratio was 0.40 and the electrochromic television windows had a visible permeability range from 0.11 to 0.38. The dimmable electrical lighting system ensures constant lighting on the working level. The EC window control strategy used in the simulation was based on sun protection. The daily energy consumption of the automatic EC window system decreased from 24% to 6% compared to the static window with low transmission (Tv = 0.11). on the other hand, compared to the reference case with static windows with Tv = 0.38, the daily consumption of lighting energy increases by 13% (Lee et al., 2000). Unfortunately, no thermal comfort was measured in this study.

Lee et al. It was built to monitor the energy efficiency of south-facing absorbent EC windows in a private office environment (Lee et al., 2005). EC windows were controlled in different ways, and some cases were exposed to blinds, and some cases concerned the division of the EC window wall.

When prioritizing visual comfort requirements, the 2-zone EC window configuration resulted in an average daily energy saving of 10 ± 15% and a cooling load reduction of 0 ± 3% compared to reference with fully reduced blinds. If there is no daylight control in the reference frame, the energy saving of the lighting is 44 ± 11%.

When the demand response mode was provided, the maximum need for clear and sunny days was 19-26% due to a reduction in window cooling loads and a 72-100% reduction in window cooling loads. Maximum use of lighting energy compared to the reference situation in lighting control (Lee et al., 2005). From this study, it was concluded that controlling glare and sun is of great importance for the use of light energy and that further studies on occupancy comfort should be carried out.

2.2.5 Overview

In general, simulations and monitored data show low energy savings through Electrochromatic glasses. nevertheless, these results cannot be generalized to existing EC products because the software used in the simulations has limitations regarding the properties of the glass that differ from the last glass product. The monitored data is also unreliable and may contain random errors, Occasional data collection errors. Performance simulations for EC glasses are not uncommon, studies on thermal comfort in humans are very rare in this area.

2.3 Previous Thermal Comfort Study

The thermal comfort of occupancy is different when exposed to sunlight near the windows. Post-occupancy work is an alternative way to obtain satisfaction and comfort responses for passengers. It is helpful to learn which software people use in practice, to find limits on the tools available and to choose more effective software in the future.

2.3.1 Thermal Comfort Close to Glass Facades

Glass offers great design possibilities and the transparent space can provide a lot of light and images. On the other hand, glass areas often cause excessive energy consumption and people exposed to the sun may have thermal discomforts. When a person is sitting or standing within the perimeter of the glazed area, the effects of the facade on air temperature, long wave radiation, solar charge and air movement must be taken into account. (Hoffmann, 2012). The glass surface influences the passenger's thermal comfort in two ways: the transparent property allows solar radiation to enter the space and the temperature of the internal surface of the glass can be different from the other temperature of the internal surface, which can cause an exchange of long wave radiant heat and convective heat flows. In general, the glass region affects the body's thermal equilibrium, long wave radiation and short wave radiation.

2.3.2 Post-Occupancy Study

The Lawrence Berkeley National Laboratory (LBNL) conducted an evaluation in collaboration with the Center for Built Environment (CBE) of the University of California at Times Company in Manhattan, New York (Lee et al. 2013). The building is a new 52-story commercial building with an area of 1.5 million square meters. All Times employees received an online survey, 665 responses and accounted for 35% of the total number of respondents. The corresponding responses related to thermal quality and thermal environment quality (Table 3) (Lee et al., 2013). The answers were on a 7-point scale. 1 not very satisfied ", 4" neutral "and 7" very satisfied ".

Questions	Greater than neutral satisfaction	Average Rating
Temperature in your workspace	46%	4.06
Humidity Level in your workspace	68%	5.26
Does thermal comfort in your workspace enhance or interfere with your ability to get your job done?	39%	4.14

Table 3: *Questions Related to Thermal Comfort (Lee et al, 2013)*

The statistical analysis concluded that the general satisfaction of the occupants with the building was strongly linked to satisfaction with humidity and not with thermal comfort. Their responses were strongly related to thermal comfort, not humidity (Lee et al. 2013).

In terms of temperature, 206 people thought the thermal environment was very cold and 31 people thought the temperature was too high. Based on occupant concerns, construction operations adjusted and refined temperature set points, while saving energy Although the EC glazing is not the window system used in this building, post-occupancy work in this building, a possible means to evaluate the thermal comfort of the occupants and their consequences can be very useful to adjust the construction system.

2.3.3 Thermal Comfort Simulation Software in Practice

In practice, some tools are used to simulate thermal comfort. EnergyPlus is managed by the United States Department of Energy. And it is used by architects, engineers and researchers to model energy generation and heat comfort generation as part of the human object (Webb 2006). EnergyPlus can provide analysis results based on the Fanger model or the adaptive ASHRAE Standard 55 model. The software can be downloaded free of charge. Further information on the simulation of thermal comfort can be found in the reference manual for input and output of the program. Definition.

ROOM has been developed in Arup over the past 30 years in the form of a two-dimensional spatial mapping that provides energy analysis, radiation and shading analysis, analysis of thermal comfort and results of thermal comfort (White et al., 2009). However, the results are an average day for each month of the year and do not provide results for every hour of the year (White et al. 2009). The Center for Built Environment (CBE) has developed a complete web application for the calculation, visualization, design and compatibility of thermal comfort according to the latest standard ASHRAE 55 and especially according to the Comfort model. beyond the current standard requirement (Arens et al., 2015). The vehicle does not provide information about the use of building energy or thermal conditions and can provide information about the thermal conditions at a single point and at a single point in space. This information is available free of charge at http: //comfort.cbe.berkeley.edu. A further developed version of the CBE Thermal Comfort model has a detailed human body with the surrounding thermal environment. This tool can be used to estimate thermal comfort for the human body in general and for certain parts of the body. Like a web application, this tool cannot predict energy consumption and provides results that are based on specific times only (Webb, 2012).

Although the PMV Fanger model and its internal standards do not mention the effects of solar comfort on the thermal comfort of the thermal environmental conditions according to ASHRAE for the human profession, the direct impact of solar radiation on the human body cannot be excluded (Arens et al., 2015).

2.4 Limitations of the thermal comfort study for Ec glazing

The main parameters that are ignored using current software or simulation measurements, the limits of tests on human subjects, long and expensive problems are the main problems for the operation of the thermal comfort of EC glasses.

2.4.1 Time Consuming

Some tools can take a long time because the calculation methods are too complex or a completely separate tool that cannot be integrated into a company's current analysis workflow. On the other hand, the feedback on the thermal comfort of the post-occupation evaluation requires a lot of time and human effort. However, since time is limited and very valuable, it doesn't work for the analysis to take too long.

2.5 Physical Model Fabrication

The production of a large-scale model is different from all previous software simulations. A great opportunity to learn from the process of creating physical models. It is also a good opportunity to buy materials from different manufacturers. Giroux Glass kindly donated four Sage glasses (34 7/16” x 35 1/8 each) and Arcadia Inc., a manufacturer and reseller of aluminum windows and facade systems. store. Arcadia Inc. supplied aluminum frames and seals for the unit. Sage Glass offered frame cables, cable glands and control systems. Note that if water enters the air gap, the EC coating will deteriorate rapidly, so the edge of the glass must close properly. the glass cannot be cut on site (Munshi, 2012), the size and shape of the glass must be manufactured before shipment and installation.

Figure 1: Glass Unit Materials from Different Company

Distinctively conventional glass manufacturing, EC glass requires more attention throughout the process. Guided by SageGlass, here are some basic instructions for the manufacturing actions:

- Mount the aluminum frame
- Amplitude the diameter of the chassis cable to choose the correct drill size.
- Make a crater in the stile for the frame cable and place a washer on the frame to avoid damaging the cable.
- Be sure to leave a cable of appropriate length in the glass bag to connect it to the Pigtail.
- Slide the glass to the IGU pigtail frame cable.
- Place seals on all four glass sizes to prevent leaks.
- Connect the cables to the chassis so that they are protected during transport.

Figure 2: Fabrication Process

In the building network, the wiring network is essential. The wiring is connected to the controller through the hollow frame of the flexible cable of the IGU EC and is supplied to the wall box. In different circumstances, the controller is linked to the power supply and the control system must be preprogrammed according to the needs of the project, according to the level of daylight, the brightness of the event, the air temperature or load in the field. The full-size Ec glass unit produced was moved to the third floor of the USC School of Architecture for the exhibition. Each part of the EC window is connected to the manual controller with four basic states. On the left it was colored and on the right it was open.

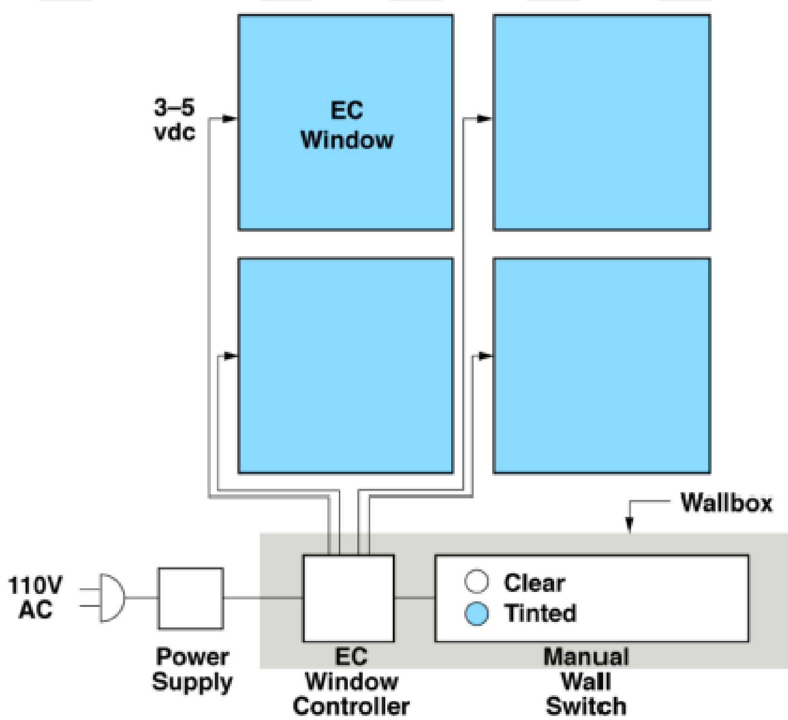


Figure 3: EC window

2.6 Overview

The affiliated previous electrochromic glass studies have examined glass using only two control cases. With the development of technologies, the control of the intermediate state has only been commercially available in late time. Further research is needed to keep up to date with the latest products and to better understand EC glass with four color conditions. The influence of solar radiation cannot be overlooked when assessing thermal comfort near the window. The process of creating a physical model is considered basic research to learn more about the product. However, no further research is carried out.

Year	Author(s)	Paper name	Studied location	Simulation type	Simulation tool	Glazing type	Climate type	Building type	Study type
2017	Ahoo Malekafzali Ardakana, Eloïse Sokb, Jeff Niemaszc	Electroc perform	Minneapolis , MN *USA.*	The **Glare** control performance of EC glazing.	1) Daysim 2) Radiance	Electrochromic (EC) five layers of coating glass	humid continental subarctic	Commercial Service Airports	Experimental & theoretical
2010	Pacific Northwest National Laboratory Richland,	An Exploratory Energy Analysis of Electrochromic Windows in Small and Medium Office Buildings – Simulated Results Using Energy Plus.	*USA. Chicago, Baltimore, Atlanta.*	comparison between the EC and static glazings,	Energy plus	Electrochromic (EC)	*non*	small & medium office	Experimental & theoretical
2009-2013	Christopher meek university of washington	Simulating Visual Comfort and Energy Performance	*USA*	Simulating Visual Comfort and Energy Performance	Energy plus	EW-ECWs		office building	theoretical
2017		building simulation	*launsanne, switzerlan d*	Electrochromic glazings: dynamic simulation of both daylight and thermal performance	DAIL +	Electrochromic (EC)		office building	Experimental & theoretical
2015	Ahoo Malekafzali Ardakan	Dayligh Analysis Electrochromic Glazing And Light Shelf	*USA*	Daylight	Energy plus -diva	Electrochromic (EC)		office building	Experimental & theoretical
2012	Niccolò Aste et al	Comparative energy and economic performance analysis of an electrochromic windo and automated external vene	*Milan, Italy*	Solar radiation	EnergyPlus 7.0 dynamic simulation engine	Electrochromic (EC)		office building	theoretical
2012	Neil L. Sbar a,⇑ , Lou Podbelski b , Hong Mo Yang c,1, Brad Pease d,2	Electrochromic dynamic windows for office buildings	*USA*	Solar radiation	*None*	Electrochromic (EC)		office building	theoretical
2013	Jonatan Mäkitalo	Simulating control strategies of electrochromic windows		illuminance	IDA	Electrochromic (EC)		office building	theoretical
2015	Youness Ajajia,*, Philippe Andréa	Thermal comfort and visual comfort in an office building equipped with smart electrochromic glazing: an experimental study		thermal	*None*	Electrochromic (EC)		office building	experimental study

Table 4*: Study case*

CHAPTER 3
CLIMATE STUDY CASE

3.1 Climate Weather Summery

Time has been a problem in building design and control is an important factor governing architecture. The shape of the buildings has been strongly influenced by meteorological needs, since time limits the problem of designing buildings compatible with the weather. Although time seems to be a new science, the architect has become a climatologist much longer than he can understand, because for centuries the architect has applied climate control through guidance, location and urban planning devices such as sun protection. Before going into the physics of the effect of the sun, temperature, wind and humidity precipitations, it should first be clear what is meant by "climate" and "architectural expression» ». Climate The meaning of the word in the dictionary is the temperature and climatic conditions of a place ". In this context, "macroclimate" and "microclimate" can be used instead of "climate". The macroclimate refers to the general climatic conditions of a region or country and explains the main phenomena of the region. "The microclimatic ifad refers to local climatic conditions in a given place, such as radiation, air currents at ground level, temperature, humidity and only specific rainfall in a limited area. The second is that architects must know them and get to know them closely, not to compete with him, but to accompany him and obtain the best results of his useful properties and to protect himself from the destruction of his qualities. undesirable. Not only superficially, it can be said that it is part of the nature that surrounds and penetrates immediately in a building deep in its character. Architectural expression "expression or expression"; reflection of emotions and thoughts; When they are successfully reflected in the external appearance or appearance of the building, the internal character can mean "architectural expression". The buildings can have individual personalities and views, given the same floor. On the ground floor, the two buildings are the building blocks that can be very different from each other depending on the treatment, properties, etc. For example, a simple rectangular top can be made of wood, such as in Malabar, or a building fringed with fringes and open edges with deep edges with open edges or often in Morocco. A building with white plaster walls, a flat roof and openings narrow, so that two similar plans for similar use can be very different from each other, history can provide valuable lessons and explain these differences. Sir Bannister Fletcher gave importance to six: (i) geography, (ii) geology, (iii) climate, (iv) religion, (v) social customs and (vi) history. An examination of the history of architecture can provide examples of the important role of climate in the development of architectural features. Simultaneous effects of other factors, such as geographical and geological conditions.

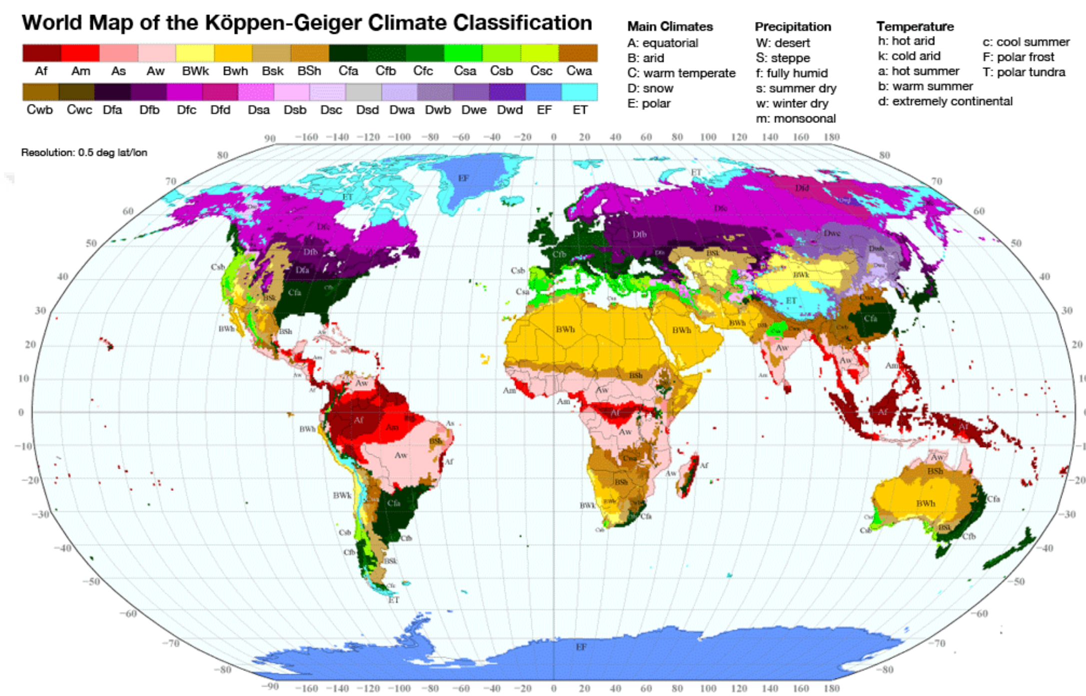


Figure 4: Köppen Climate Classification (World Map of Köppen − Geiger Climate)

3.2 Climate Classification & Location

The climate in the study case is hot and humid, specifically in the Middle East, Abu Dhabi, United Arab Emirates, the climate is dominated by a subtropical anticyclone and the real desert climates are between 15 ° and 30 ° latitude. The United Arab Emirates (UAE) has a desert climate with the humidity of the Persian Gulf, which is characterized by pleasant mild winters and very hot and sunny summers, which makes the heat unbearable.

Latitude: 24 26N

Longitude: 054 39E

Elevation: 89 feet

The Köppen climate classification subtype for this climate is "Bwh". Tropical and subtropical desert climate. The average annual temperature in Abu Dhabi is 27.2 ° C. The hottest month is July with an average temperature of 35 ° C (95.0 ° F). Temperatures are on average the highest in January, around 18.3 ° C. The highest temperature recorded in Abu Dhabi is 47.2 ° C, recorded in June. The lowest temperature recorded in Abu Dhabi is 5 ° C in February. The average annual temperature in Abu Dhabi is 5.1 "(129.5 mm). Most rainfall falls in February with an average of 0.8" (20.3 mm). Most of the precipitation falls here in January, averaging 0.4 mm. The highest rainfall falls in February with 6.0 days and the average rainfall is 24 months and the lowest rainfall occurs in May with 0.0 days.

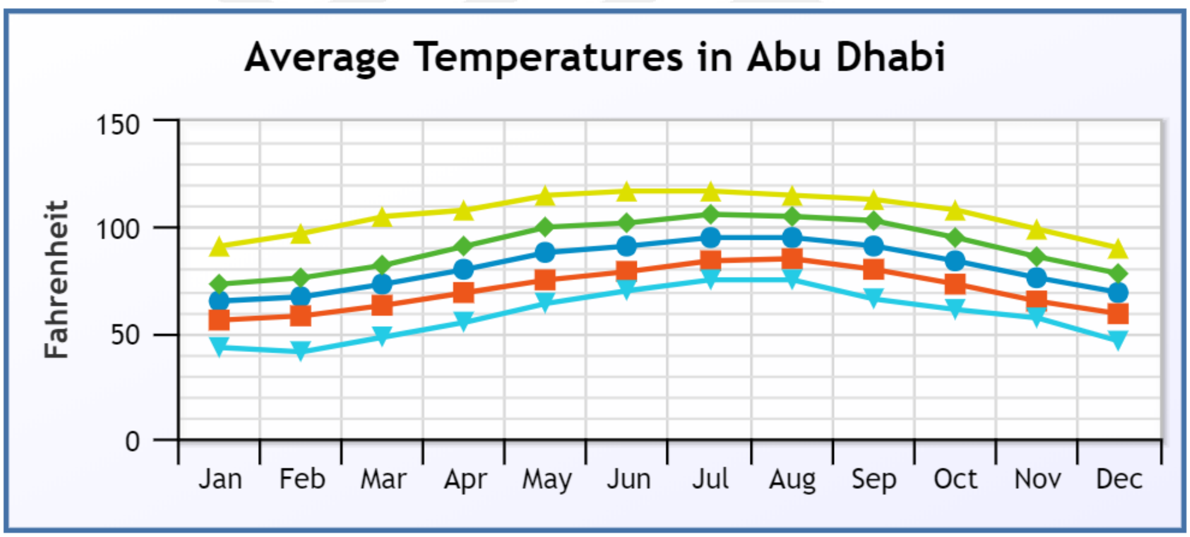


Figure 5: Average Temperatures in Abu Dhabi (Köppen Climate Classification)

CHAPTER 4
ELECTROCHROMIC

1.1 Introduction of Electrochromic Glass

Definition of electrochromic glass (Ec) and basic principles on how to introduce glass manufacturing. The main advantages and disadvantages of EC glass are also clarified.

Glass is an incredible material and our buildings will be dark, dirty, cold and wet without it. But there are inconveniences. It provides light and heat even when you don't want it. On a blinding summer day, the more heat solar gain in your building, the more you need to use a waste of money and a terrible loss of energy that damages the environment. That is why most windows in houses and offices have curtains or blinds, but it is uncomfortable in cold, and practicalities as well. Curtains and blinds are technological devices to compensate for the great integrated disadvantage of glass: transparent or translucent even when you don't want it (Chris Wood, 2017).

Electrochromic devices modify the properties of light transmission in response to voltage and, therefore, control the amount of light and heat that passes (J. Talin, A. Alec, 2016). In electrochromic windows, the electrochromic material changes its opacity. An electrical is necessary to change its opacity, but once the change is made, electricity is not required to maintain the particular tone obtained (American Scientist. Recovered 2018).

First-generation electrochromic technologies tend to have a dominant yellow in their luminous state and blue tones in their color state. The attenuation moves from the edges and is a slow process, which varies from a few seconds to a few minutes 20-30 minutes depending on the size of the window. The new electrochromic technologies eliminate the light yellow color and color the shades of gray even more neutral, regardless of the size of the glass, color the exterior evenly and increase the coloration rates to less than three minutes. Electrochromic glass provides visibility even in the dark, thus maintaining visible contact with the outside environment.

1.1.1 The Definition of Electrochromic Glass

Electrochromic glass (smart glass or dynamic glass) is an electronically tintable glass used for windows, skylights, facades and curtain walls. Electrochromic glass, which can be directly controlled by building occupants, is popular for its ability to improve occupant comfort, maximize access to daylight and outdoor views, reduce energy costs and provide architects with more design freedom (Sage Glass, 2017).

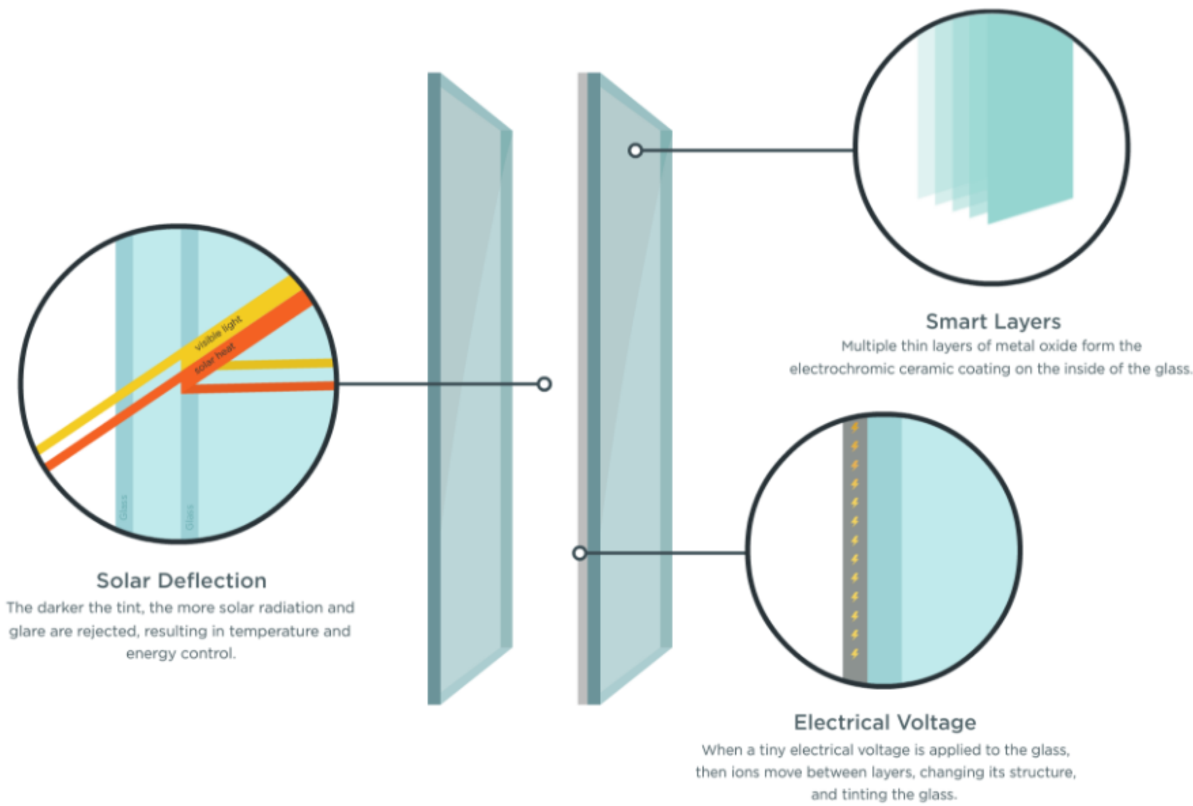


Figure 6 Electrochromic Glass (View Inc, 2017)

1.1.2 How Does Electrochromic Work

According to Chris Woodford, ordinary windows only have one panel, while double-glazed windows consist of two glass panels separated by an air gap to avoid external heat and noise (Woodford, 2017). EC glass and low glass windows have much more sophisticated coatings than plywood. As for EC glass, there are five ultra-thin layers on the inner surface of the coating: a separator in the center, two electrodes on each side of the separator and two transparent layers of electrical contact on each side of the electrodes. Basically, the principle of operation is that when voltage is applied across the coating, lithium ions pass through the separator between the two electrodes. When most of the light can pass through the glass, the lithium ions remain in the innermost electrode, which is obtained in the transparent state of the glass. The ions remain in this layer until voltage is applied, then the ions migrate from the innermost to the outermost layer. In this case, the outermost layer will reflect more light, which makes the glass opaque. No energy is needed to keep the electrochromic glass in an open or dark state, but only when the ions are changed from one state to another (Woodford, 2017).

Whether clear or colored, visible and near infrared radiation in the glass can pass through the window inside the building. EC window films can be completely painted from one color to another and can be captured between these two situations. The film absorbs a certain amount of solar radiation depending on the color level. More color, more light is absorbed. The energy absorption heats the EC panels and, therefore, heat is preferably returned through the cavity. The visible transmission never reaches zero (Tvis = 1% in color), therefore, the external aspect is always maintained (Burdis et al. 2007). According to Chris Woodford, ordinary windows only have one panel, while double-glazed windows consist of two glass panels separated by an air gap to avoid external heat and noise (Woodford, 2017). EC glass and low glass windows have much more sophisticated coatings than plywood. As for EC glass, there are five ultra-thin layers on the inner surface of the coating: a separator in the center, two electrodes on each side of the separator and two transparent layers of electrical contact on each side of the electrodes. Basically, the principle of operation is that when voltage is applied across the coating, lithium ions pass through the separator between the two electrodes. When most of the light can pass through the glass, the lithium ions remain in the innermost electrode, which is obtained in the transparent state of the glass. The ions remain in this layer until voltage is applied, then the ions migrate from the innermost to the outermost layer. In this case, the outermost layer will reflect more light, which makes the glass opaque. No energy is needed to keep the electrochromic glass in an open or dark state, but only when the ions are changed from one state to another (Woodford, 2017).

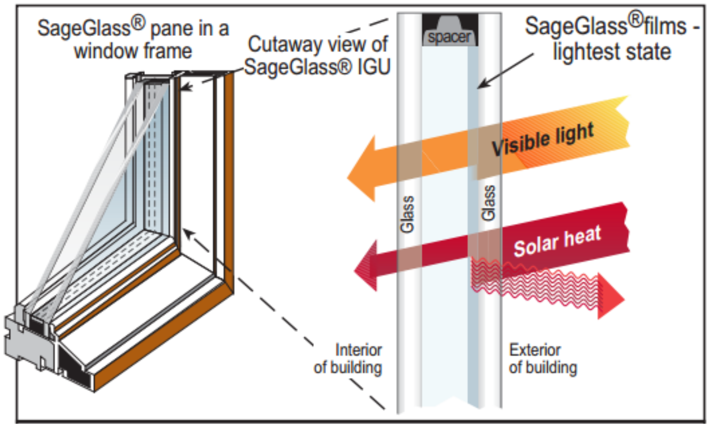


Figure 9: EC glass in Clear state (Burdis et al, 2007)

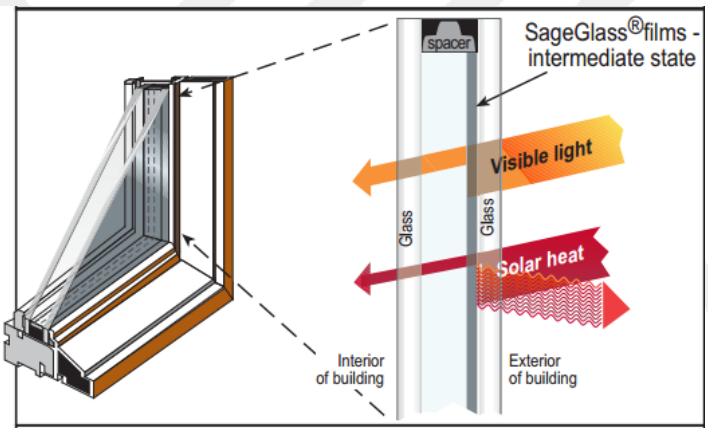


Figure 8: EC glass in Intermediate state (Burdis et al, 2007)

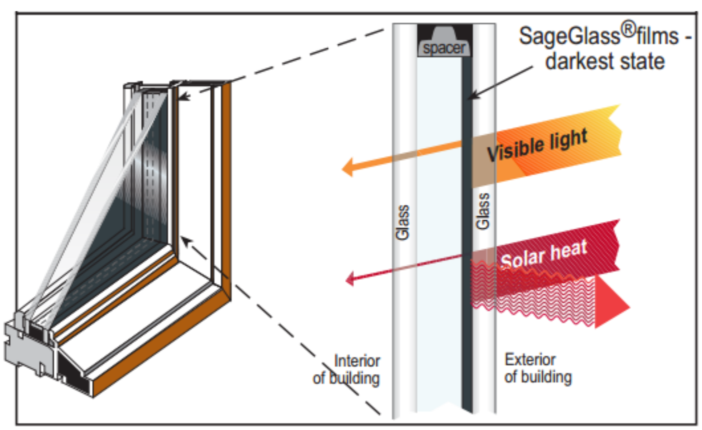


Figure 7: EC glass in Tinted state (Burdis et al, 2007)

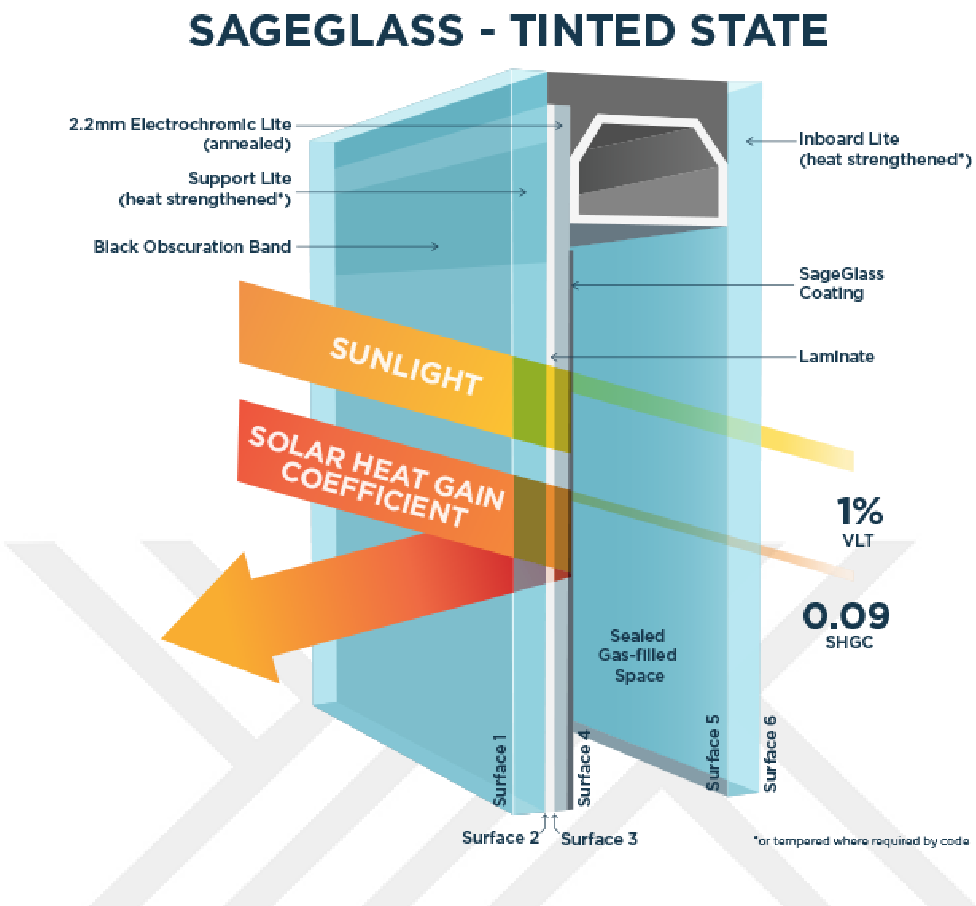


Figure 10: configuration of an electrochromic dual-pane

1.1.3 Advantages of Electrochromic Glass

Electrochromic glass is an intelligent solution for buildings where solar control is difficult, including classrooms, sanitary facilities, commercial offices, outlets, museums and cultural institutions. Interiors with atrium or skylights also benefit from the use of smart glass. SageGlass has completed a series of installations to provide solar control in all these industries. Protects passengers from heat and reflections. Electrochromic glass retains access to daylight and exterior views associated with faster learning and patient recovery rates, better emotional health, greater productivity and less absenteeism to the employees (Sage Glass, 2018).

Electrochromatic glass offers a variety of control options. With the advanced SageGlass algorithm, users can use automatic control settings to manage light, reflection, power consumption, and color reproduction. Controls can also be integrated into existing building automation systems. For users who want more control, SageGlass can be manually overwritten using wall panels, allowing users to change the color of the glass. Users can also change the color level through the SageGlass mobile application (Sage Glass, 2018).

SageGlass also helps building owners achieve their sustainability goals through energy savings. By maximizing solar energy and reducing heat and glare, SageGlass allows building owners to save money by reducing the total energy load in the building life cycle by 20% and demand by 26% advanced energy. However, not only do the owners and residents of the building use it, but the architects have the freedom to design without the need for curtains and other shading devices that interfere with the exterior of the building. (Sage Glass, 2018).

1.1.4 Disadvantage of Electrochromic glass

Rregardless of all the benefits that EC glass can offer, there are some common problems, daylight problems and energy problems to consider when applying EC glass in a building.

- General Issues: The sophisticated coatings make EC glass more expensive than ordinary glass. Also due to the complexity composition of electrochromic glass, there are also questions about how durable the glass is compared with conventional glazing. Besides, not as most people might have expected, instead of taking several seconds, EC glass may need several minutes to change from one state to another (Woodford, 2015).

- Daylight quality Issue: In order to reduce the human discomfort caused by solar glare at the perimeter zones of the floor plate, EC glass is set to tint to its lowest level of visual transmittance when a high level of daylight is incident on the window, especially when sunlight is present. While this strategy maintains the light level within optimal range, normally between 100 lux to 2000 lux (NOAO, 2015) for the perimeter zones, it can make the inner zones of the floor darker than the perimeter zone (Ardakan, 2015).

1.2 Basic terminologies about electrochromic glass

Unlike conventional glass, some unique components (e.g. frame cable, pigtail) about EC glass have to be explained. EC glass, as a switchable glazing, has different tinting states and gets tinted when receiving a command. The control strategies are illustrated and how fast the glass with switch is also discussed.

1.2.1 IGU

The dynamic insulating glass unit (IGU) are assembled with multiple layers of glass (commonly consist of two layers), filled with air or a noble gas, such as argon or krypton inside, acting as a thermal barrier to increase energy efficiency. The noble gases are likely to conduct less heat through the IGU, providing a further insulation. The EC glass coating and deployment of noble gas also improve the window's overall u-value, which is a measurement of the heat transmission through a building part. The IGU is assembled with a prewired connection to the intelligent control system, and with high level of precision and process control in state-of-the-art dynamic glass manufacturing facilities (View Inc, 2017). With larger panels of glass available in IGUs, the application of EC glass is broader which can be used in curtain walls, skylights, atria etc.

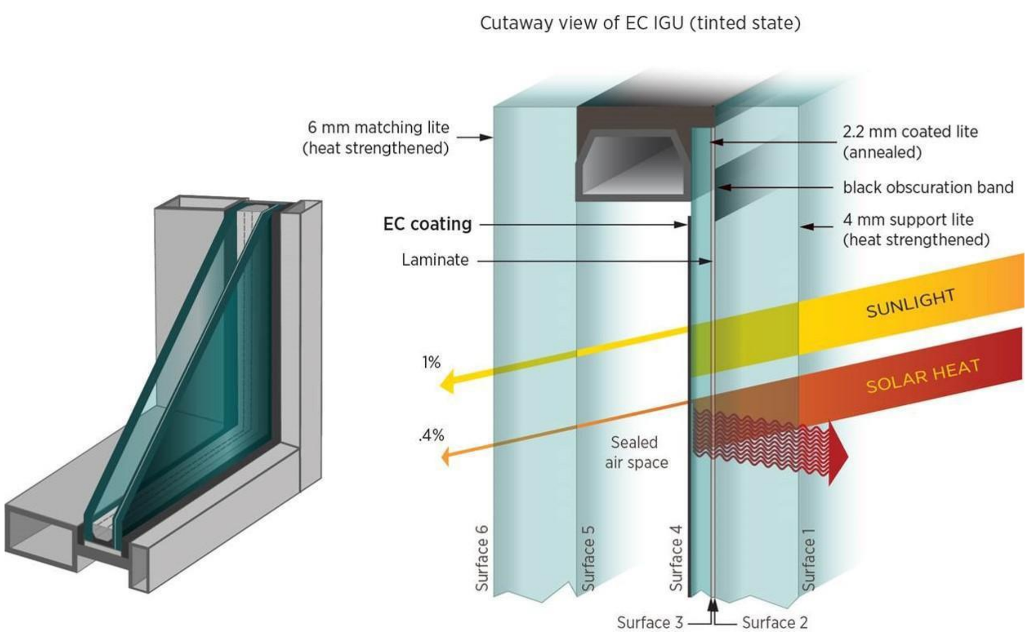


Figure 11: *Dynamic Insulating Glass Unit (SageGlass Architect Brochure, 2016)*

1.2.2 Frame Cable

The IGUs are connected to the control system by frame cable. To be more specifically, frame cable attaches to the IGU pigtail on one end, routes through the framing system, and connects

to the control system. The lengths and conductor configurations can be ordered in a variety of sizes to meet specific installation requirements (SageGlass Frame Cable, 2017).

1.2.3 Pigtail

Each IGU is connected to the frame cable by another cable called pigtail which extends from one edge of the IGU. The pigtail stores an electronic serial number and provides the electrical connection to every single IGU. It also includes IGU-specific data that can be used for system start-up, commissioning and troubleshooting. The pigtail can be manufactured extending from multiple locations as needed for flexibility in installation (SageGlass Pigtail Cut Sheet, 2017).

Figure 12*:Frame Cable*

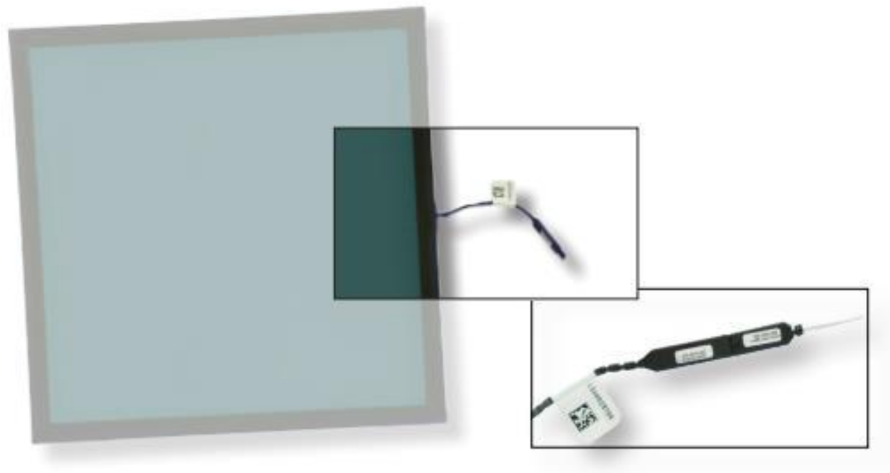


Figure 13*: IGU Pigtail (SageGlass Pigtail Cut Sheet, 2017)*

1.2.4 Tinting States

The visible light transmission of EC glass can be varied from 1% (fully tinted state) to 60% (clear state). A standard Sage glazing can also be programmed to have two intermediate states which has 18% and 6% visible light transmission respectively. When fully clear or tinted states are not necessary, these two intermediate states often provide optimal shading effects, and this range of variability of tinting states provide many new design considerations for the architects and building owners (Sage Glass Control System, 2016). Based on project daylighting design needs, the EC glass system can be fully customizable and programmed to designated specifications (Sage Glass Product Guide, 2017).

The performance specifications of a standard EC glazing of Sage Glass include Tvis, SHGC, U-factor, %Rb Int., %Tsol, % Tuv, %Tdw-K . "Visible transmittance (Tvis) represents the amount of visible light that passes through the glazing material. Solar Heat Gain Coefficient (SHGC) is defined as the fraction of incident solar radiation that enter the space through entire window assembly as heat gain. U-factor is the standard way to qualify overall heat flow" (Window Technologies).

Level of Tint	Inner Lite	%Tvis	%Rf Ext.	%Rb Int.	%Tsol	SHGC	U-factor btu/hr.ft².°F	%Tuv	%Tdw-K
Clear State	6 mm Clear	60	16	14	33	0.41	0.28	0	15
Intermediate State 1		18	10	9	7	0.15	0.28	0	5
Intermediate State 2		6	10	9	2	0.10	0.28	0	2
Fully Tinted		1	11	9	0.4	0.09	0.28	0	0.6

Table 5*: Sage Glass Tinting State (Sage Glass Performance & Acoustic Data, 2016)*

1.2.5 Control Strategies

When it receives a command from the control system, EC glass changes its tinting states. Electronics are housed in control panels and are pre-programmed with the algorithms that carry out the commands which can best meet the project requirements. The algorithms are often determined by the building's designer, and the control systems have advanced tools to manage the following factors, such as daylighting, color rendering, energy usage, glare incident on occupants and interior light levels. For optimum performance, there are several control strategies can be used to determine what tinting state the glass should be, including daylight control, schedule control and glare control, etc. (SageGlass Control System, 2016).

- Daylight Control

This control strategy is for maximum natural daylight which control the dimmable electric lighting and natural light coming through the windows synergistically. A daylight sensor can control the tint level depending on sky conditions, sun positions. When the sky is overcast, the glass is more likely to be set to clear state and admit more daylight to 17 obtain better illumination for the interior space. When the sky is clear, the daylight sensor can tint the glass to block certain daylight into the space to achieve the same illuminance target, which at the same time can reduce direct solar gain space (Pease et al, 2010).

- Schedule Control

EC window can be controlled according to time and desired solar energy passing into the space. The basic principle is limit solar gain in summer which may reduce the air conditioning systems load and allow needed solar gain during the winter so as to reduce the heating energy consumption. The seasonal variation along with daylighting controls can help to achieve a better energy performance with EC glazing space (Pease et al, 2010).

- Glare Control

"Glare is a visual sensation caused by excessive and uncontrolled brightness" (Lighting Research Center, 2017). Glare causes visual discomfort, and the direct solar irradiation improves contrast at the work plane which will affect occupant work efficiency. Luckily, EC glazing can directly be controlled to reduce glare. Under direct sun or when exposed to severe reflected light, the glass will tint to fully tinted state. Typically, this control strategy allows users to tint the offending window zone while allowing daylighting coming into the space through other panes (Pease et al, 2010).

The system is highly customized and can be programmed to meet the different needs of any project. When the sun rises and shines directly on the east elevation at a low incidence angle, the east façade is set to tint to reduce glare, and the rest of glass is set to maximize daylighting. With the sun pass overhead in the early afternoon, glass on the east and south elevations tints to intermediate states to achieve specific light levels. In the late afternoon, direct glare becomes a problem in certain areas, so the west window need to be fully tinted to block direct sun light coming through, while the glass elsewhere in the building need to be clear for maximum daylighting. As the sun keep going down to sunset time, the top windows transition to clear mode to harvest as much daylight as possible. During nighttime, windows can be programed to either fully clear state if outside view is desired or fully tinted state to reduce light pollution at night (SageGlass Control System, 2016).

1.2.6 Glass Switching Speed

According to a design guide for EC windows early market done by Lee et al in LBNL, EC glass switching speed depends on the following factors, such as ambient temperature, glass size and distance between the bus bars. Normally, a higher outside temperature results in a faster glass transitioning speed. Smaller panes transition faster than larger panes, and larger panes with a center bus bar will transit faster than those panes without a center bus bar. However, instead of transitioning from fully clear to fully tinted state, EC glass often changes in smaller increments in daily use, for example from one state to the next lighter or darker state, so in this case the transition takes less time (Lee et al, 2006).

CHAPTER 5
METHODOLOGY

5.1 Workflow Overview

The DIVA plug-in model is used to evaluate the effectiveness of the instrument for daylight comfort for EC glass. Among the available software that can simulate daylight comfort, the DIVA extension is selected because the software has access to the EC glass selection in the glass library where users can create specific glass functionalities in the software. Some other software can also perform daylight simulations, but it is not taken into account.

The general workflow can be divided into two parts: workflow development and workflow evaluation. The workflow includes examining the software's capabilities to perform existing thermal comfort simulations and, if possible, improve the process. However, in this case, the study only includes the analysis of daylight for electrochromic glazing behavior,

Workflows are evaluated according to three main criteria: if the solar charge pulses are taken into account, the four conditions for tinting the current electrochromic glass are taken into account and the tool could apply glass tinting schedule in the simulation process. To compare the results of the analysis of solar radiation and daylight, a case study is carried out with three different types of glass, such as single, double and triple, in the EC glass test room (office) and The Low-E glass reference room.

5.1 DIVA for RHINO (plug-in)

The DIVA add-on was chosen as one of the proven software, because it has many powerful add-ons and makes simulation tools usable. For example, as an open source environmental add-in, DIVA can transfer standard Energy Plus Weather files to the Rhino model canvas on the website.

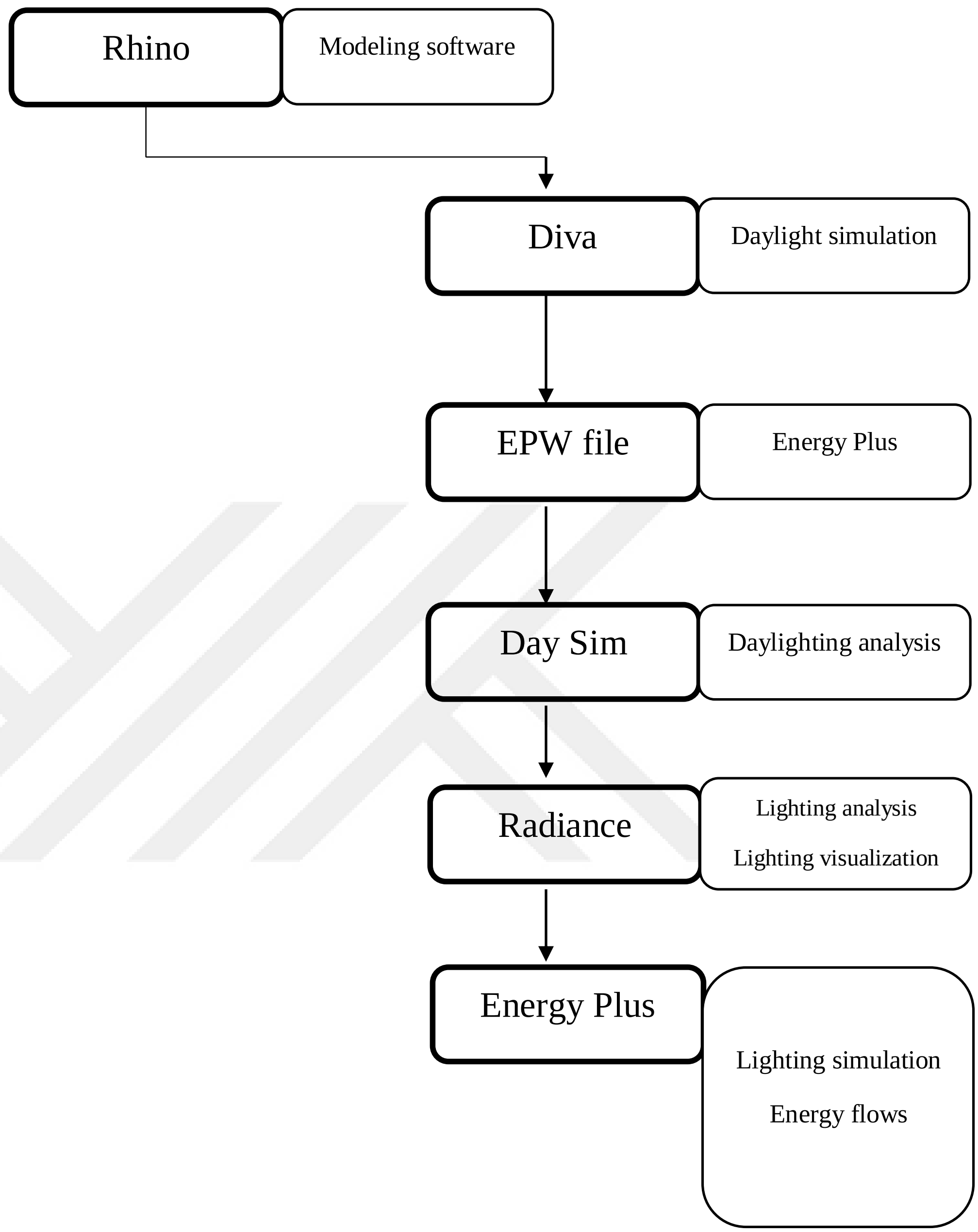


***Figure 14**: Workflows for DIVA*

5.2 Setting up a Rhino model for daylight Analysis

The following includes information about the correct installation of the Rhino model for use with the toolbar. To ensure that all geometries are used in the analysis, it is a good idea to first run the "Visualization" metric and examine the image for unexpected problems, such as "holes" or gaps.

- **Units**

The metric that is in the study case is meters.

- **Orientation**

Orientation definitely important to the façade, due to glazing type selected it's going to be facing the southern façade.

- **Diva layers**

When you run the DIVA **Location** button, several DIVA layers are created. These layers store the various nodes, node values, grid and legend information that DIVA generates.

5.3 Climate Based Metric

Climate-Based Metrics use recorded climate data in the form of *.epw files to simulate the sun and sky conditions for various simulations including Daylight Autonomy, Daylight Availability, Continuous Daylight Autonomy and Useful Daylight Illuminance. The second important aspect of Climate-Based Metrics is that they are **annual** calculations which means they take the entire year into account. The metrics use Radiance and Daysim as their calculation engines.

5.3.1 Units

(Lux, Footcandles)
Although Radiance and Daysim only use lux as a unit of illuminance.

5.3.2 Occupancy Schedule

(always_occupied.60min.occ.csv,never_occupied.60min.occ.csv,
weekdays9to5withDST.60min.csv)
In this dialogue annual hourly occupancy schedules can be selected. These occupancy schedules are used to determine when a lighting or shading group is occupied. These files are stored in csv (comma separated value) format under c:\DIVA\Schedules.

5.3.3 Target Illuminance

Select a target illuminance level for your space. This level should depend on space type for example 500 lux of an office. For predominantly daylit spaces it has become customary to assume a target illuminance of 300 lux.

5.3.4 Use DGP schedules

This option controls how a manually controlled dynamic shading system is being modeled. If the the user has run an annual glare analysis beforehand and this option is checked, the Lightswitch model will close the blinds as soon as the DGP in the annual glare schedule is above 40% (disturbing glare or worse). If left unchecked of if no annual glare analysis has been conducted, the blinds will be closed once direct sunlight above 50w/m2 is incident on the specified work place.

5.3.5 Adaptive Comfort

This parameter determines how annual glare simulations inform the use of a dynamic shading system. If the shading system is manual controlled and more than one view point was provided for the annual glare calculation, then the former selection assumes that a user can adapt to the space and pick the position with the least amount of glare. In the latter case several occupants are in the space and the occupant with the worst glare condition determines whether the shading device needs to be readjusted.

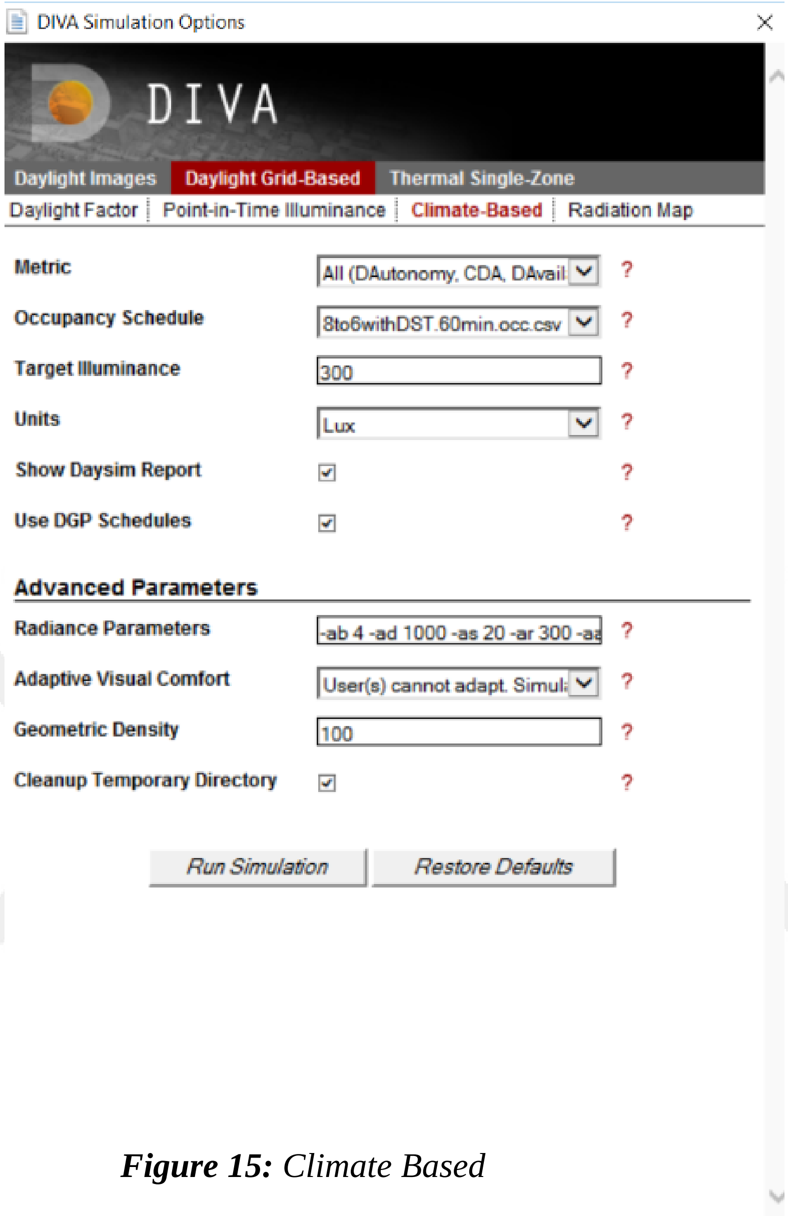


Figure 15: *Climate Based*

5.4 Site Location

The site location and description (simulated model)

Latitude: 24 26N

Longitude: 054 39E

Elevation: 89 feet

5.5 Geometric model

The main installation of the geometric model is a functional office model designed in Abu Dhabi. The test area was designed as (x): 10 m, depth (y) 8m and height (z) 3m. Due to the geometric aspect ratio, so it has divided into 30 sensor models (mesh). The sensors are subtracted from 0.75m above the geometry floor, in which case the sensors are a total of 30, so it will be a long process to simulate each point individually, so I decided to make the simulation process much shorter than 9 points and calculate each point. The main installation of the geometric model is a functional office model designed in Abu Dhabi.

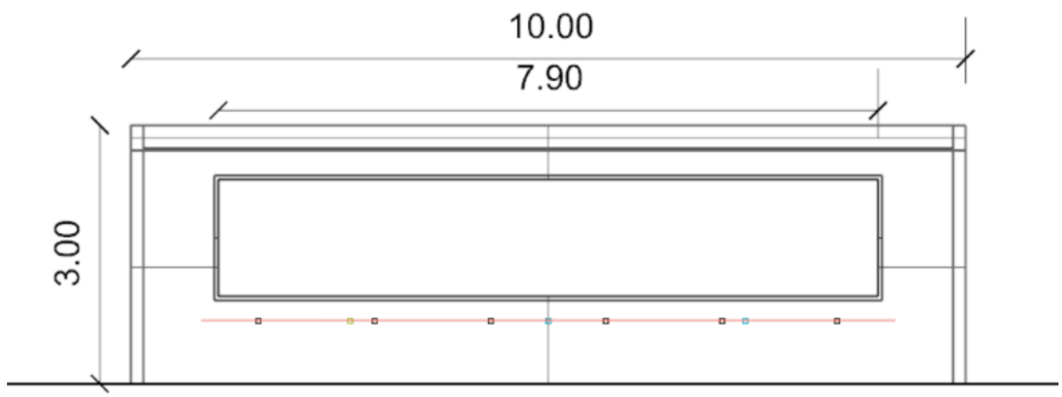
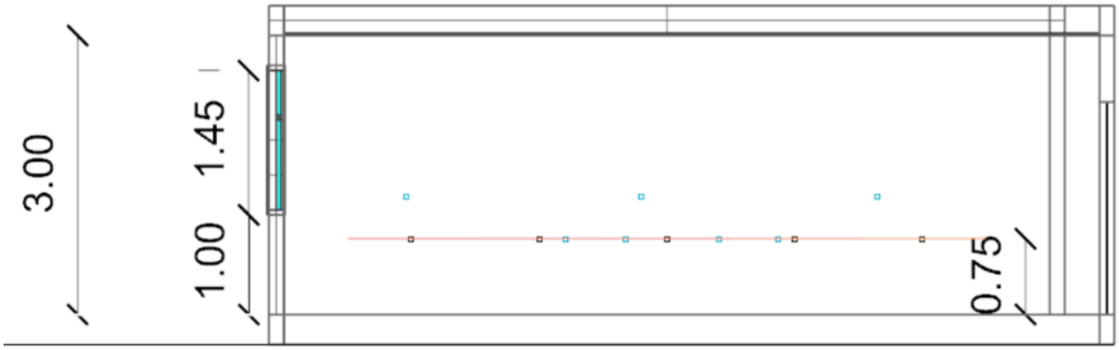


Figure 16: *Elevation of South facade*



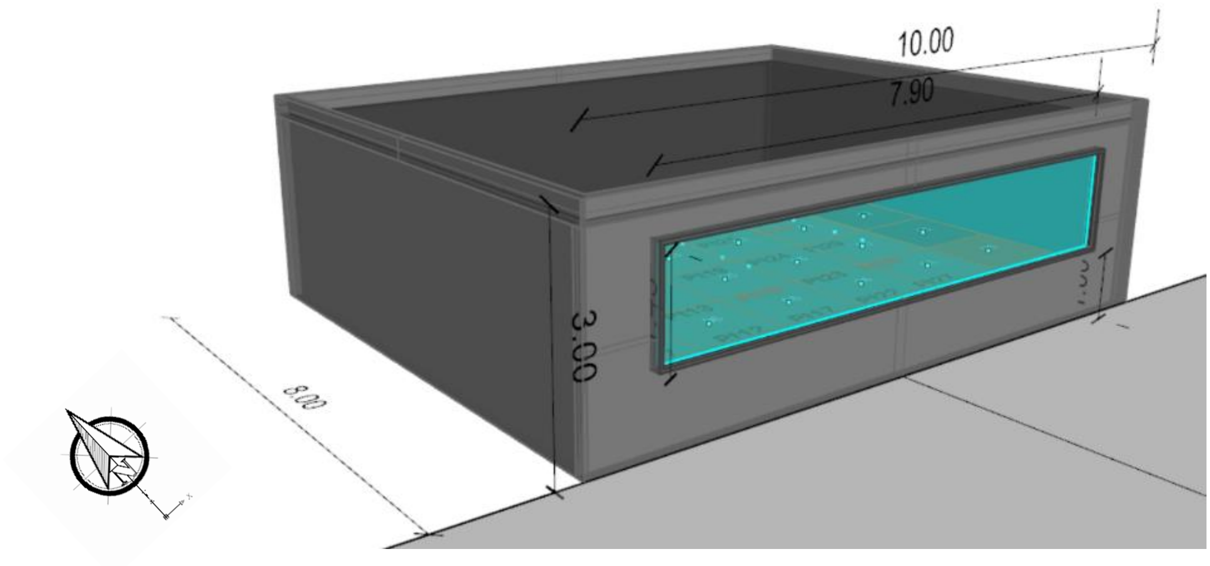


Figure 18: *Overview 3D model*

Sequence of the points (sensors): pt1, pt3, pt5, pt16, pt18, pt20, pt26, pt28, pt30, the daylight simulation is annual, according to weather conditions, the test of these 9 pt(s) will be carried out in summer and in winter to simulate these results and evaluate the behavior of the electrochromic response. To optimize the electrochromic behavior, it covers two days between summer and winter, summer (June), 18-19-20, winter (January) 19-20-21.

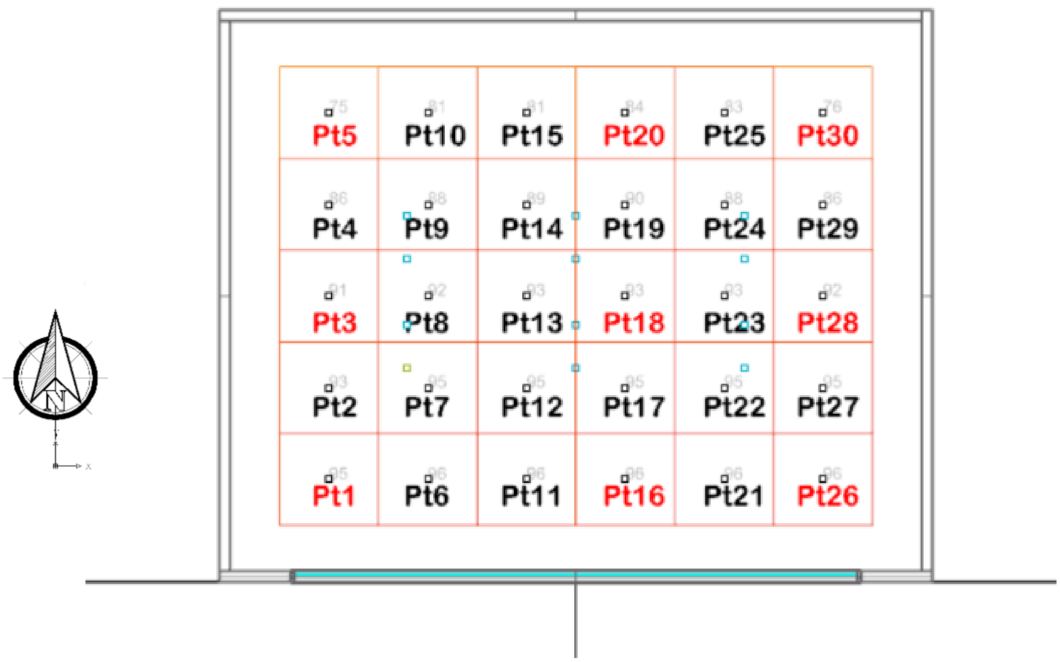


Figure 19: *Top view representing the points*

Glazing type	tvis	SHGC	U-value	Transmittance	Transmissivity
Single pane	0.88	0.82	5.82W/m2K	88%	96%
Double pane low-E	0.65	0.28	1.63W/m2K	65%	71%
Triple pane Krypton	0.47	0.23	0.57W/m2K	47%	96%
EC clear 60%	non	non	non	60%	65%
EC clear 30%	non	non	non	30%	32%
EC clear 02%	non	non	non	2%	2%

Table 6: *Glass material values*

CHAPTER 6
RESULTS AND DISCUSSION

6.1 Results of Abu Dhabi

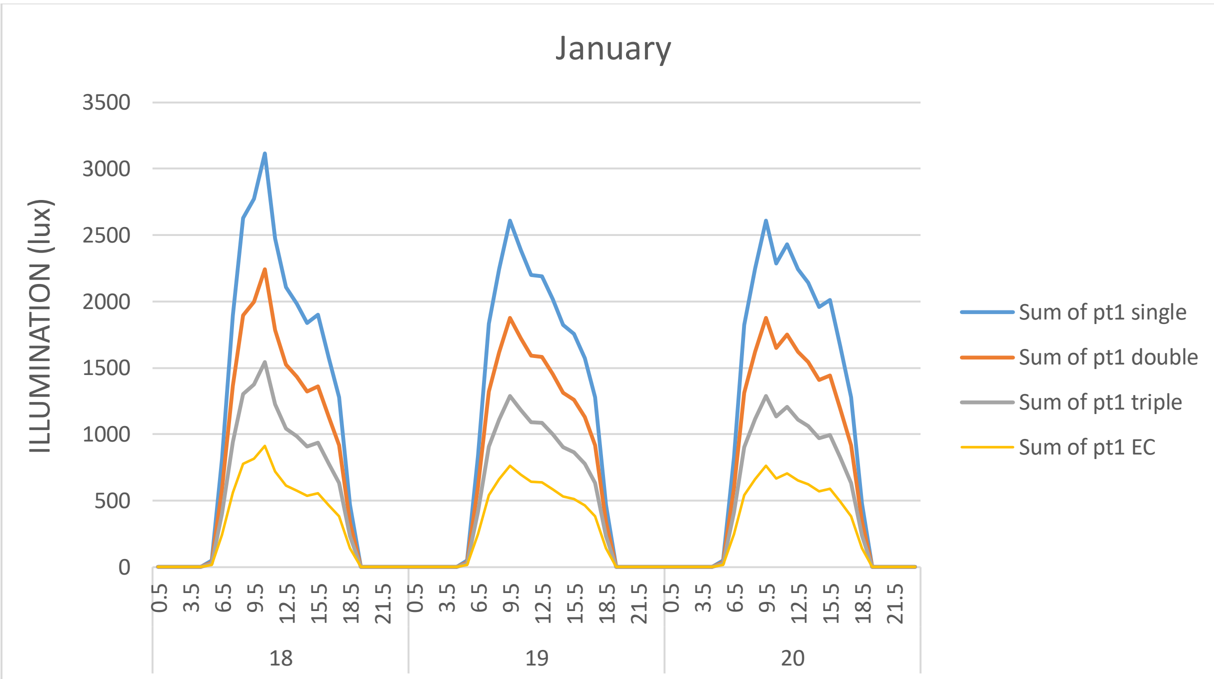


Figure 20: 18-19-20 January Pt1 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 3000 lux, 2600 lux, and 2600 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt1 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

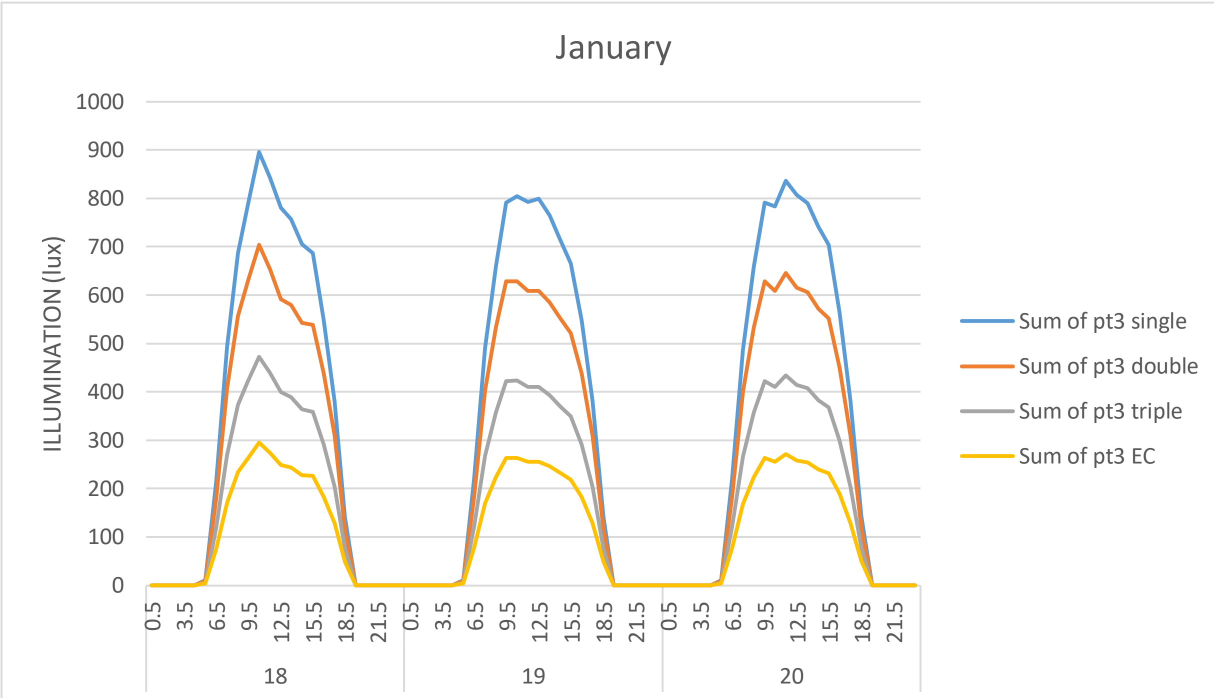


Figure 21:18-19-20 January Pt3 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 900 lux, 800 lux, and 850 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt3 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

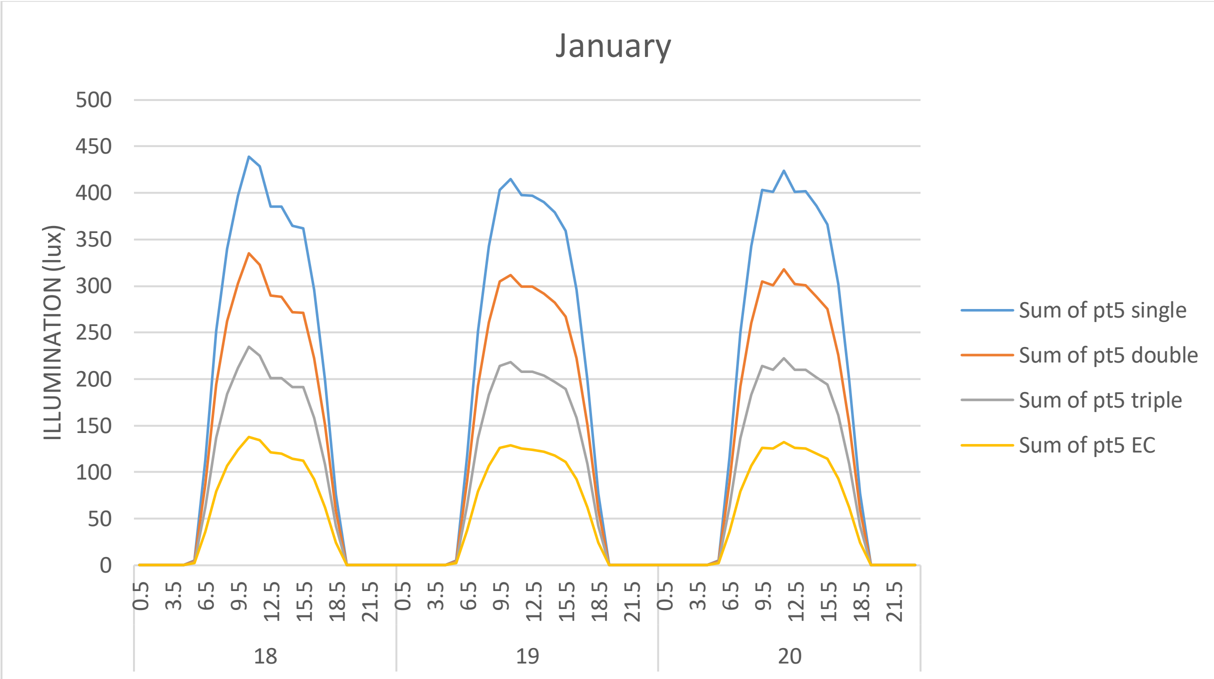


Figure 22:18-19-20 January Pt5 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 440 lux, 410 lux, 415 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt5 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

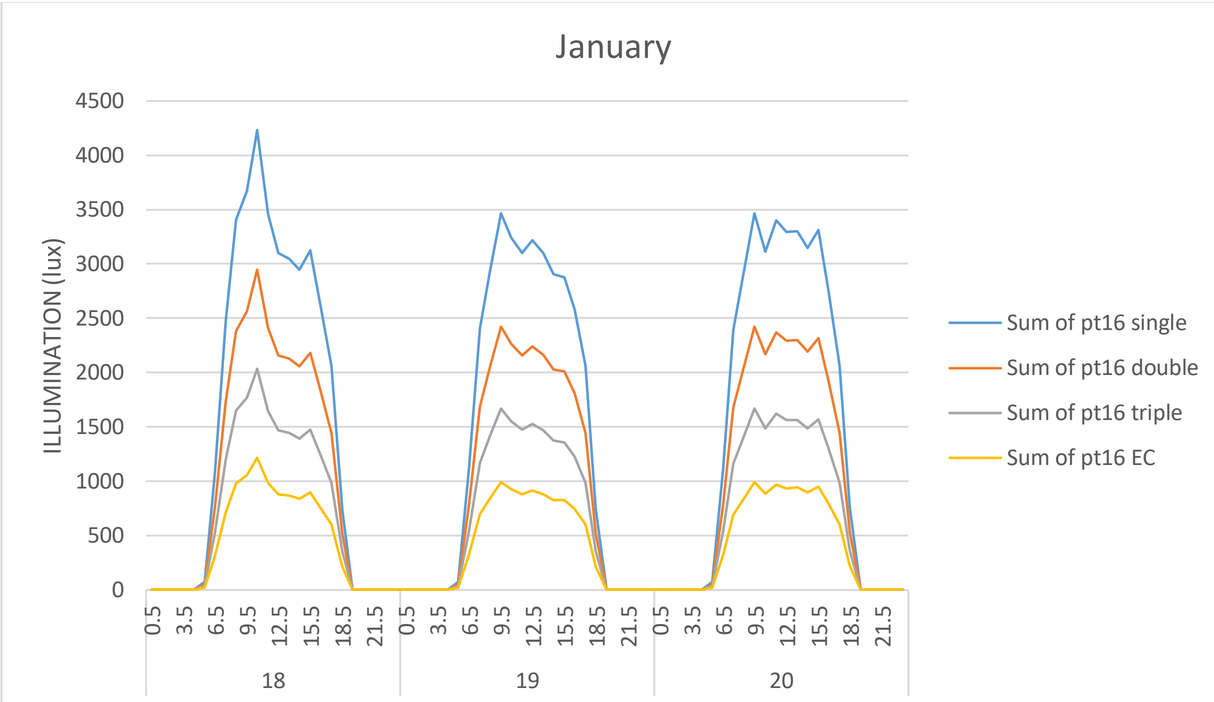


Figure 23:18-19-20 January Pt16 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 4100 lux, 3500 lux, 3500 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt16 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

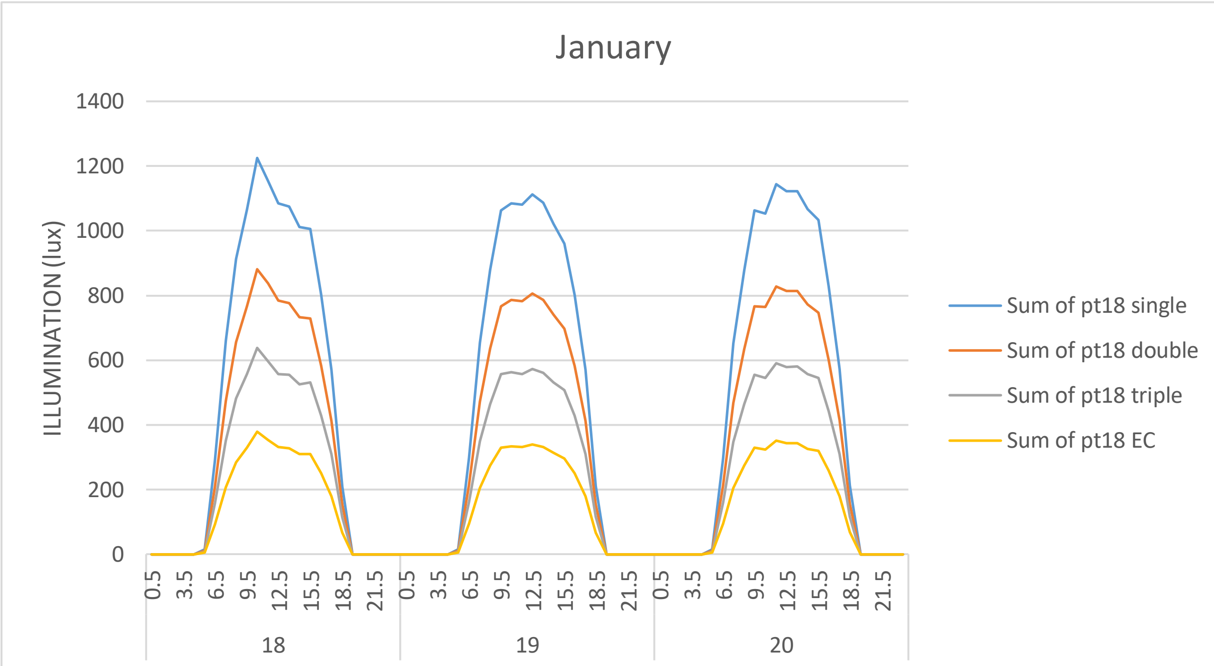


Figure 24:18-19-20 January Pt18 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 1200 lux, 1100 lux, 1115 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt18 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

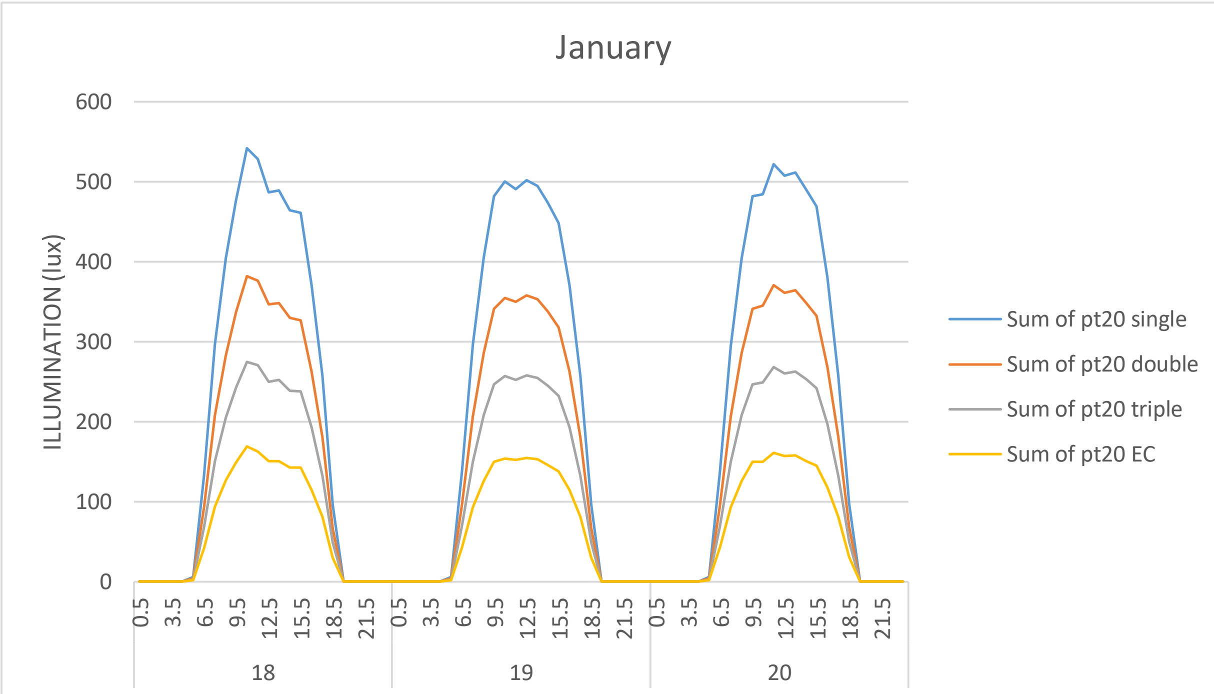


Figure 25:18-19-20 January Pt20 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 550 lux, 500 lux, 520 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt20 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

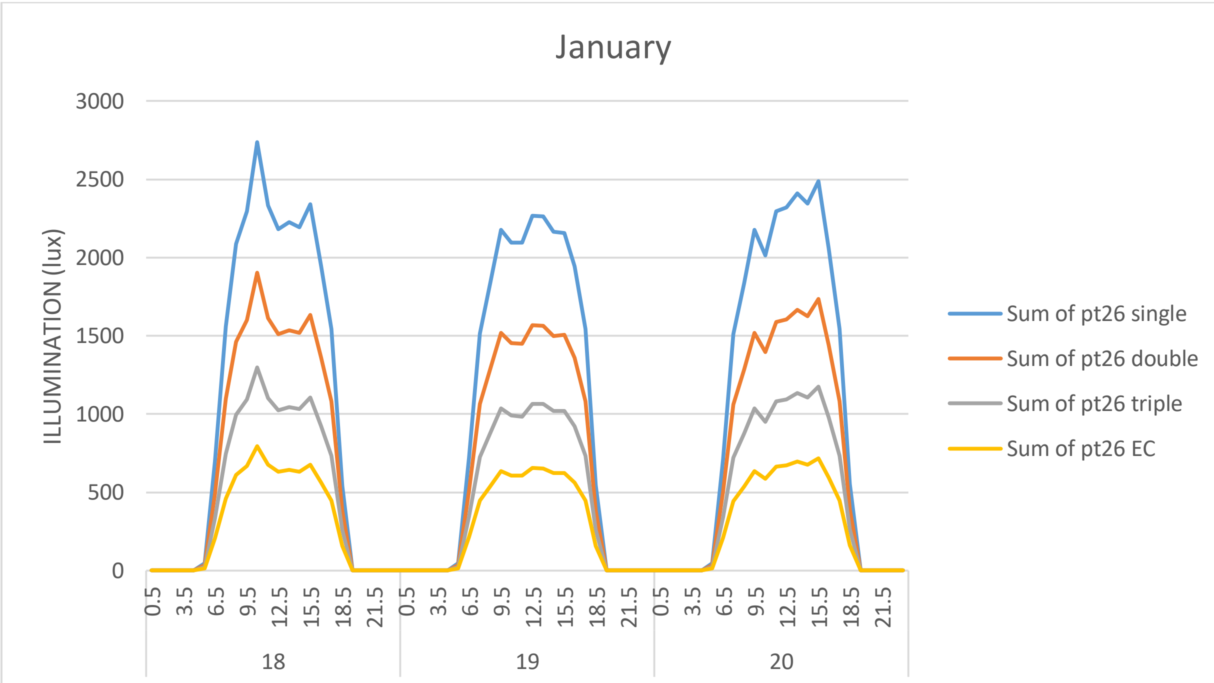


Figure 26:18-19-20 January Pt26 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 2700 lux, 2300 lux, 2500 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt26 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

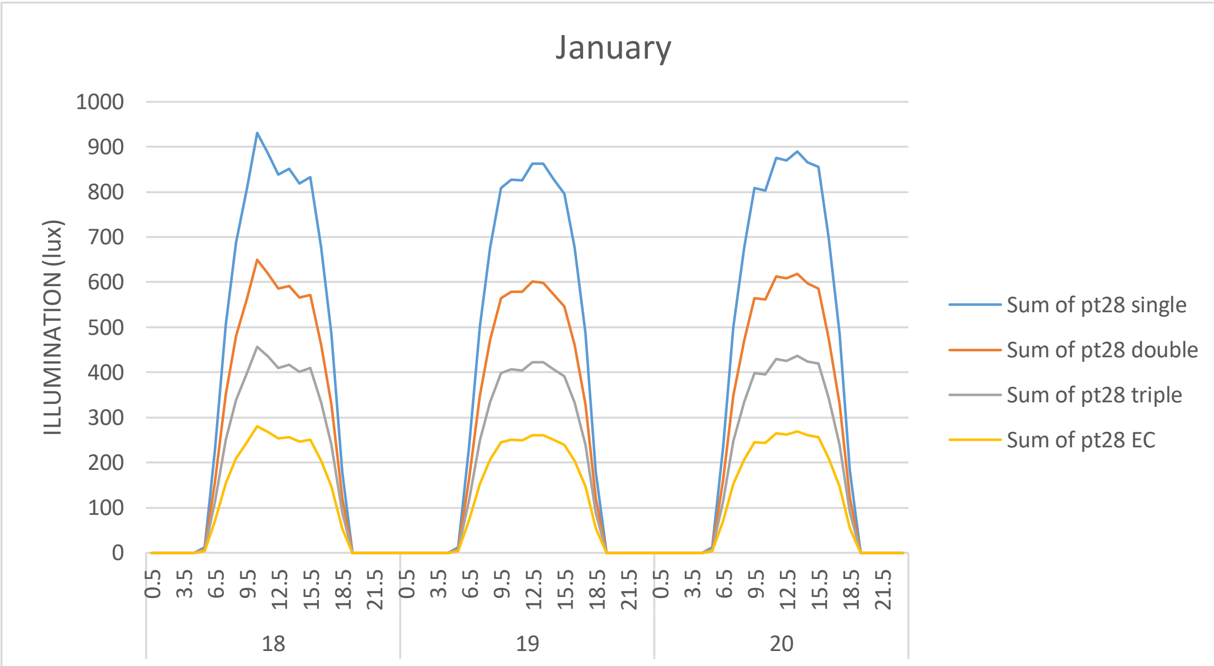


Figure 27: 18-19-20 January Pt 28 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 910 lux, 850 lux, 870 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt28 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

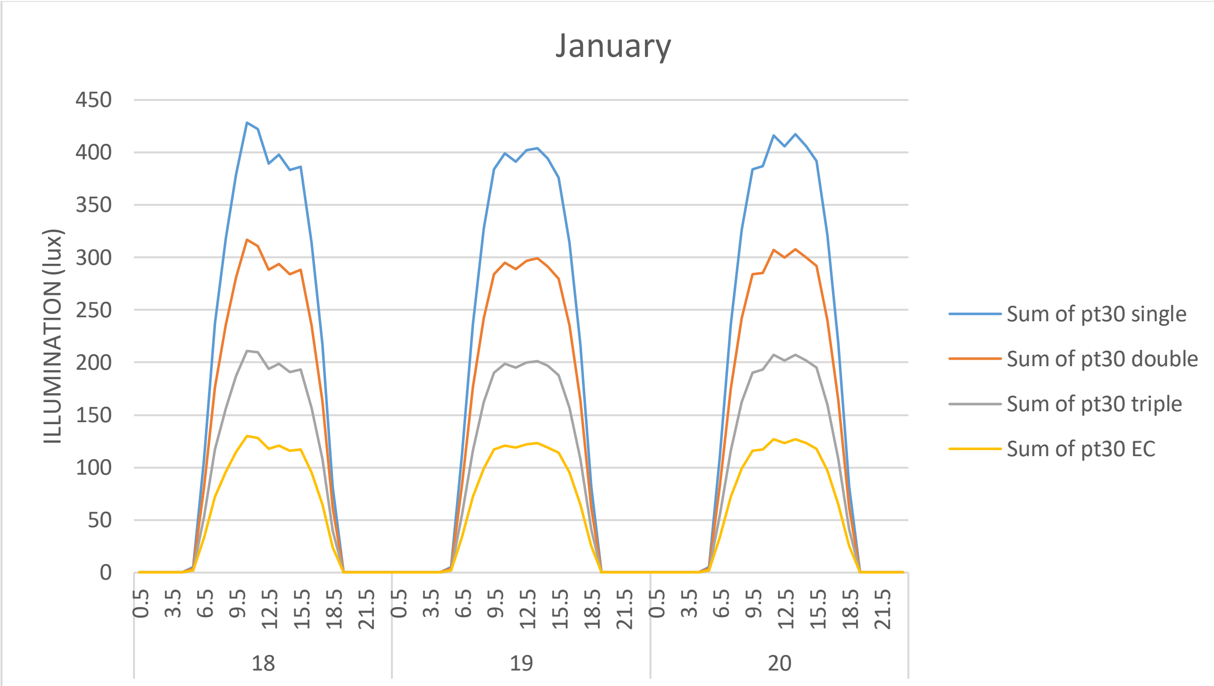


Figure 28:18-19-20 January Pt 30 illumination

As seen in the figure above the illuminations start increasing at 7.30, goes to the higher illuminance value at 12:00, decreasing to the minimum at 18.30, the illumination values are 430 lux, 400 lux, 410 lux these are the values for the following days 18-19-20. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt30 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

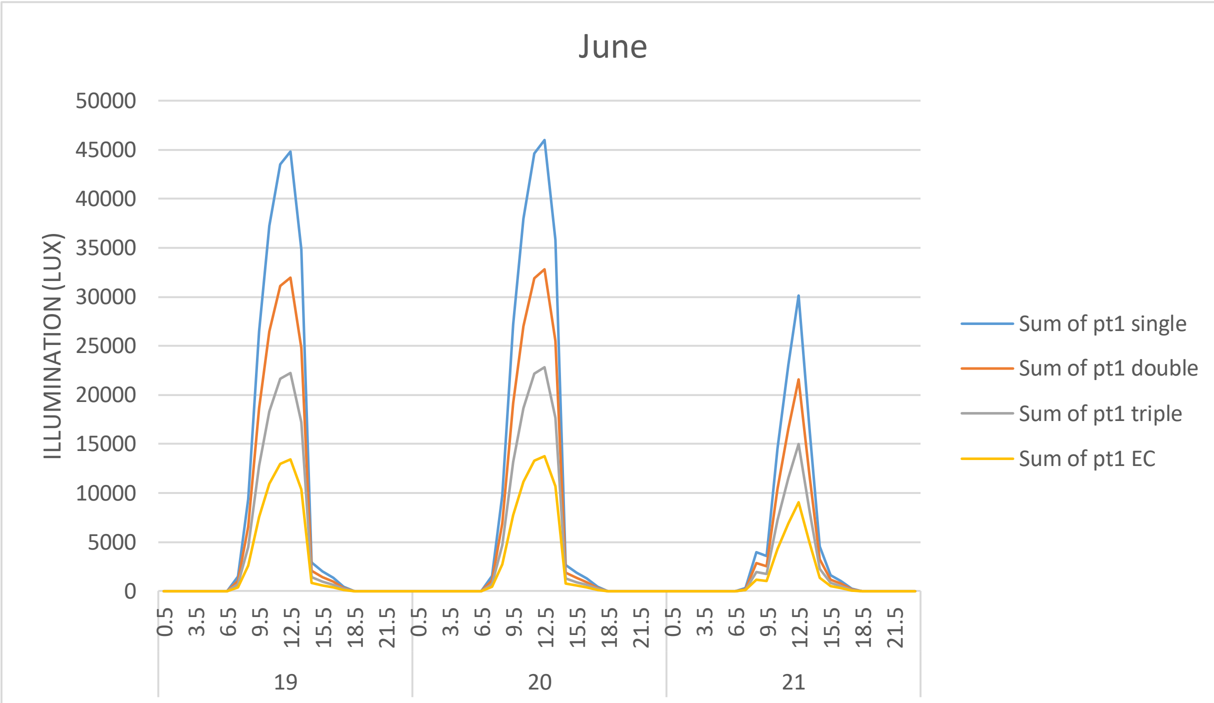


Figure 29: 19-20-21 June Pt 1 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 45000 lux, 46000 lux, 30000 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt1 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

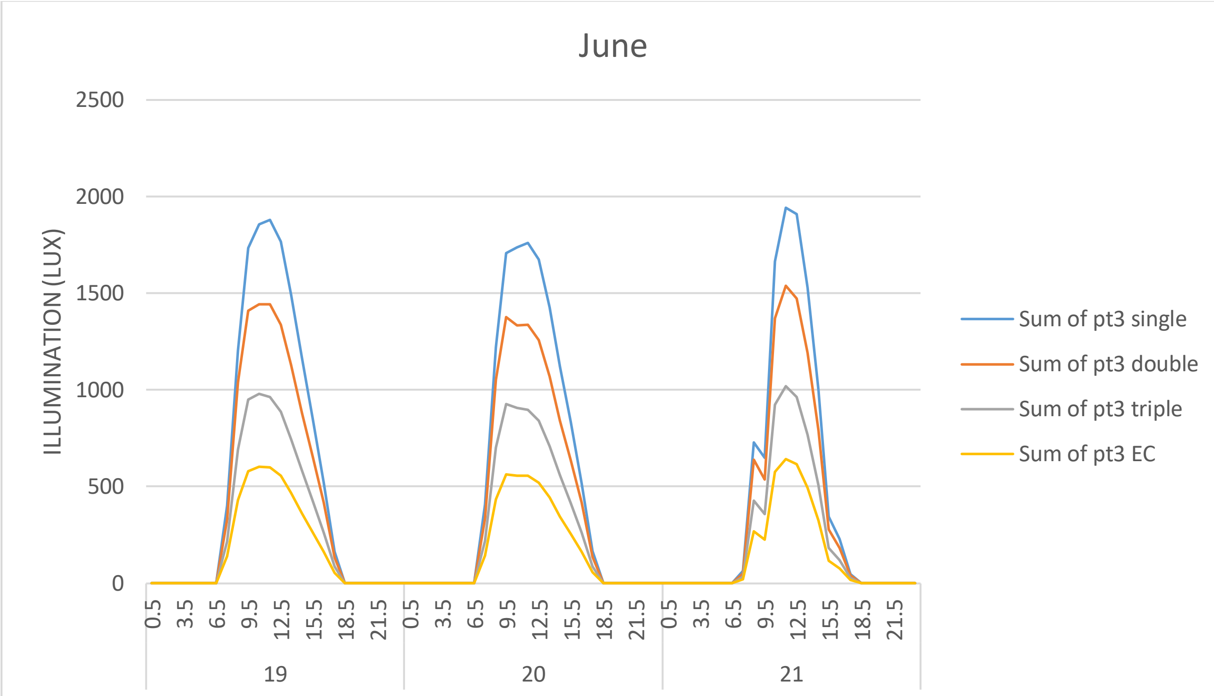


Figure 30: 19-20-21 June Pt3 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 1700 lux, 1600 lux, 1850 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt3 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

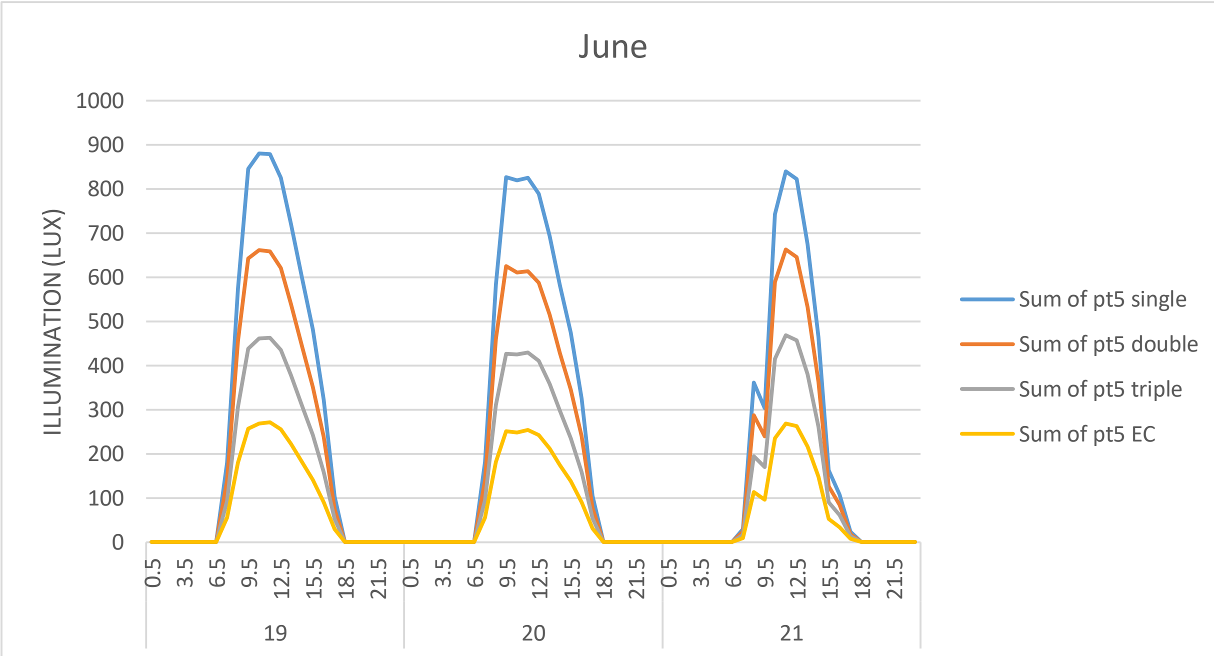


Figure 31: 19-20-21 June Pt5 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 890 lux, 810 lux, 820 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt5 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

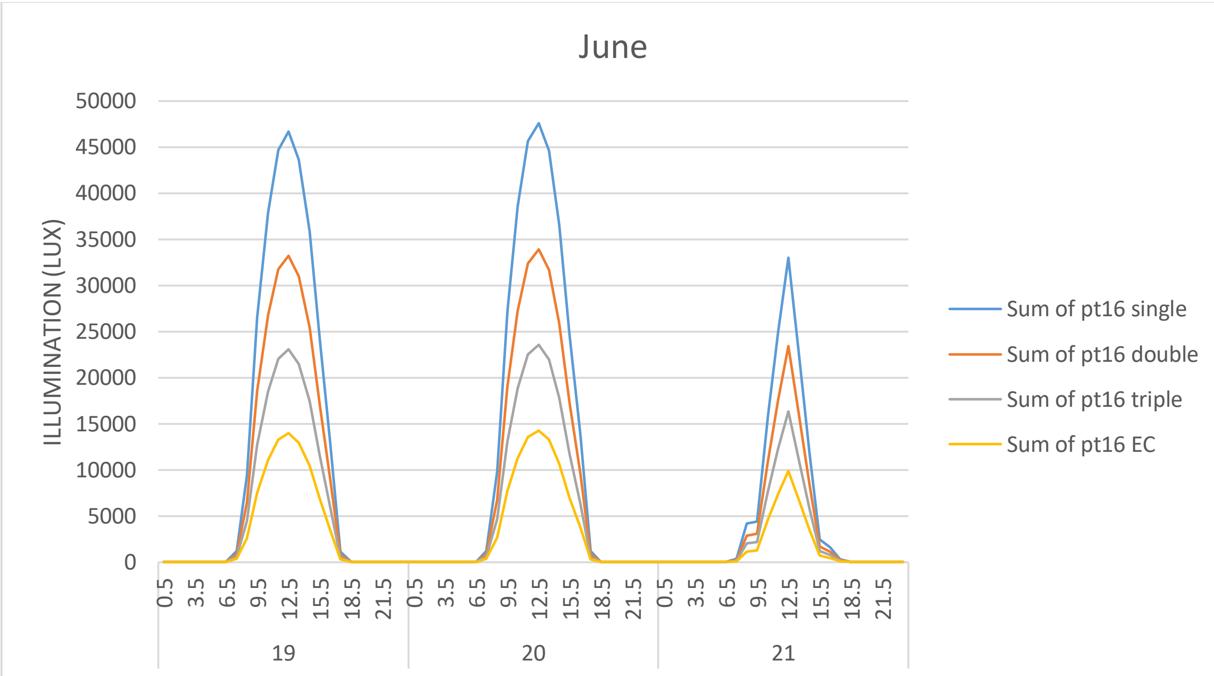


Figure 32: 19-20-21 June Pt16 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 46000 lux, 47000 lux, 3250 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt16 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

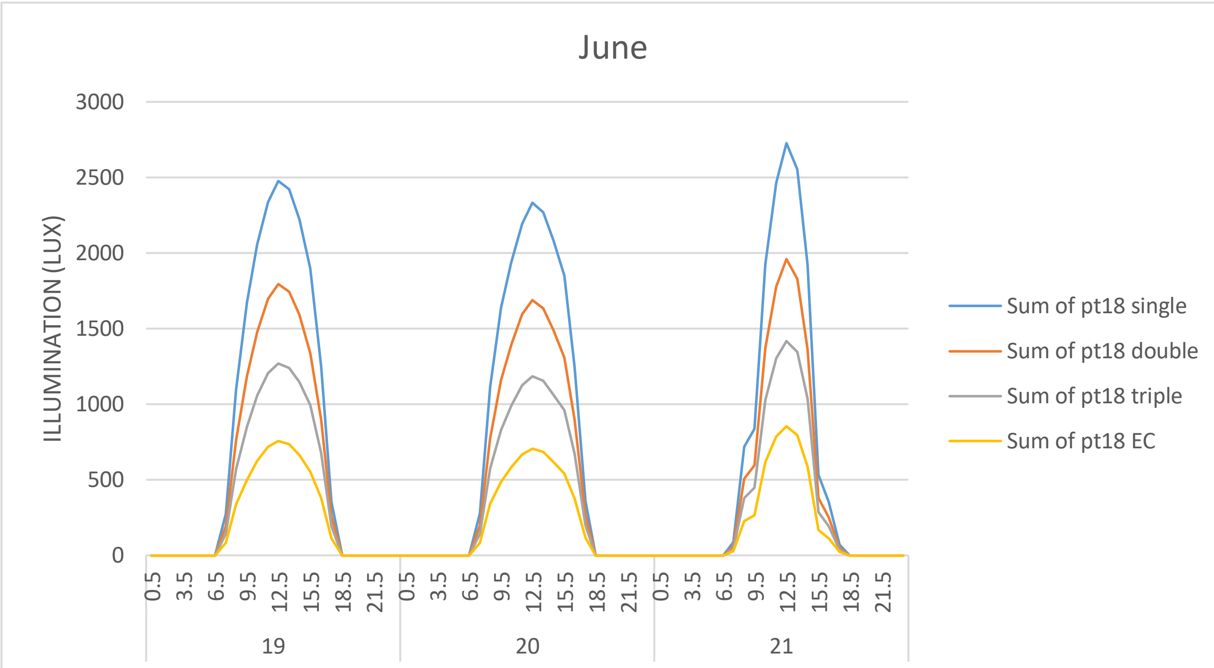


Figure 33: 19-20-21 June Pt18 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 2500 lux, 2300 lux, 2700 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt18 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

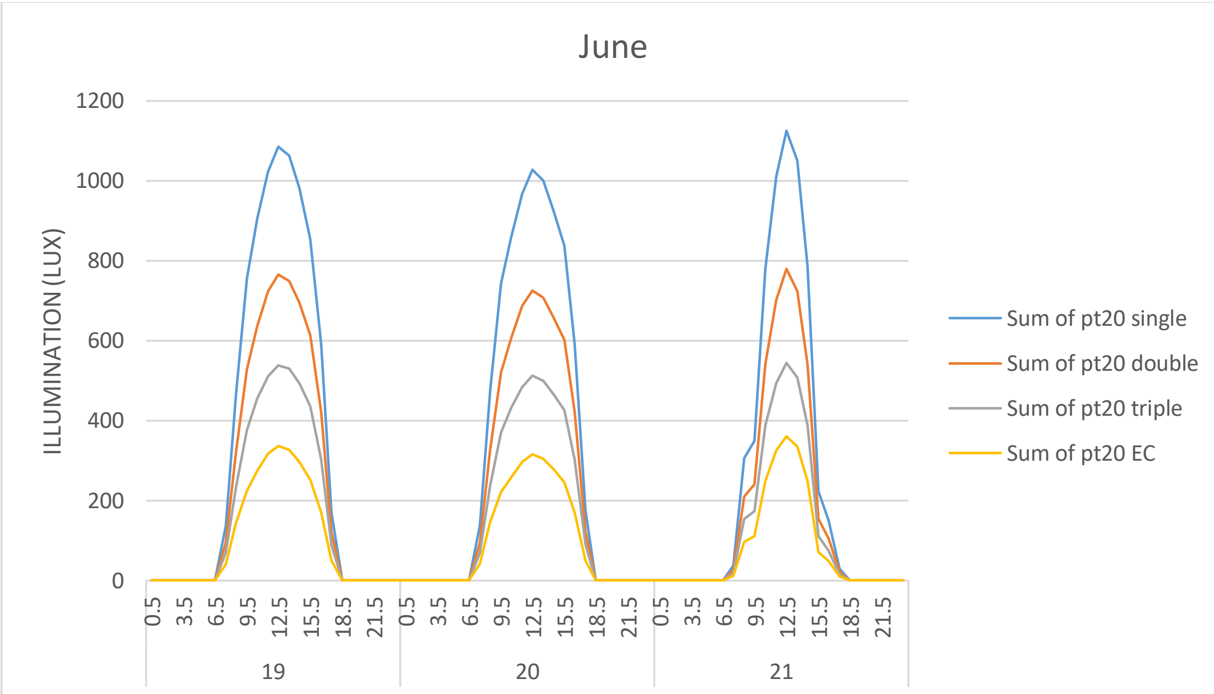


Figure 34: 19-20-21 June Pt20 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 1050 lux, 1010 lux, 1100 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt20 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

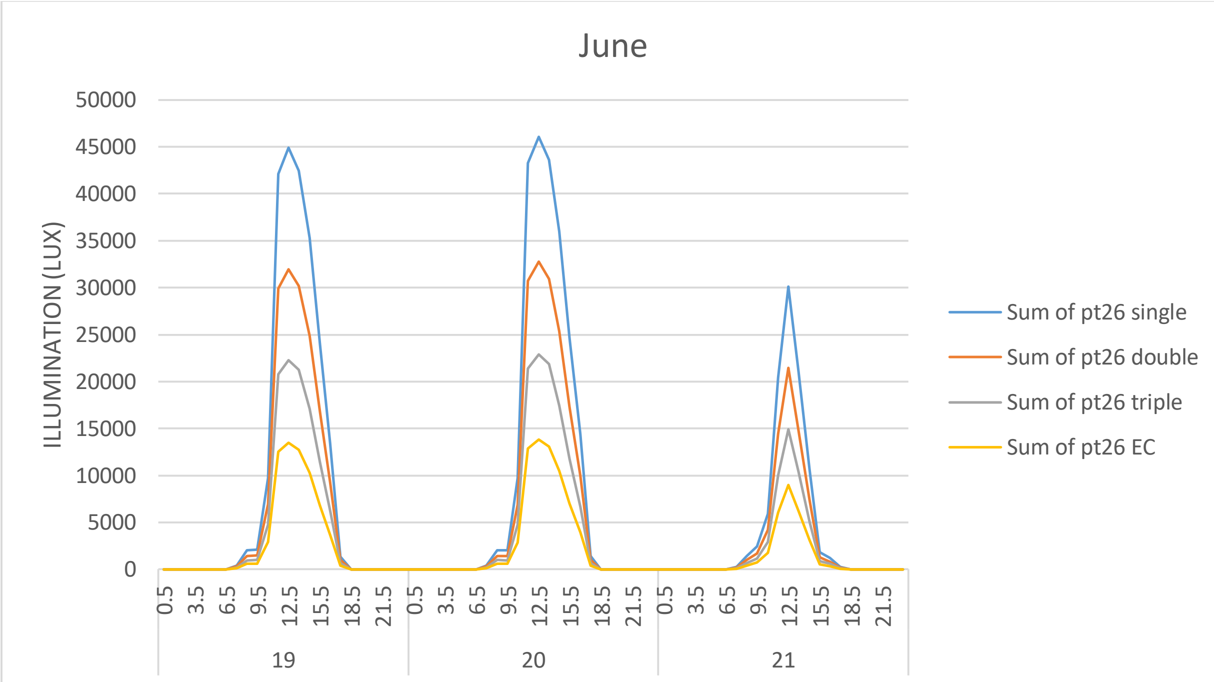


Figure 37: 19-20-21 June Pt26 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 45000 lux, 45100 lux, 30000 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt26 known as one of the closest point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

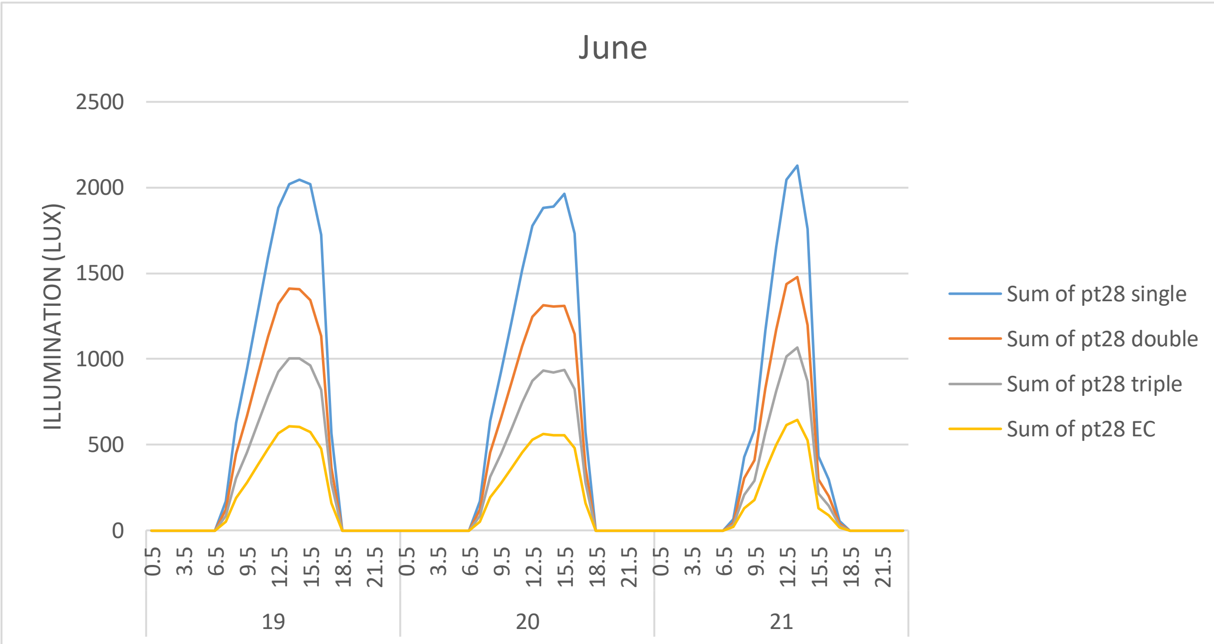


Figure 38: 19-20-21 June Pt28 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 2000 lux, 1900 lux, 2100 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt28 known as one of the mid-point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

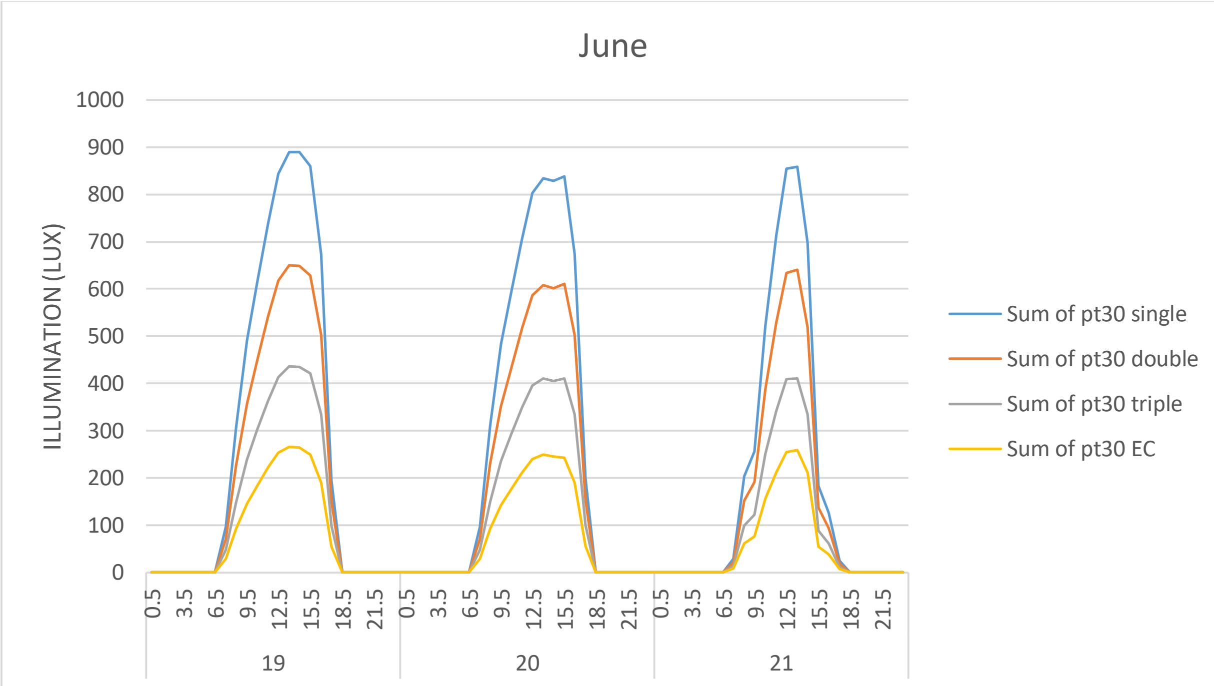


Figure 39: 19-20-21 June Pt30 illumination

As seen in the figure above the illuminations start increasing at 6.30, goes to the higher illuminance value at 12:30, decreasing to the minimum at 18.30, the illumination values are 900 lux, 810 lux, 850 lux these are the values for the following days 19-20-21. The evaluation includes the different type glazing single, double, triple, and electrochromic glazing, Pt30 known as one of the far point to the façade, as a result the sequence of the glazing type from the higher illuminance to the minimum, the EC has the lowest luminance behavior.

CHAPTER 7
CONCLUSION

The past research and work has been conducted on energy saving and visual comfort in EC glass buildings. Yet, the studies on EC glazing are often overlooked in research. Daylight analysis models are particularly complex when windows allow a certain amount of light into space, in which case the effects of solar loading must be taken into account. The changing functionality and sophisticated EC glass coloring program make software simulations even more difficult. Workflows are developed using the DIVA plug-in. The limits of each workflow have been clarified and the workflows in daylight analysis seem to indicate significantly improved reliability which can be very useful for manufacturers, designers and owners who want to see the model and model DIVA.

How EC glass can grow for the environment and is positive for the expansion of the CE glass market in the future. It has shown that external solar control systems have better energy in general efficiency more than a glass system without external shading devices, among the systems compared, EC was the most efficient in terms of primary energy consumption.

During the winter solstice day, the tinting schedule generated based on the illuminance calculation and control algorithm seems reasonable. The glass turns to relatively dark states from 10AM to 4PM and stays in clear state in the early morning and late afternoon. However, the tinting schedule on summer solstice day only has two tinting states.

The interior illuminance level on winter solstice day and summer solstice day from 7AM to 6PM were studied for the test room assuming the EC glass stayed in clear state so as to get the actual sunlight distribution in the space. As the solar altitude is low in winter, the sun light goes far into the interior space. However, as the solar altitude is high in summer, the direct solar radiation only falls in the areas close to the window.

The result analysis of Diva’s, visual Comfort Model are focused on winter solstice day and summer solstice day, so the conclusions and evaluations are only applicable for these days. The limited data sets make it difficult to draw conclusions for the developed workflows. However, studying the most extreme days in a year is representative and can be helpful in suggesting trends.

The workflows developed in the visual Diva-Plugin model have provided some methods for assessing visual comfort for EC glass, but it is difficult to draw conclusions due to limited data. It is necessary to verify research hypotheses such as the lighting control strategy and the use of sensor positions. Further simulations are needed to verify the efficiency and accuracy of the proposed workflow. Control algorithms can be evaluated on disturbing clock data. It is possible to perform tests on physical models and tests on human subjects to further test the EC product and verify the effectiveness of the proposed work flows by comparing the actual final data with the simulated data. Additional workflows can be performed in future jobs using other dynamic simulation software and methods.

In this study, the EC glass was assumed to be controlled by daylight, coloring was made in response to light sensors to maintain a comfortable daylight level, but this control strategy is not necessarily about thermal comfort. To achieve maximum visual comfort, more studies are needed to find out which control strategy will be best for visual comfort and to find better spots and thresholds that determine the condition of the glass. Another problem is that it is preferable to mount the light sensors on the outer surface of the glass, rather than placing the sensors indoors, assuming to use the daylight control strategy. If the glass is open, sunlight can also be filtered through the window. In future studies, the glass tinting program should be based on data from the external sensor.

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