

**Investigating the Performance of Dynamic
MONOCRYSTALLINE SILICON PVs to Energy and
Visual Comfort Case Study of an Existing office building in
Dubai**

التحقيق في أداء ألواح كريستالات السليكون الديناميكية على الطاقة والراحة
البصرية: حالة دراسية لمبنى مكتبي في دبي

by

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**Dissertation submitted in partial fulfilment
of the requirements for the degree of
MSc SUSTAINABLE DESIGN OF THE BUILT
ENVIRONMENT**

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ABSTRACT

The facades are a major factor in the energy consumption of the buildings, as the large glass facades are a great source of energy consumption, especially in hot climates. The UAE is one of the countries that contribute to spreading awareness and applying the use of alternative energy as a means to dispense with coal sources due to their impact on the environment. In addition, buildings equipped with solar panels have a promising future in terms of focusing on smart and adaptive aspects.

The effect of vertical dynamic solar panels for an office building in Dubai was studied during the dynamic Rhino\DIVA program. This is to delve into the extent of the impact of the angles of the panels in terms of energy and visual comfort for the interior of the buildings, as the number of angles for three scenarios reached 314 angles during the year. Three scenarios for the panels were studied based on tracking the movement of the sun's angles, in addition to changing the type of window glass.

The visual comfort of the second and third scenarios has been achieved within the required range. As for the southwest office, it achieved a reduction of 81.75% in the lighting energy and 72% in the cooling energy compared to the base case when using the third scenario with EC tinted glass. The scenarios were compared in a final step, and the absolute scenario was identified and compared with the actual bills for the entire building, in addition to the energy generated for the scenario panels. The results indicated that it is possible to reduce the energy consumption of the entire building by 43% compared to the actual bills of the building when using semi-dynamic and fixed panels during the year. In addition to the highest scenario for generating energy during the year, especially the southern office.

نبذة مختصرة

تشكل الواجهات عامل اساسيا في استهلاك الطاقة للمباني حيث تعتبر الواجهات الزجاجية الكبيرة مصدر استهلاك كبير للطاقة خاصة في المناخات الحارة. تعد الامارات من الدول التي تساهم في نشر الوعي وتطبيق استخدام الطاقة البديلة كوسيله للاستغناء عن مصادر الفحم لتأثيرها على البيئة بالإضافة تعد المباني المزودة الالواح الشمسية لها مستقبل واعد من ناحية التركيز على الأوجه الذكية والمتأقلمة. تم تحقيق الراحة البصرية في السيناريوهين الثاني والثالث ضمن النطاق المطلوب. أما بالنسبة للمكتب الجنوبي الغربي، فقد حقق انخفاضاً بنسبة 81.75% في طاقة الإضاءة و 72% في طاقة التبريد مقارنة بالحالة الأساسية عند استخدام السيناريو الثالث مع الزجاج الملون.

تمت مقارنة السيناريوهات في خطوة أخيرة، وتم تحديد السيناريو المطلق ومقارنته بالفواتير الفعلية للمبنى بأكمله، بالإضافة إلى الطاقة المتولدة للوحات السيناريو. أشارت النتائج إلى إمكانية تقليل استهلاك الطاقة للمبنى بأكمله بنسبة 43% مقارنة بالفواتير الفعلية للمبنى عند استخدام الألواح شبه الديناميكية والثابتة خلال العام. بالإضافة إلى أعلى سيناريو لتوليد الطاقة خلال العام وخاصة المكتب الجنوبي.

DEDICATION

I dedicate my letter to my beloved family, my parents who encouraged me all the time and supported me to continue my studies.

My supportive friends AZRA, LINA, MAHA, ETHAR and AMIRA who have been there all the time for me, my beloved sisters who encouraged me all the time.

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CHAPTER 1 : INTRODUCTION

1.1 Global energy profiles

The world is currently facing a crisis of pollution and major depletion of the earth's resources, especially for energy production. The natural disasters nowadays increase, and the news lately is full of environmental hazards such as flooding in east Asia, deadly heatwaves in Europe, and forest fires in different places in the world. all of these are impacts of climate change and global warming that affect the melting of the south pole and increase the water level. Since the beginning of the industrial revolution in the seventies, fossil fuels started to be used to generate energy by burning the fuel which causes CO₂ emissions. Energy is consumed 82.67 percent of fossil fuels, with consumption reaching 11 billion tons of fossil fuels annually at the global level, which has contributed to global warming (Al-Shetwi et al. 2020). Figure 1 shows the last recorded data for 2019 by the Our World in Data of the global CO₂ emissions in billion tons by region. The CO₂ emissions amount increased through the last decades, especially after the seventies. In the future is expected to increase further If the same situation continues without effective control over it.

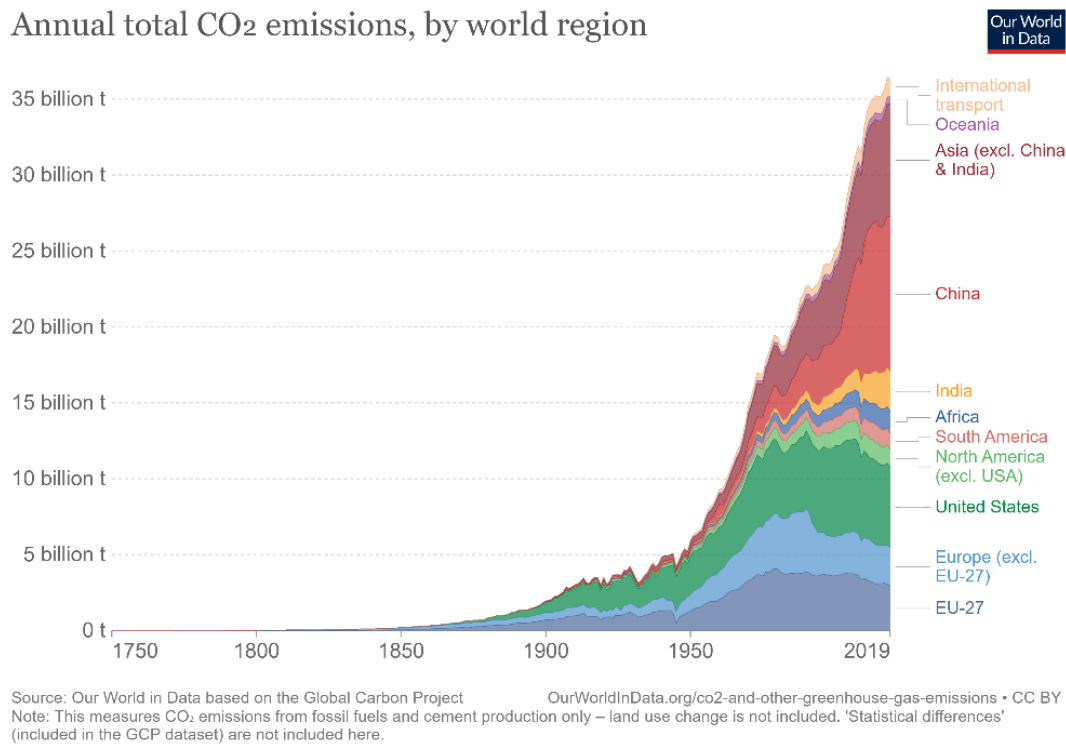


Figure 1: Annual total CO₂ emissions Data by region (Roser 2020a)

The global CO₂ emissions reach 36.42 billion tonnes in 2019, where the United States and Europe dominate global emissions, with more than 90% of emissions in 1900, and in 1950 they produced more than 50% of emissions, but this has changed rapidly in recent decades, as emissions have been increased in the rest of the world, especially Asia, and China leads the most emissions-producing country in the half Twenty century (Roser 2020a).

As a result, most of the developed and industrialized countries decided to follow the approach of generating clean and renewable energy as much as possible. And those actions were taken after the serious situation of climate change and global warming's impact on the environment because of the high CO₂ emissions. Where the aim is to reduce the largest amount of pollution caused by the industrialized countries currently and at the same time to generate sufficient and clean energy. The research organization of the European Union Commission in 2015, decided to focus on supporting research programs for reducing fossil fuel consumption, reducing pollution, and verifying the efficiency of energy consumption by using new and innovative

technologies for renewable energy(Khan, Khan & Binh 2020). Where fossil fuels in general are nonrenewable types that pose potential threats due to the potential depletion of their resources(Al-Shetwi et al. 2020). However, there is still a dominance of fossil fuels. shows global fossil energy consumption in 2019 accounted for 84.32%. Where, over the past decade shows in Figure 2, global primary energy consumption has experienced long-term steady growth of 16.90%. but the global ratio of lowest primary energy consumption has been dropping steadily reaching its lowest level over the past decade(Li et al. 2020). While, renewable energy consumption in 2019 contributed 3.2 EJ of primary energy consumption, accounting for over 40% of the global increase in primary energy. As for energy sources, the largest contribution was from wind generation, where the growth was 1.4 EJ followed by solar energy at 1.2 EJ(BP 2020).

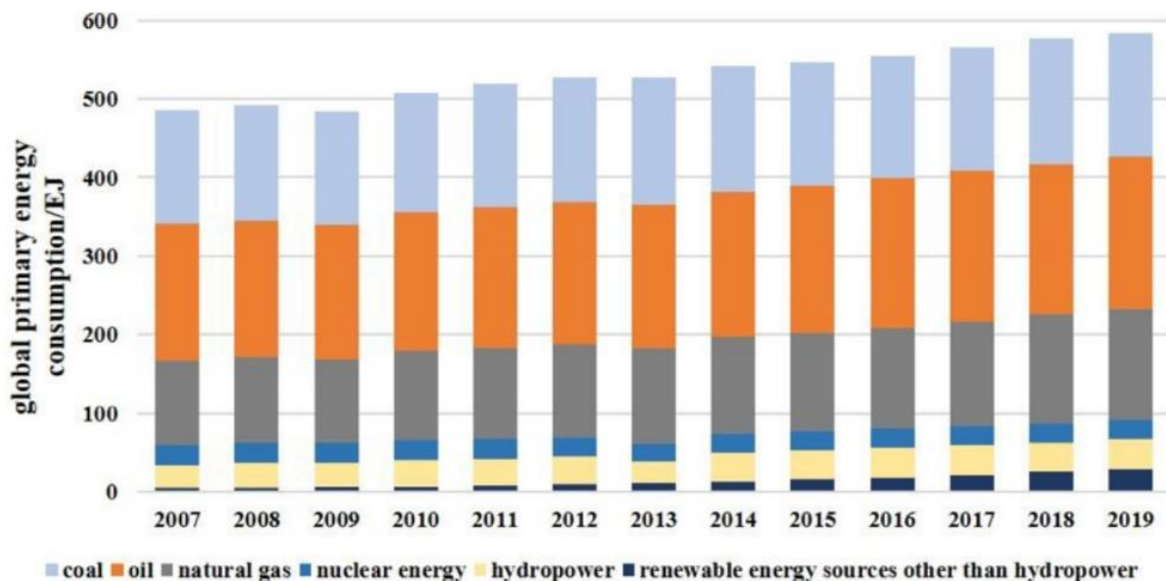


Figure 2:The global growth of primary energy consumption (Li et al. 2020)

The following data by IEA Figure 3 shows that renewable energy for electricity generation, as it's increased in 2019 to 3%, which went against the trend that was scheduled to achieve an increase of approximately 7%. Wind achieved the highest rate of energy generation for this year with 17%, and it is expected globally to increase PV electricity generation by 18% for this year(IEA 2021).

Generating renewable energy poses a real challenge, such as wind turbines and solar PV need specific geographical locations to generate the largest amount of commercial energy. Also, the financial costs of building and transporting equipment and periodic maintenance procedures, where all of these need more supervision and planning along with the financial aspect that is difficult to control for all countries in the same way.

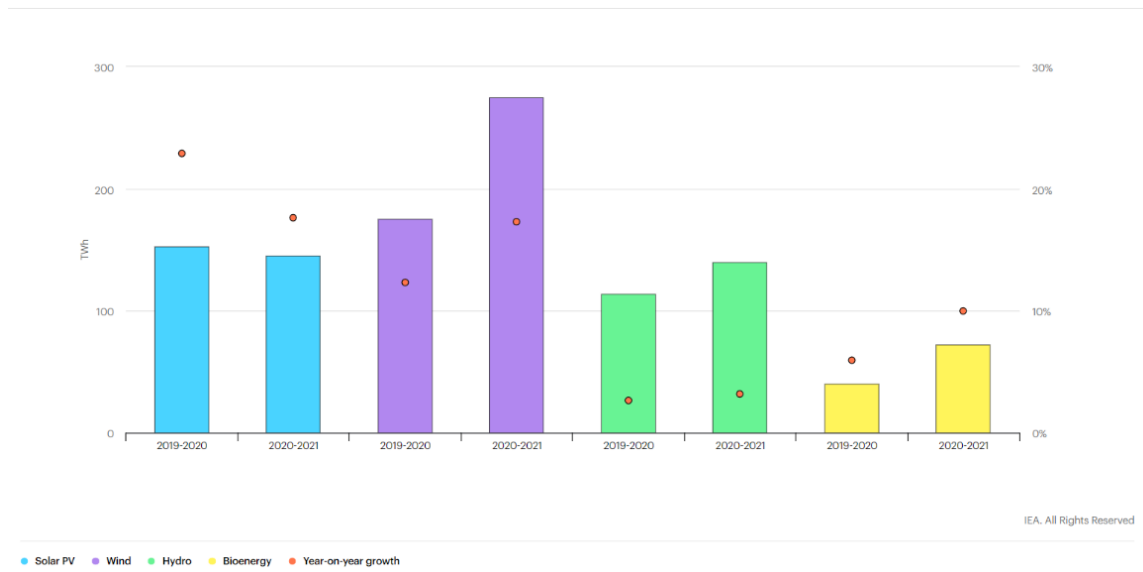


Figure 3: The renewable electricity generation growth by technology (IEA 2021)

Globally 40% of total energy consumption comes from the building sector which emits 33% of overall greenhouse gas emissions, especially buildings with a fully glazed envelope that affects energy efficiency (Sheikh & Asghar 2019). In 2019 the average global energy consumption has increased by 0.4% where North America has the highest per capita usage (236 GJ/head), with the CIS (158 GJ/head) following closely behind the Middle East (151 GJ/head) which increased by 1.4% in Figure 4 (BP 2020). Therefore, the consumption of energy around the world varies, so it depends on the population density in certain spaces or countries. Wealthy countries consume more commercial energy resources than poor countries, such as electricity, coal, and oil.

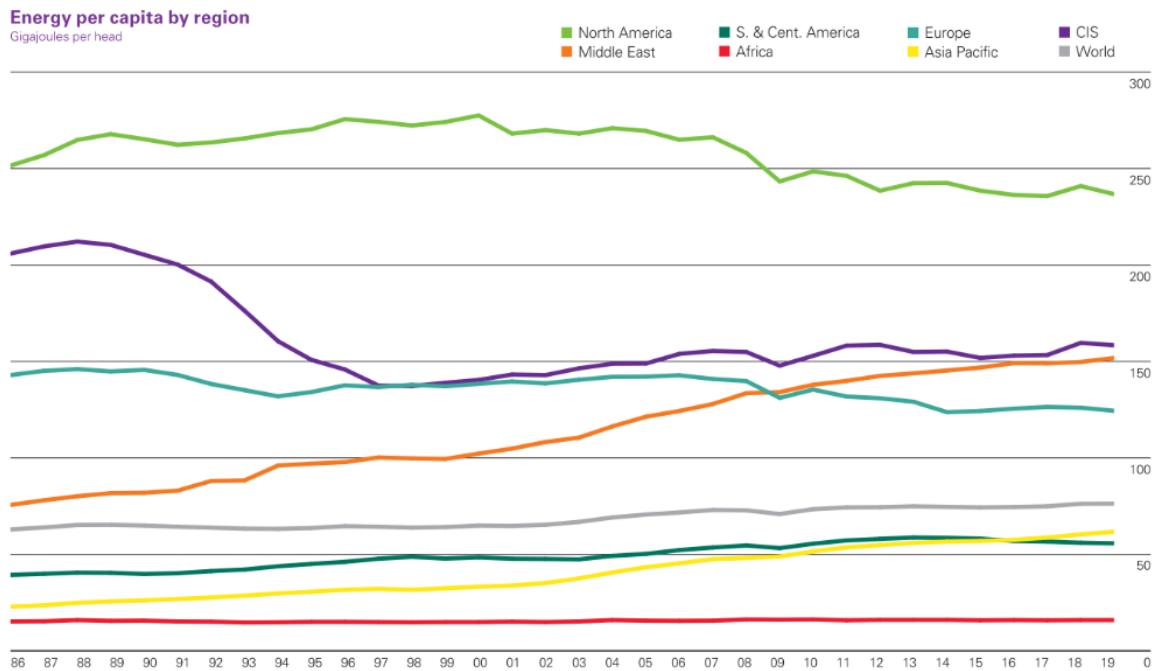


Figure 4: The Energy use per capita by region, GJ per **head** (BP 2020)

1.2 Architecture aspect

Population growth increases over the years, especially in cities made pressure on the building sector. as the construction sector seriously affects global warming, the built environment as buildings part of it. The construction industry's building component is considered one of the most energy-intensive sectors. The measurement of energy usage in buildings has been the subject of much research. According to the studies, consumes over 70% of all electricity produced and over 30% of greenhouse gas emissions emits from developed countries (Balali & Valipour 2020). Modern architecture plays a serious role, in this case, using huge curtain walls in a high-rise, mid-rise commercial, and office buildings. Where globalization affects the wide usage of curtain walls despite the variation of weather and climate from one country to another.

Glazing building system design enables thermal interactions with the outside and the inside environment, and their design adds significantly to the building's thermal requirements. However, the majority of building skins and facades are not constructed to meet climatic needs, implying a significant demand for the specific heating and cooling solutions in various climate situations (Badeche & Bouchahm 2020). Due to the use of many curtain wall structures and huge

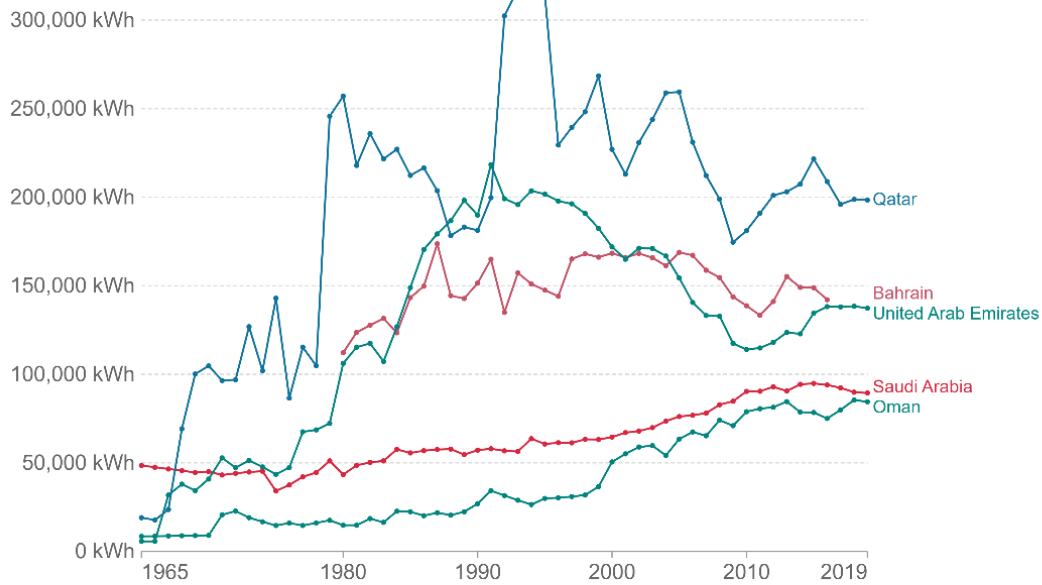
glass windows, particularly in workplaces, envelopes and facades are therefore significantly impacted by direct solar radiation, causing a visual disturbance in addition to a significant increase in cooling energy use.(Romano et al. 2018). Where, Facades have an important part in energy loss, accounting for 20–60 % of a building's total energy use(Balali & Valipour 2020).

In hot climates, cooling may account for more than half of the total energy required to run a medium office building. Where cooling demands necessarily in commercial buildings, is a result of large internal gains which are exacerbated by the influence of solar radiation on generally lightweight and substantially glass façades. And will continue to increase the importance of cooling demands on a worldwide scale because of climate change and economic growth impact(Prieto et al. 2018). In the European Union, a building's exterior has a significant impact on energy use, and building facades account for more than 40% of global energy use for heat loss in the winter and 30% for overheating in the summer. Hence, improving the design of building facades can dramatically improve energy efficiency. Since the glass façade affects the amount of solar heat gain that enters or leaves the inner area, and thus how considerable cooling or heating is needed in that place., the design of the facade becomes even more significant in lowering energy consumption in highly glazed buildings(Sheikh & Asghar 2019).

1.3 UAE situations

The UAE is one of the wealthy Arab countries, as it presented remarkable economic progress during the past fifty years. Figure 5 shows the energy usage per capita for gulf countries, where Uae comes in second place after Qatar by 137,318kWh for 2019. With this development, of course, the construction and building sector has increased significantly, especially in Abu Dhabi the capital, and Dubai the commercial capital. With the era of globalization that we live in now, the glazed buildings of modern architecture had a large part of the sector(Roser 2020b).

Energy use per person



Source: Our World in Data based on BP & Shift Data Portal
 Note: Energy refers to primary energy – the energy input before the transformation to forms of energy for end-use (such as electricity or petrol for transport).
 OurWorldInData.org/energy • CC BY

Figure 5:Energy usage per capita in gulf countries (Roser 2020b)

Due to the obvious hot climate of the United Arab Emirates, buildings account for a considerable part of electrical energy usage, especially air conditioning consuming 80% of this energy over the year (Khoukhi, Darsaleh & Ali 2020). Where in Abu Dhabi building electricity consumers with 89.6% of the total electricity consumption and 92.% of water(Qadir, Haddad & Hamdan 2019). Data for the United Arab Emirates in terms of electricity consumption Figure 6 indicated its highest level ever at 131,442,880 GWh in 2019. While the lowest record level was 48,155,000 GWh in 2003. Data for electricity consumption in the UAE as shown in, UAE still active and reported by the Ministry of Energy and Infrastructure (Data 2021).

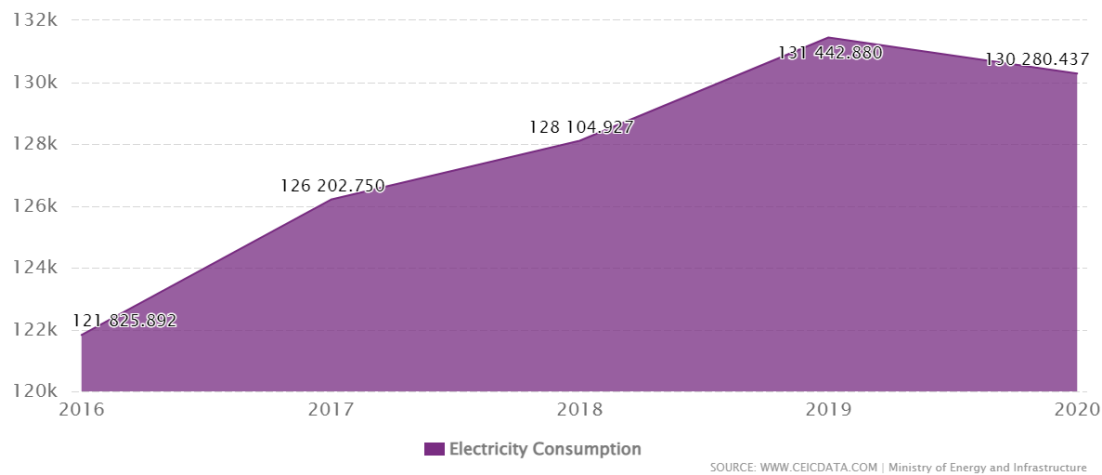


Figure 6: Electricity consumption 2016-2020 in UAE (Data 2021)

Additionally, Renewable Energy Roadmap 2010 highlighted that the commercial building sector in the UAE is the first-largest consumer of primary energy, and the second is the residential building sector accounts for 29% of Dubai's overall energy consumption (Abu-Hijleh & Jaheen 2019). Undoubtedly with this economic growth and population will continue in the future, thus the energy demand will continue to rise as well. Like many countries, the UAE has taken actions to enhance and reduce the amount of energy in buildings with a rating system.

In 2010, the Dubai Municipality released the Dubai Green Building Regulations and Specifications, which were for new government buildings initially an obligatory requirement. It became in the second level, it turned into a requirement for all sorts of buildings. (DUBAI 2021). Similarly, the Department of Urban Planning and Municipalities (DPM) of the UAE's capital Abu Dhabi established a comparable sustainable development program called Estidama in 2010. It's the Middle East's first program of its type. Estidama is a desire and a vision to develop a sustainable lifestyle in the Arab world, not just a rating system (Qadir, Haddad & Hamdan 2019). Moreover, Al Sa'fat's Dubai rating system improves the safety of building occupants while also ensuring a more sustainable future environment for the next generations. Also, encourage innovation in building design incorporates green systems and technology, improving performance, reducing energy use, increasing mechanical and electrical system efficiency, and reducing carbon footprint. (DUBAI 2021).

1.4 Scope and motivation of the work

The UAE is showing its interest in the field of a smart sustainable environment. It has shown a clear and unparalleled distinction in terms of governments' encouragement and financing of various projects aimed at reducing damage to the environment. In addition to spreading awareness and knowledge at the community level of the importance of using alternative sources to generate energy and reduce building energy consumption, especially with modern architectural buildings. It issued rules and regulations that must be followed, such as Sa'afat, by the Dubai municipality for buildings to applicate the standards of sustainability, preservation of the environment, and energy consumption. Despite that, many previously built buildings in Dubai need to be transformed into energy-efficient buildings.

Several studies around the world have shown the effectiveness of the dynamic aspects of buildings in terms of daylighting, and recently also focused on their impact on energy consumption in buildings. It also included several studies, which have been focused on lately, BIPV. However, a limited number of studies collected panels in terms of facades, where the most uses of panels were on the roof of buildings or in a fixed facade. There is also a clear lack in terms of focusing on BIPV in the United Arab Emirates concerning facades, which is the main motivation and scope of the study.

Through the research papers that were published regarding building facades and BIPV, they were reviewed and verified the current situation and promises for the future. In this paper, an investigation will be conducted using dynamic solar facades for an office in Dubai, which is ten years old. Emphasis will be placed on the impact of dynamic solar panels on buildings in terms of energy efficiency and lighting. Emphasis will be placed on the best appropriate angles of the site in terms of the movement of the sun for different scenarios. In the end, it will also provide an opportunity for pre-construction planning for the future and how to choose the best available scenarios for building efficiency and consideration must be taken for installation.

1.5 Aims and Objectives

The paper aims to provide sufficient information on the extent of the impact of facades in reducing energy consumption, in addition to taking into account lighting and the extent of its impact in conjunction with the extent of electrical energy generation through solar panels. And thus gather the maximum benefit from the use of facades in terms of smart glass and shaded Dynamic PV panels. The focus will be on integrating solar panels as the performance of vertical louvers through the results of a study in the UAE climate(Lee 2019), which proved that the rotated vertical louvers are more efficient than the horizontal ones. Therefore, the study will follow the guidelines below and the objectives:

- Investigation of works and techniques results that were recently used for the UAE climate, as well as others with the same climate.
- Assessing the performance of the dynamic louvers from several parameters such as office direction, and four seasons (a year) as well as by comparing three different scenarios and analyzing each of them.
- Setting the different scenarios based on the sun file and analyzing the different results for each and comparing them with the current status of the office building.
- Effecting of installing solar cells on the dynamic louver and relation to the daylighting factor and cooling load inside the building.
- Investigation of the availability of sufficient power for the dynamic PV Louvre and the effectiveness of saving total energy during the year.
- Selecting and highlighting the optimal results and discussing future work that Future work can be continued.

CHAPTER 2 : LITERATURE REVIEW

2.1 Background

This chapter includes a review of alternative smart façade categories. Where it includes the type and extent of its impact on a building's energy consumption and how it affects natural lighting. Emphasis will be placed on the impact of the adaptive facades in terms of dynamic façade, smart glass, and building-integrated photovoltaics in the built environment.

2.2 Introduction to Adaptive Façade

Building facades, also known as vertical building envelopes, serve as a barrier or link between the inside and exterior spaces(Bui et al. 2020). Facades create a buffer between a building's internal and external environment, acting as a skin for the building since they are constantly open for outdoor circumstances. Building facades can differ in architecture depending on the architect and the building's specialties, such as location and technology. It may be argued that building facades play an important role in forming city identities as well as functional specialties. Building facades, which have become increasingly popular as advertising methods in recent years, have an impact on the increase or decline in city trade values. They can increase interest in city centers or cause them to be replaced in this manner as an impulsive or appealing force for structures. The external appearance of modern buildings is synonymous with colorful and constantly changing displays which affect how individuals locate buildings resulting in confusion and difficulty in locating buildings. This raises the question of whether advanced technology in façade designs has eroded the originally desired architectural and functionality goals. Shari & Ali (2021) in their paper on “The Impact of technology on external architectural Appearances” provides insights by comparing basic ideologies of facades with modern developments to assess functionality and performance levels. The case study focuses on various iconic buildings from various parts of the world, including Villa Savoye in Paris, Baghdad university in Iraq, the Red House in England, Figure 7 Shanghai Finance Center in China, and

the Brazilian parliament building. The conclusions ascertain the hypothesis that there is a reduction of visual consistency in contracts due to changing less in façade image by old pioneers of building design that shows a high level of image consistency as a result (Shari & Ali 2021).

Modern façade construction practices focus on design and the effectiveness of incorporating various devices in the building fabric to enhance the living environment. Undeniably daylight is a primary component of building facade design, its influences the physiological and psychological human needs. Previous investigations have shown that a building's indoor environment with sufficient natural light, improves academic, job, and human well-being performance(Lin & Tsay 2021).



Figure 7:Shanghai Finance Center by Heatherwick Studio and Foster (Shari & Ali 2021)

Envelope openings design affects the usage of daylight inside spaces where the design should match the function of the spaces. In addition to the inhabitant's privacy, glare protection view, and solar heat gain management. Furthermore, the optimum utilization of daylight can differ according to the geographic variables, skylight, and sun exposure which complete daylight exclusion inside building spaces(Knoop et al. 2020). The modern architectural facade design is

a vast section of glazing screens. the external screen design as well as the shading effect has a considerable impact on the distribution of internal daylight (Lin & Tsay 2021). Therefore, visual, thermal, and physical discomfort is caused by the brightness and spectral power of daylight. According to the study, lighting conditions influence contentment with room temperature, with lower lighting levels resulting in poorer satisfaction. This could indicate a higher thermal discomfort in daylight circumstances. While the visual discomfort is caused by some causes, together with flicker and glare from the light source due to high luminance or luminance contrast from electric lighting or daylight(Knoop et al. 2020).

In addition, energy is a key determinant of facades for sustainable innovation technology. As a result, upgrading facades while conserving energy is unavoidable. In recent years, the use of garden technology on building facades has been shown to reduce urban heat island effects and transform cities into more loveable locations. Areas with hot climates like the middle east synonymous with deserts and semi-arid conditions compel residents to spend long hours indoors hence the development of façades to regulate energy consumption.

The energy requirements have been stipulated and are followed to ensure a positive impact on the building with creative designs and implementation to address challenges and climate change issues. The automation of control systems enhances the effectiveness of facades in buildings improving the internal environment. The development of adaptive facades enhances the performance of the skin resulting in better energy conservation and occupants' comfort. Ricci et al., (2020) focus on facades designed to adapt to changing climatic conditions through technological solutions. The represented solution is using a customized Ladybug Tools methodology that is validated depending on collected thermal-mechanical behaviors and allows for the prediction of energy, visual and thermal comfort dynamic performances.

Smart facades are the latest trend with innovative approaches to ensure high performance and environmental suitability. Buildings that are considered by information technologies specific to their designs are known as Figure 8 smart buildings, as they have flexibility and response to varying needs and are also able to adapt to users' systems. In addition to supporting communication between equipment, human systems, and embedded communications, as well as actuators and remote sensors (Alsarraf & Alobaidi 2020).

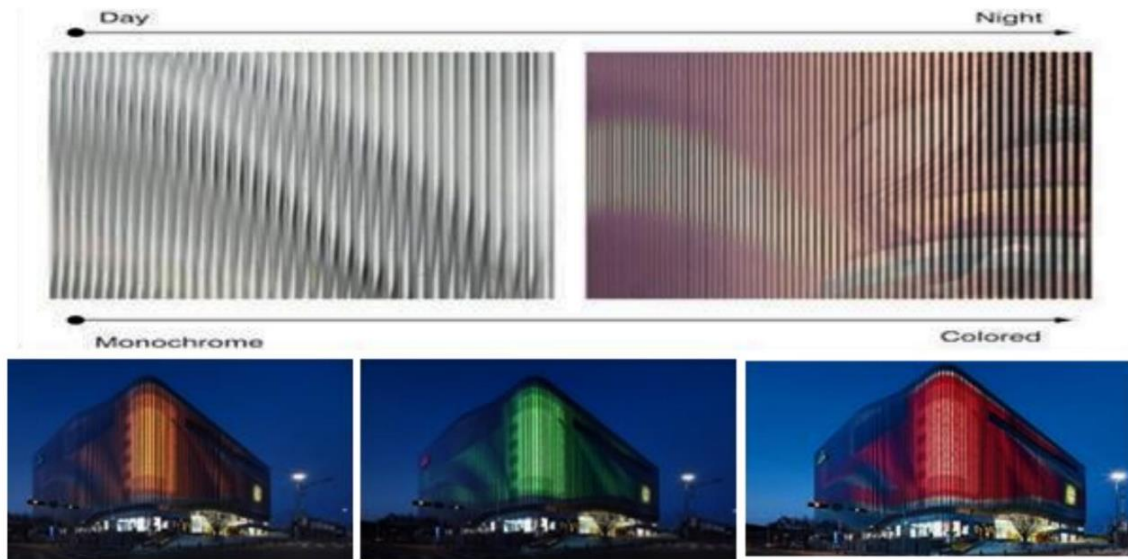


Figure 8 : Institute du Monde Arabe in France (1987) (Alsarraaf & Alobaidi 2020)

The history and importance of facades indicate their importance in sustainable development in energy conservation, with global efforts being directed towards minimizing fossil fuel use. The building should be appropriate to the prevailing climatic conditions, soil type, and environment. The goal is to integrate buildings into the environment with a minimal footprint, especially in temperature control. Therefore, the future of sustainable development relies on creating facades that address arising challenges like energy conservation and enhancing indoor satisfaction for occupants. The main considerations for future technologies in the design of adaptive facades encompass external appeal, automation for better control, and improving the comfort and safety of the occupants while contributing to global environmental conservation goals. Research in adaptive technologies includes the use of dynamic shading, chromogenic glazing, and active facades to improve the performance and effectiveness of facades. Temperature regulation problems can be resolved through smarter innovations in adaptive facades with the development of a better categorization and design approach to enhance performance.

Even though power is a crucial component of contemporary civilization, more than 1.2 billion people worldwide—the bulk of whom reside in rural areas—live without it. This data highlights the value of using renewable energy to provide electricity in remote places to meet local demand. According to predictions, up to 25% of the world's electricity would be generated by renewable

energy in 2018. (Powell et al. 2018) In contrast to other renewable energy sources, photovoltaic (PV) technology is rapidly developing, and as a result, several studies on the topic have been conducted.

2.3 Dynamic Shading façade

Dynamic facades are defined as those that may respond to their surroundings by either a typological change in material qualities that alters the overall form or a local change in energy usage to reflect the surrounding environmental circumstances(Shari & Ali 2021). Modern architecture façade designs improved on traditional practices which were less adaptive to the constantly changing environmental conditions. Therefore, dynamic facades adapt and enable the internal building environment to ensure the occupants' satisfaction and protection from the changing external environment. The external environment factors include temperature or heat, wind speeds, moisture, and daylight or solar radiation.

The material utilized in the technology of facades creates a skin for the building, which is an envelope between the external and internal environment. Over time, dynamic facades have evolved using technical solutions as they work between the indoor and outdoor environment as filters, providing ventilation, sunlight and appropriate shade, in addition to visual communication for users. Therefore, the reason for creating these facades is to develop responsive and sustainable architecture(Luna-Navarro et al. 2020).

Figure 9 indicates the solutions provided by the dynamic facades for the various situations that the building is exposed to, which shows the ability of the facades to adapt according to climatic conditions. It is characterized by the presence of smart materials and automatic or manual control, depending on the degree of complexity of the building or the type of user(Romano et al. 2018).

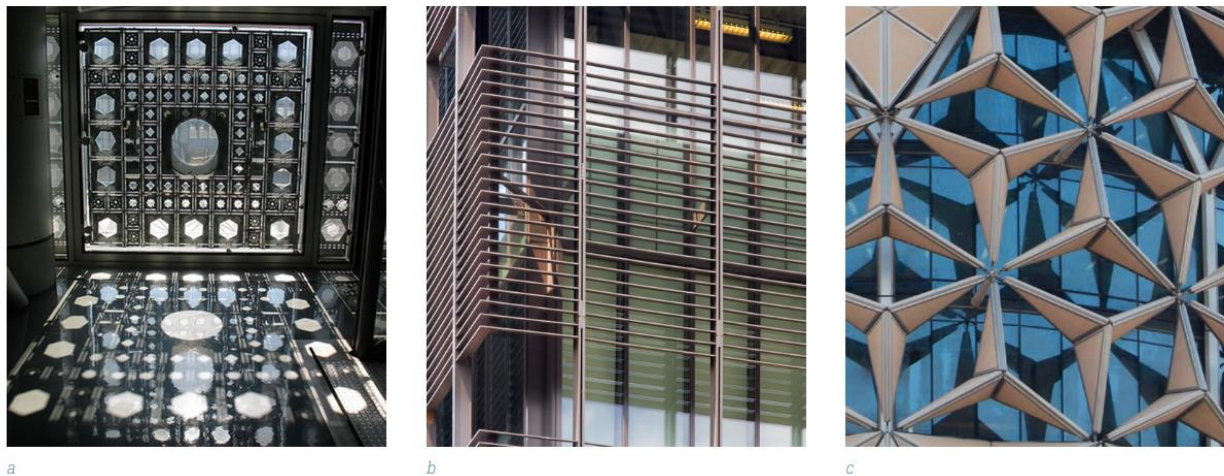


Figure 9: Arab World Institute, Paris (FR), b) Yale Sculpture Building, New Haven Connecticut (USA), c) Al Bahar Towers, Abu Dhabi (UAE) (Romano et al. 2018)

Dynamic facades are characterized by the widest range of solutions, which can be blinds, openings, or shutters, and occupy the largest market share among the technologies for adaptive facades (Attia, Lioure, and Declaude, 2020).

2.4 Innovative window blinds

Based on anecdotal evidence as well as the results of our ongoing poll, window blinds are one of the most popular types of windows covering. It appears that people prefer window shades to curtains, as 58 percent of those polled prefer blinds over all other window treatment options. Nowadays, technology is at the core of sophisticated product development. To keep up with the rising recognition of the engineering cohort, the industry is quick to adopt changes in consumer tastes and perceptions. Eltaweel et al. (2021) Changes in lifestyle are also innovating across every industry. Consumers are always on the lookout for the next best thing on the market, eager to take advantage of the latest technology and research. This trend has resulted in massive investment in research into creating window treatments that are suitable for the modern lifestyle. As a result, they are demanding that their everyday items be more environmentally friendly. In response to the growing concern about waste disposal, much research is being conducted into making window treatments recyclable or using recycled materials to make them.

The consumption of household energy has a significant impact on climate change and global warming. A reduction in energy consumption has a visible effect on energy bills as well. For

these reasons, businesses all over the world are preparing to modify their products to become more energy-efficient and reliant on renewable energy. Tabadkani et al. (2020) Window treatments are undergoing a massive transformation to provide more insulation, heat resistance, and energy-efficient functionalities, in line with this trend. For instance, Eco-friendly blinds and shutters are popular, owing to their numerous advantages. These advantages can be seen in the materials used, energy-saving properties, and recycling capabilities. To reduce waste, some eco-friendly blinds are made with plastic recovered from shorelines, preloved textiles, and recycled yarns. In recent years, scientists have become increasingly concerned about the impact of plastic on the marine environment. As a result, any product that uses plastic taken from the oceans has a significant impact on improving the marine ecosystem. The same is true for recycled polyester blinds and shades, as well as curtains.

Furthermore, as in Figure 10, they are simple mechanical devices that connect blinds and shades to a centralized home-automation system or the home Wi-Fi and allow them to be controlled via Smart devices and remote controls. All of these features, as well as many others, combine to make the SMART motorized blinds and shades the most versatile innovation in window treatments.



Figure 10: Smart shading blinds for exterior and interior facade (Romano et al. 2018)

2.5 Electrochromic Glazing

Building technology has evolved over the years leading to the development of smart glass or dynamic glass. The modern considerations for aesthetics, reduction of energy costs, better views, and access to daylight ensure client satisfaction and environmental conservation. Windows are vital to any structure, and their size, design, and positioning are key in bringing out the beauty of the living space, ensuring enough light is allowed. The development of electrochromic glass has enabled engineers to improve the internal environment of a building while contributing to environmental conservation goals (Woodford 2021). The technology infused in the building has advanced, prompting innovative interventions like electrochromic glazing in energy consumption regulation. Buildings serve various purposes, which are always increasing, and as robust constructions are undertaken, electrochromic technology becomes vital in controlling lighting and enhancing the building's functionality.

2.5.1 Mechanism and Applications

Electrochromic glass varies clarity automatically with electronic technology infused with a control mechanism. The building's occupants control the visibility levels as desired, bringing adaptability and privacy. The glass's properties are manipulated with a variation in heat, light

or voltage applied, varying from transparent to translucent or opaque. The amount of voltage delivered to the electronic glass controls the tint of the glass. As shown in Figure 11, electrons and lithium ions move from one electrode layer to another when a low voltage is applied, and the coating darkens. When the voltage and polarity are turned off, all ions and electrons return to their original layers. reversed, resulting in the brightness of the glass and return to its see-through state (Woodford 2021). The need for blinds is eliminated, providing a technological solution that is more appealing, enhancing interior space architecture and ambiance.

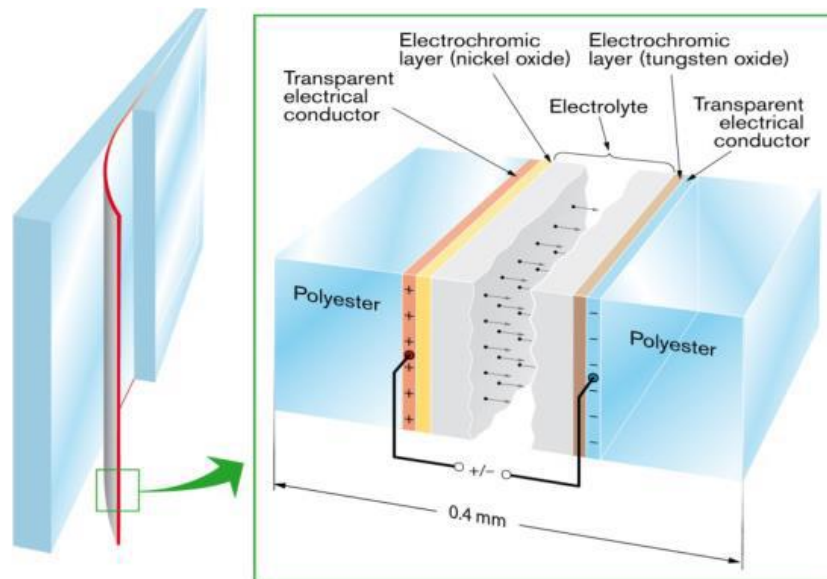


Figure 11: Basic design of the EC device and the transmission of ions when a low voltage
(Granqvist, Bayrak Pehlivan & Niklasson 2018)

The light's wavelength versus visibility levels can be set such that when the incident rays exceed a certain maximum level, the glass automatically readjusts clarity levels to regulate the internal atmosphere. The glass can also get fitted as a regular window using some types of smart film, which can be utilized for other purposes like security and advertising.

Smart glass is most applied in residential, office spaces, institutions, hotels, retail, and hospitals to enhance privacy and save energy. For example, conference rooms and offices get enclosed from prying eyes to ensure the non-verbal cues or information displayed on monitors does not leak confidential information. In private residences, instead of using blinds, smart glass helps enclose the space and decoration of the interior space (SAINT-GOBAIN 2019). Moreover, the film used in making the glass enables use as a display screen where information can be projected in meetings or for advertisement purposes. The transition from transparent to translucent can be

utilized in a store display window where the products are visible when the shop is open and enclosed during closure. The next generation of public, business and private spaces will increasingly utilize electrochromic glazing as the most desired building trend.

2.5.2 Classifications of electrochromic materials

Understanding the properties of electrochromic glass requires the description of electrochromic material. An electrochromic material is described to have continued color changes that are reversible due to an electrochemical reaction. The color variation depends on solar radiation and the low electric voltage the material is subjected to but is not required to maintain the new color scheme. There are various types of electrochromic materials in the market whose properties and capabilities slightly vary, and they include:

- organic materials, covalent organic frameworks, polymers, and viologens
- inorganic materials, Prussian blue, transition metal oxides, and polyoxometalates
- plasmonic materials
- inorganic-organic hybrids(Zhang et al. 2020)

2.6 BIPV building type

Building integrated PV (BIPV) systems have attracted a lot of attention as a photovoltaic technique used in recent years and have since been destroyed as a feasible renewable energy generation technology to help buildings partially fulfill their load requirements. Applications for BIPV are becoming more varied. Going from ordinary to integrated solar goods is the most sensible development for the solar industry. BIPV is one of the aspects of the solar industry that has been studied the most, although it remains a long way from becoming widely used. According to Sinovoltaics, the BIPV market is decreasing as a result of solar panels that are standardized, a commodity, and have significantly decreased in price. So yet, BIPV solutions have only been limited to small quantities. Particularly, several nations promote the usage of BIPV materials.

Building Integrated Photovoltaics (BIPV) is intriguing since the possibilities for integrated solar applications are only limited by your creativity. The pricing of Integrated Photovoltaics, in

addition to inventiveness, is a key factor in making concept applications a reality, as indicated by the number of designers and project developers working on this area of study (Shahin 2019). The power generated by BIPV panels, as well as the alternating current (AC) and direct current (DC) electricity possibilities, are well known: solar cells provide DC power, which can be used directly to run water pumps, traffic signs, and (LED) lights, and other devices. Integrated photovoltaics may provide alternating current (AC) when linked to an inverter, which can power whatever a home wants to connect, from televisions to microwaves to electric cars.

Secondly, BIPV panels are often used on flat roofs to replace the roof in essence. Several approaches might be taken to deal with this. The external sheathing needs to be rebuilt when installing photovoltaics throughout a full system. BIPV panels will become more appealing when they are put on a new building in place of conventional tiles, economizing on the "traditional roof" (Alkhatib et al. 2021). Using embedded frames, a BIPV solution for a pitched roof. Glass BIPV panels can be used almost everywhere, including windows and skylights, to create a semi-transparent facade that allows a specific amount of light into the building. BIPV installation necessitates more planning and skill than standard solar panel installation. The main issue is that integrated solar should be explored at an early stage of a building's construction. This necessitates tight collaboration between architects, project developers, and solar system designers. The usage of integrated solar components might be problematic because there are often few reference projects available for the materials employed. Integrating photovoltaics into a building is a massive step for some architects, as integrated solar products are entirely novel materials.

2.6.1 Solar potential and application

The evaluation of local photovoltaic (PV) potential is essential for the creation of planning regulations and finance plans that will enable the effective installation of PV systems in cities. The prospective solar study at the local or municipal scale should be broadened to include irradiation on vertical surfaces given the substantial area available on facades in contemporary urban environments. The resultant 3D database makes it possible to geographically exhibit the solutions to some of the most baffling queries concerning brand-new solar energy systems for

structures.(Mazzucchelli et al. 2018). The GIS database can be used to assist municipal/local decision planners because statistics for each building's solar potential can be easily evaluated. This technology is particularly well suited to determine which areas of a structure (roofs and/or facades) are more advantageous for the installation of solar arrays, as well as the area available for installation, to optimize solar collecting.

Accurate estimation of rooftop solar energy potential is critical for enabling the widespread adoption of renewable energy in heavily populated regions. It has proven to be problematic due to the complex shading effects of buildings and varying rooftop availability.

Thermal photovoltaic collector combines the production of electrical and thermal energy in one device, and it is one of the most exciting technologies for solar energy conversion, especially in countries with cold climates such as Europe. The vapor-compression heat pump is already widely regarded as the most suitable clean technology for meeting building thermal energy requirements. These two technologies working together in a "photovoltaic-thermal solar-assisted heat pump" (PVT-SAHP) system allows renewable energy sources to meet a large proportion of the building's thermal needs while also improving the performance of both the photovoltaic-thermal collector and the heat pump(Miglioli et al. 2021). While the use of opaque PV panels in hot and tropical climates is for shading from the sun's heat, in addition to making use of the sun's radiations to generate energy. indicates that 80% of the applications of most of the panels are on the roofs of buildings, whereas the left 20% are applied to the faces and shading of buildings as shown in Figure 12 (Abdullahi et al. 2021). Numerous industries employ solar energy, including those that produce solar electrical energy, solar thermal power, sun heating of buildings, solar distillation, solar water heating, and solar furnaces, and solar water heating. (Sánchez et al. 2019).

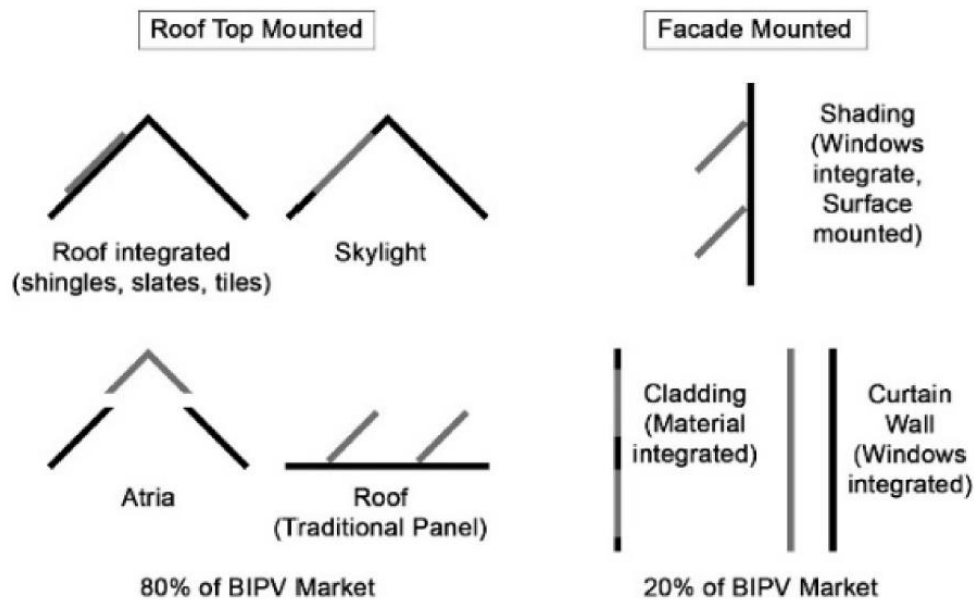


Figure 12: Different strategies and methods for applying BIPV (Abdullahi et al. 2021)

2.7 Results of Previous Researches

This section aims to explore and review research papers that study the impact of adaptive facades (Dynamic Shading, Electrochromic Glazing, and BIPV). Thus, understanding and comparing the used methods and variables to achieve maximum building energy efficiency, and determining the most appropriate approach taken for the study and how to improve it.

2.7.1 Responsive and Adaptive Façade Studies

The paper (Al-Masrani & Al-Obaidi 2019) critic analysis was used to analyze several systems and identify various models, applications, and methodologies. where building platforms and components that employ specific methods to produce dynamic shading systems, and evaluation tools to rate system performance are the two main components of the work. The systems were analyzed based on the multiplicity and integration of the aspects involved through several components, including components for architecture, mechanics, operations, and automation. The findings of this paper focused on different categories for shading system design that needed to be more than one methodology, especially in terms of weather climate and affecting the type of façade and shading in indoor zone requirements. It also, highlights the matter of annual energy of building for the dynamic façade where most studies show results in daylight matter

only, especially for classes room and offices. As dynamic shadings are not only aesthetically pleasing and lighting improvement, nonetheless it must consider enhancing the performance of facades, especially for tropical and hot climates. Specifically about controlling the angles of shading from the mechanical and electrical point of view to find an effective solution to the cost(Al-Masrani & Al-Obaidi 2019).

While this research by Shi, Abel & Wang(2020)aims to study the effect of the motion mechanism on the performance of light for a dynamic facade. The study was a tropical climate for an administrative office in which the focus was on the movement mechanism of the dynamic facades aiming to get an appropriate absolute design solution, it was investigated using the folding and rotation movement. The study included three cases, the base case, that is without any window shading devices, the folding condition, and the rotation condition.

The results in Figure 13, were for 36 cases for each motion, indicating a decrease in energy consumption for each of the dynamic shading (folding and rotation), which reached 14-21% compared to the base case. The application of the two motions façade was on south, east, west, and north. However, they concentrate more on east-side results. Nonetheless, as for the lighting,

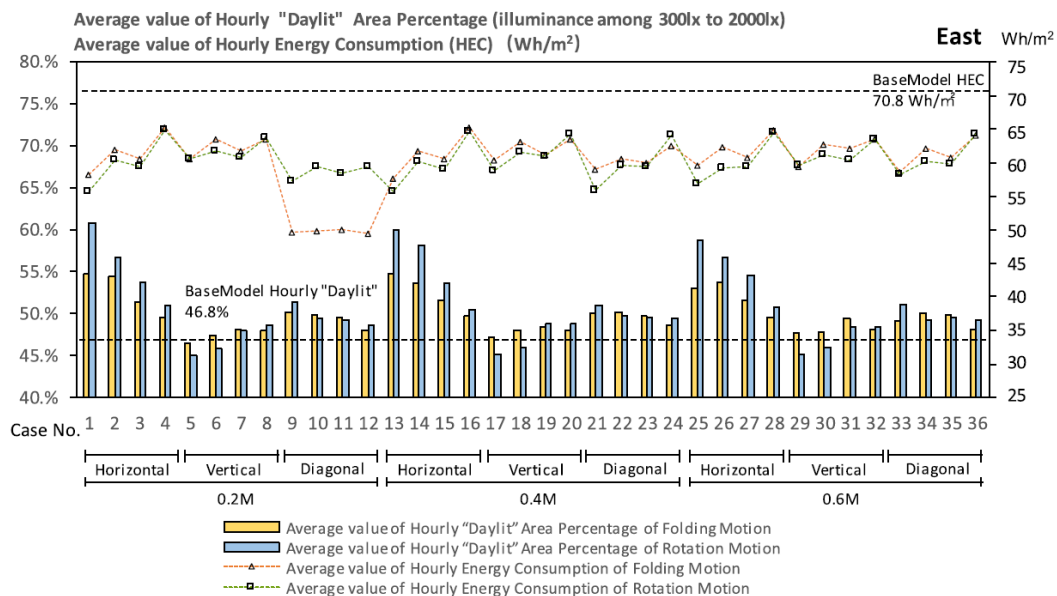


Figure 13: The average values calculation of 36 cases for two motions in hour for energy consumption and daylight area percentage (Shi, Abel & Wang 2020)

the rotating mechanism had better performance compared to folding, as the percentage of illumination increased than the base case by 30%. As for energy saving, the folding dynamics

of the horizontal axis were better than the rotation facade. The final optimal solutions record that, the percentage of energy saving was a range of 15-32% as 14% decreased for the north, 16% south, 17% west, and the last 20% east with an absolute angle of 90 for two motions.

Moving to research paper indicated the importance of modern technology in retrofit envelopes and building façade, and the lack of its current practice in the construction sector may be a reason for its use in the future. The results of the research included the importance of using PVs and responsive facades to produce energy in buildings. In addition to solutions to enhance the use of new materials or structures for structural reinforcement of buildings and to discover their global performance in depth. Determining the recurring benefits and potentials of facade retrofitting solutions from reducing energy consumption, exploiting renewable energy sources, reducing CO₂-equivalent emissions, and conceptualizing the transformation of the building envelope is the main objective of the research. In addition to the low efficiency of photovoltaic cells, the risks of overheating transparent panels compared to conventional cells, and the high cost of responsive elements are risks and challenges that must be addressed and resolved in the future. Due to the present inefficient stock, it's essential to address the issue of energy and environmental refurbishment. Reduced heating use and the switch to electric power advance the development of communities reliant on renewable energy, where each industry (particularly transportation and construction) is viewed as a link in a shared energy network, where each individual is both a consumer and a producer(Ascione et al. 2021).

2.7.2 BIPV Studies

Solar panels PV usually produce waste heat when used, as a real scale was established using air collectors for cooling, to exploit and collect wasted heat to improve the efficiency of energy production for buildings in terms of electricity and investigation of thermal performance as taking to consideration of the thermal coefficient, is one of the most important parameters that affect the efficiency of panels production of energy(Kim, Kim & Kim 2021). The results were achieved in comparison with PVs without cooling, and PV panels provided with cooling, where the temperature between the air panels decreased by 22 Celsius compared to the other panels. Besides, the air-type panels produced more energy by 30 watts, which produced about 800 watts per square meter. When the solar radiation increased in the middle of the day, the antenna panels

remained stable at the electrical efficiency, which amounted to 14%, while the regular solar panels reduced the electrical efficiency due to the high temperature of the panels, which reduced the efficiency by 12%. Thus, the air-type panels are classified with higher efficiency, even with the highest solar radiation. The cooling panels also proved the possibility of heating in the cold seasons, as the units were supplied with pre-heated air, in addition to heating the cold outside air, as the heated air reached 32 degrees, which is 15 degrees Celsius higher than the outside air (Kim, Kim & Kim 2021). In the end, the study serves as a basis for future studies on an integrated system of panels, especially in the early design stage.

Another study (Qadir, Haddad & Hamdan 2019) included the use of solar panels (PVs) on the roof of a traditional house in the Emirates of Abu Dhabi climate, to improve the performance of the house in terms of energy. Besides other aspects in terms of ventilation and building materials to achieve the Green Building Assessment System. The results of using the PVs indicated a generation of 35,837 kilowatt-hours or 21% of the building's total energy performance

While in this work, applications of BIPV in tropical climatic regions are discussed with a case study of Nigeria, along with expectations and challenges in terms of its performance, efficiency, and power generation capacity. There is a variety of information in the literature about the capacity of BIPV to generate electric power, with an efficiency range of 5–18%, as well as the various uses for façade and roof-top BIPV and tropical climates may experience a 30% reduction in space cooling as a result of the shielding effect of BIPV (Abdullahi et al. 2021). BIPV may meet 70% of the energy needs for buildings. Also, the results of the research paper indicated to focus on: To obtain the highest energy production from solar photovoltaic energy, the solar collectors must be in the correct tilt according to the location. Certain studies should be conducted regarding electrical load demand, building location and integrity, and constraints associated with roof design and projected photovoltaic production. Design principles like flexibility, durability, and efficiency, and constructive issues need to be considered. As is the practice around the world, these countries should take care that BIPV roofs have the same function as regular roofing materials, such as noise security, airtightness, insulating, and climatic security establish design standards for BIPV.

Moreover, the results of a study carried out in Saudi Arabia for the use of a BIPV, through the fixed horizontal light shade device equipped with solar panels, this study concentrated on the

lighting element of the building. The study investigates the shelf extenders, reflectance, and height above the ground. The findings indicated that the shade device's optimal level is reached at a height of 1.3 meters when a 30 cm reflector above the window with a 10° internal curved angle is added. Regarding the production of power for the solar panels, they must completely cover the two-study shelf case which is a fixed panel angle shelf at a 30-degree angle. Except for winter, this configuration delivers consistent daylighting and decreases energy use by nearly 85%. The integration of PV, which has a conversion efficiency of just 10%, may offset the energy required for lighting. also minimize glare, which is particularly uncomfortable in the winter. Similarly, compared to a light shelf without a solar module, a horizontal shelf with PV with a flat and 30° tilt angle exhibits a superior homogeneity of lighting(Mesloub & Ghosh 2020).

While a study in France was conducted to test the efficiency of installing solar panels on an external wall of an external room on the south side. where the findings indicate that the thermal statistics show that from December 2018 to December 2019, there was a mean yearly efficiency of 6.3%, which is good for a façade integrated system, and daily mean temperatures between - 4.4 and 68.3 C in January 2019. The solar field generated a total of 63.8 kWh/m² of electrical energy over the same time, which corresponds to a performance ratio of 0.73 and may be attributed to the bifacial PV modules' increased production on the backside. At both low and high amounts of solar radiation, it also decreased heat fluxes through the concrete wall. A considerable energy savings of up to 92% was made possible by the photovoltaic prototyping integration of two test cells, especially during the colder months. The cumulative total energy usage in the test cell with the solar facade was 636 kWh, compared to 1963 kWh in the reference wall, which represents a 68% reduction during the entire period(Assoa et al. 2021).

Another research paper is taking part in (BIPV) in Egypt, where the focus was on horizontal shade devices equipped with fixed four PV angles in three building orientations to reduce heat gain and balance with visual comfort and improve energy efficiency. The results for 16 cases (were that the angles of 30 degrees for the east and south sides decreased from 20.6 to 1.6 for the ASE (annual sunlight exposure) significantly, which led to a reduction in the energy load. As for the electric energy, it was surprising to generate about 90% of the eastern side from the south side at angles of 15 and 30 degrees(Marzouk & Atwa 2020).

Skandalos et al. (2022) praised the importance of the special climatic and environmental conditions for the local solar engineering of BIPV for PV. To build and facilitate the transition to sustainable buildings and mitigate climate change, by creating a classification according to the value of global horizontal radiation (GHR) for four climate zones (cold, temperate, warm, and hot) where the findings: Photovoltaics, together with other renewable energy sources including geothermal and air sources, along with energy storage, may be used to cover buildings in cold climates, increasing the BIPV adaptability ratio. Buildings in this area can now be 100% self-sufficient and self-consumed. Positive energy buildings are easier to achieve a mild climate with medium global horizontal radiation. Further reducing the present and increased cooling demands anticipated due to climate change is possible with PV shadings and STPV windows. BIPVs also help offset carbon emissions when used with low- or no-energy heat transfer management techniques. Refined optimization may be carried out in areas with year-round surplus GHI and higher cooling demands by first lowering cooling requirements and then producing electricity. Due to the disruption of window transparency, their installation needs to be contrasted with windows that may change their transmittance to the climatic circumstances in the area. This is because the high GHI values in a hot climate counterbalance the excess cooling need of the climate. Integration of BIPVs at optimized surfaces with less integration disturbance is particularly important. With the addition of it would be possible to achieve a zero-energy balance with a PV roof and proper ventilation.

2.7.3 Electrochromic and Low-e Glazing Studies

This study presents the results of evaluating the performance of electric glass in two different climates of Italy, where the paper focused on the thermal effect of glass and the control of radiation and also to save energy in buildings. Small size of Electrochromic glass was tested to study the thermal performance inside the glass, where the transformation was reversed from opaque to transparent for two types of glass, single EC and Low-E double EC, for west and south directions two different climates in Italy, one of which is the Mediterranean and the other is a humid continental climate. The thermal performance results for the two types were as follows:

- The temperature difference of a single EC glass was lower compared to the other type.

- The temperature differences for the first glass were 1.3 Celsius, for the degree of bleaching and 0.7 Celsius for the blue opacity(Piccolo et al. 2018)
- As for the double glass type, the differences were 1.5 for whitening and 2.5 for opacity

In general, all the results of the study recorded that the transmittance of solar radiation was reduced by 20% due to the absorption of EC glass. The simulation stage was a case study of a two-story residential house with the use of the same specifications of double-glazed glass for the experiment, where the results were:

- Through the profile (air conditioning system and lights) despite the lack of operation, the results indicated a decrease in the cooling energy for the hot climate.
- The performance of the glass is better when the demand for cooling dominates over the demand for heat and lighting, as the ratio reached between -20%-40% As for the hardest climates, it is less than 15%in Figure (Piccolo et al. 2018).

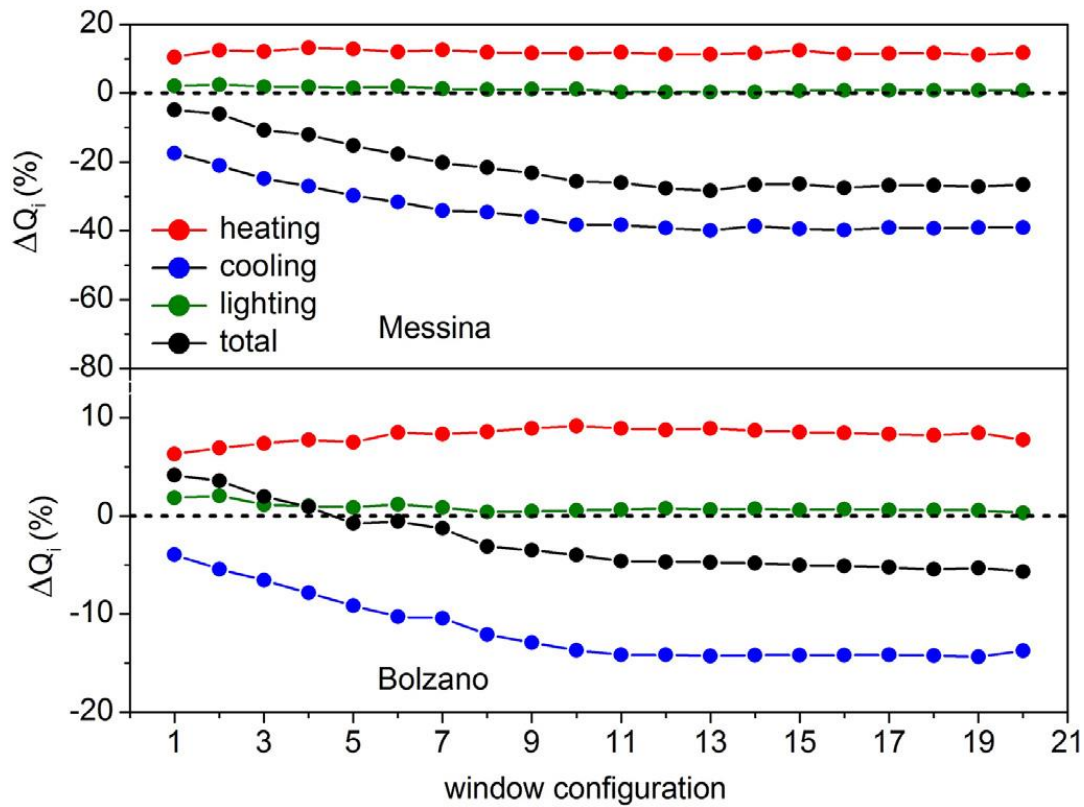


Figure 14:The result of reduction in energy for electric glass (Piccolo et al. 2018)

Finally, it was noticed that the increase in temperature inside the glass leads to thermal discomfort for users due to the absorption feature that the EC glass has. Solutions to the problem have been proposed by using an insulating coating in the inner layer or ventilated double glazing. Included several buildings for the tropical areas of buildings with double glazed units, nonetheless, some old buildings carry a type of glass for high transmission of solar energy and little thermal insulation, and therefore this study included internal glass facades in the building to improve performance. Taking into account energy savings, thermal comfort, and visual comfort is the goal of the proposed study. The study was carried out in two stages, a simulation and an experiment in Singapore weather conditions. The objective was to monitor performance in terms of lux levels and heat gain. Also, estimate annual energy consumption reduction. The results concluded that the type of glass can reduce the energy of air conditioners by 9% for the three directions of northwest, southwest, and southeast. Also, savings energy per day might reach 12% which reaches an average of 7% when using gray glass (Somasundaram et al. 2020)

2.8 UAE Renewable solar energy and Climate

The UAE is one of the countries in the field of generating energy from solar energy, and recently it has also begun to study other resources besides it, in the implementation of the new state's policy of Vision 2030. This is to reduce the level of carbon dioxide and protect the environment and reduce the consumption of electricity from the source of coal and gas, as mentioned in the first chapter.

2.8.1 Solar radiation and energy

The United Arab Emirates has huge potential to develop solar energy. It has the highest rates of sun exposure recorded in the world, (Ramachandran, Mourad & Hamed 2022). The UAE's shift to green energy techniques is an energy revolution that will encourage long-term growth. Solar energy, for example, is one of the most promising sources of renewables, and the country has high potential in the sector of renewable energy. It receives 10 hours of sunshine every day on average (Samour, Shahzad & Mentel 2022).

Throughout the year, the UAE is exposed to the sun during the day, and through the Climate Consultant software, the Dubai climate file has been included, where Figure 15 shows the months throughout the year with direct sunlight and on the surface. Annual statistics indicate a high point of solar energy reaches 2500(Btu\sq.ft per day).

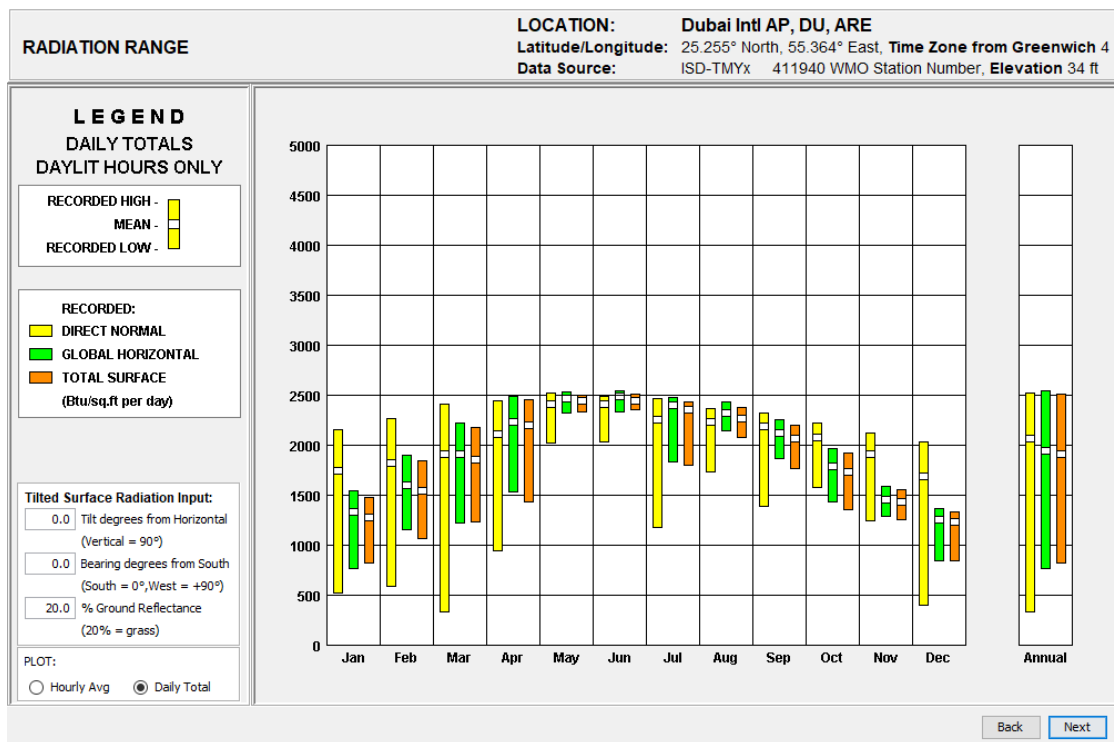


Figure 15:Solar radiation of Dubai for 2021 (*Climate Consultant 2021*)

The statistics, as shown in Figure 16, indicate that in 2019, the production of electricity from solar energy increased compared to other sources by 3.79 terawatt-hours. And the energy consumption by 7 terawatt-hours. From 1.3 TW-hours (TWh) in 2018 to about 4.8 TWh in 2019, solar energy production grow. Additionally, solar photovoltaics (PV) is one of the top technologies in the UAE, making up the majority of the country's project pipeline and around 85% of the 589 MW of built renewable energy capacity. This growing trend in the UAE is illustrated by several green energy initiatives and plans, such as the Masdar City project. Where Masdar City is the largest project of its sort in the Middle East and the nation's first renewable energy initiative(Samour, Shahzad & Mentel 2022).

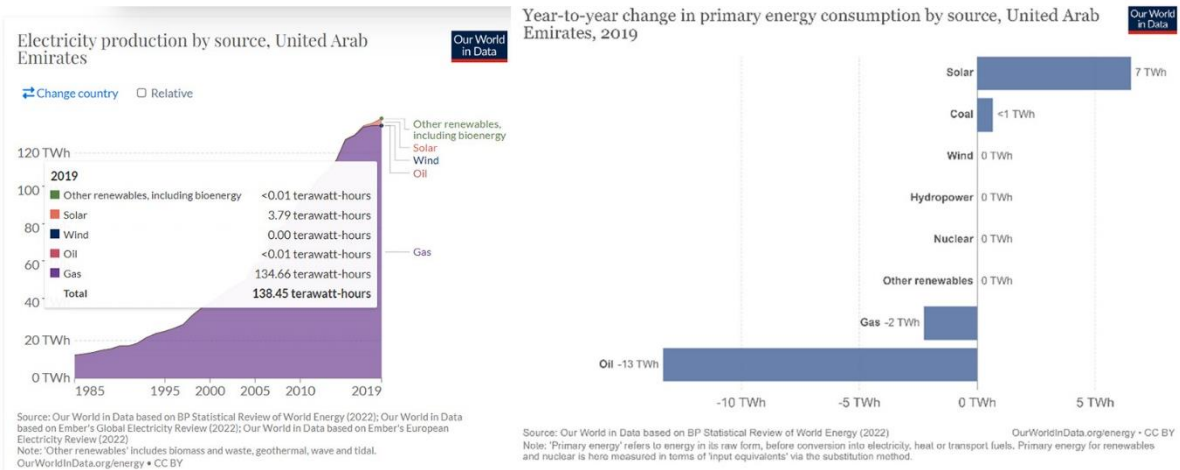


Figure 16:2 Electricity production and consumption for UAE (Roser 2020b)

2.8.2 Dubai temperature

The climate of the UAE is generally characterized by a hot and dry desert climate, where the temperature increases to the maximum degree in the summer. Recent years have witnessed a noticeable rise in temperatures due to climate change as a result of global warming. Summer begins at the end of June and concludes in September in Dubai. Summer months are June, July, August, and September. August is the hottest month of the year, with an average temperature of 35.7 °C | 96.2 °F. The typical temperature in January is 19.4 °C | 67.0 °F. It is the year's coldest average temperature as shown in Figure 17 (Climate-Data.org 2021)

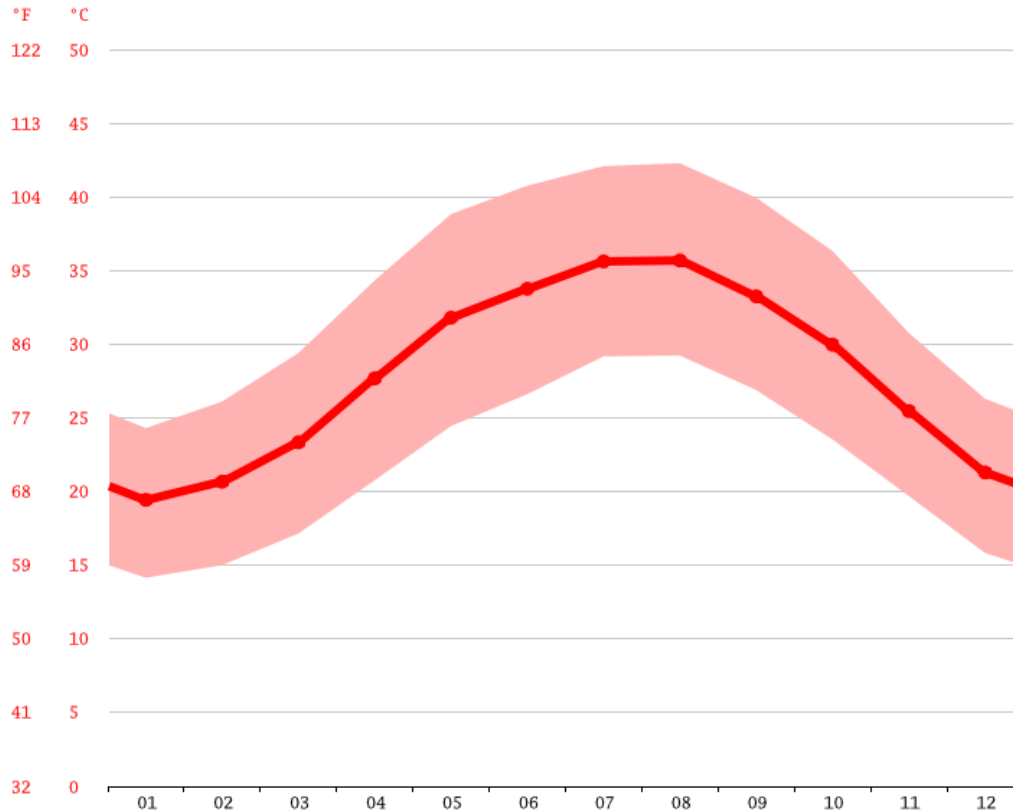


Figure 17:Average temperature (*Climate-Data.org 2021*)

2.8.3 Wind Direction and Speed

There is a relationship between temperatures and the performance of solar panels, as the United Arab Emirates has high temperatures, which affects the panels and their performance, and the necessary wind ventilation must be taken into account to extend the life of the panels (Salameh et al. 2020). Wind affects the temperature in the country and also on the solar panels, as it is necessary to supply the panels or expose them to wind to reduce the heat generated by cooling them. Through Climate Consultant software, most of the winds during the year come from the northwest. The average wind speed for the year 2021 was approximately 8 miles per hour.

2.9 Gap Analyzing

Recently, the same as the globe, the UAE is perceiving an increase in population density, which in turn has put pressure on energy resources, as mentioned in the first chapter, which is expected

to increase in the coming years. Since the Emirate of Dubai is the commercial capital of the country, office buildings are on the increase, other than buildings filled with unshaded glazing (curtain walls). This increases the pressure on the air-conditioning energy and the use of electrical energy. Especially since the UAE's relatively hot-dry climate, which contributes significantly in addition to the problems of global warming, hence has increased the temperature in the country and around the world in recent years.

By reviewing previous research papers, most of the papers offered more literature discussions about retrofit building facades in terms of using renewable energy, and few studies were taken in different climates, although many countries encourage the use of alternative solar energy through buildings (BIPV) to make them energy self-sufficient. There is a need for more studies particularly, in hot countries that are exposed to the sun in most months of the year.

However, there is still a clear lack of dynamic energy data about BIPV in terms of building envelope and façade in the United Arab Emirates as well. The state of the Emirates is one of the countries that have recently shown their dependence on solar energy to generate electricity from PVs, which has increased in electricity production during the past two years. Accordingly, the research will investigate and determine the ability of the UAE's Dynamic PV building facades, especially Dubai, to enhance the building's energy and performance from other aspects like internal lighting, in addition to energy, and contribute to opening future doors to expand research on this subject.

CHAPTER 3 : METHODOLOGY

3.1 Overview

This chapter includes a review where the focus will be on the methodology for research papers that were discussed previously and the identification of the type of each method with an investigation and what are the pros and cons of each type.

3.2 Literature Review Methodology

Literature Review Literature review is one of the important methods in terms of mentioning and investigating previous papers that included the uses of adaptive façade and BIPV. Beginning at the study of (Al-Masrani & Al-Obaidi 2019) which analyzed some research in two stages based on numerous experimental and theoretical assessments, work is separated into two main portions. The main aspects of the design of dynamic shading systems are covered in the first part. The second section offers an analytical assessment of various shading schemes using the material that is provided. These parts serve as a crucial framework for the analysis of various systems and approaches. Besides, uses two different analytical frameworks as shown in Figure 18 :(1) geometric analysis, which differentiates between straightforward and sophisticated shading models, and (2) Performance analysis, including rates shading systems using two different approaches, namely conceptual and experimental. The review's conclusion represents a precise classification of shading models and a thorough examination of their effectiveness. In general terms, this subject offers an organized framework for architects based on extensive examination and research. The method used in reviewing this paper is the analysis and investigation of 20 research papers that include different shading devices in terms of classification: design, system, location, and climate. Taking consideration of different climates, that included two papers for the UAE and three papers for Egypt, which has a hot climate, and also included different climates such as Indonesia, South Korea, and cold regions such as Denmark.

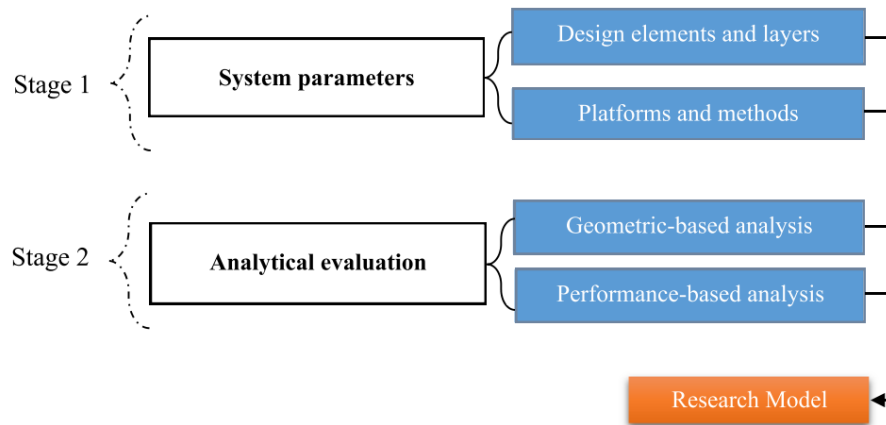


Figure 18: Review framework for Dynamic shading system (Al-Masrani & Al-Obaidi 2019)

Coming to BIPV (Abdullahi et al. 2021) used a general review of BIPV technologies which are generally discussed in this study. The review included several aspects of the papers in terms of electricity generation, efficiency, type of panels, and places of application. Twenty-three research papers were reviewed, including the uses of solar panels, fifteen for facades, seven for roofs, and one paper for roofs with the facade.

The research specifically examines how this method might be carried out in tropical climates as a case study. Included a dedicated study and a review and discussion of results in terms of the use of existing buildings on the ground for various uses. Taking into consideration, the rise in interest in BIPV systems because of their affordability and viability as an investment. Also mentioned for BIPV technology, added technology that has advanced significantly is BIPV Thermal System, which has a high implementation cost. It benefits buildings by saving energy and money on heating systems. It appears from numerous studies that this technology has hope for the future.

3.3 Simulation Methodology

Researchers(Shi, Abel & Wang 2020)took three stages: model setting, simulation, and analysis. The model case was set for an office in a high-rise building in Singapore with dimensions of 8.4m depth, 10m wide and 3.6m high. The window is also set based on the Singapore code BSA. The goals focused on hourly energy consumption, in addition to the lighting for each of the performances of the folding and rotation movement of the design, double shading devices,

which amounted to 36 designs for each motion. In place of the simulation, the Rhino program was used with the Grasshopper plugin and energy plus connected to analyze 72576 situations for lighting conditions and energy consumption for four directions for a whole year. Taking consideration calculations that were used to determine the best angle of cases for three hours for 12 days through an equation to find the optimal solution for the energy consumption and the ratio of the area to the daylight. In the final stage of this study the analysis, a comparison was made between folding and rotation to choose the best results for 36 cases for the four directions through calculations to help determine the appropriate design in the early design phase.

Simulation analysis was carried out on an office building located in Saudi Arabia facing south. Where the Diva program was used for optical analysis. The study was carried out in four stages to evaluate: the appropriate height where three different heights were used in addition to the same values for the depth, a reflective material, the angle of the curved interior light shelf, and integrated photovoltaic (PV) cells with different covers (25%, 50%, 75%, and 100 % complete). The shelf has also been tilted at an angle of 30 to the side of the base flat angle.(Mesloub & Ghosh 2020).

Another study (Qadir, Haddad & Hamdan 2019) used an analysis tool for the Revit program specialized in computing solutions to design high-performance buildings in Abu Dhabi. The energy performance of the proposed building was first analyzed as a reference to building energy performance, was used for the values of thermal permeability of building materials according to the minimum energy values of the villa classification system for Estidama, and was compared with the values resulting from the analysis by the program for the total energy consumed. Also, the extent to which the heat gained was reduced for the use of ventilation and shading devices was analyzed and compared with the base case. In the final stage, the generation of electrical energy through the solar panels was calculated by equation, and the percentage of annual electricity generation from the panels was divided by the total energy consumption of the building.

In Egypt, simulation analysis was studied. where the analysis is done through three stages: the first is to model the case study building with curtain walls. second is selecting the software of Rhino\Grasshopper with ARCHSIM plug-in and DIVA to calculate PV energy building, energy consumption, and daylight simulation. The third stage of the simulation process where the

simulation cases are based on two parameters of PV: orientation (south, west, and north) and tilt fixed angle (25°, 20°, 30° and 15°). The total number of cases was 16 and compared with the base case values to select the best scenario in daylight, energy reduction, and generating energy (Marzouk & Atwa 2020).

3.4 Experimental and Mixed Methodologies

An experimental study (Kim, Kim & Kim 2021) was conducted in South Korea in the city of Cheonan during the heating season for January and February. An external house was used for testing, where the panels were installed on the south side of the house. The experiment was set twice: the first stage thermocouples were used to evaluate the temperature of the PV module, and the temperature characteristics of the BIPVT and BIPV systems were examined. To evaluate the heat produced by the solar cells and their performance in terms of energy production, an insulation system was constructed to meet the performance of the building's exterior wall for BIPV. Photovoltaic (PV) modules have been applied to produce energy from solar cells, as shown in Figure 19. Although, it is important to consider sensitivity and inaccuracies in measuring instruments. The limitations of the measurement tools were taken into account in this experiment. Instrumentation specifications with uncertainty included a humidity and temperature transmitter, a thermometer (nonlinear) thermometer, and an energy meter data logger.

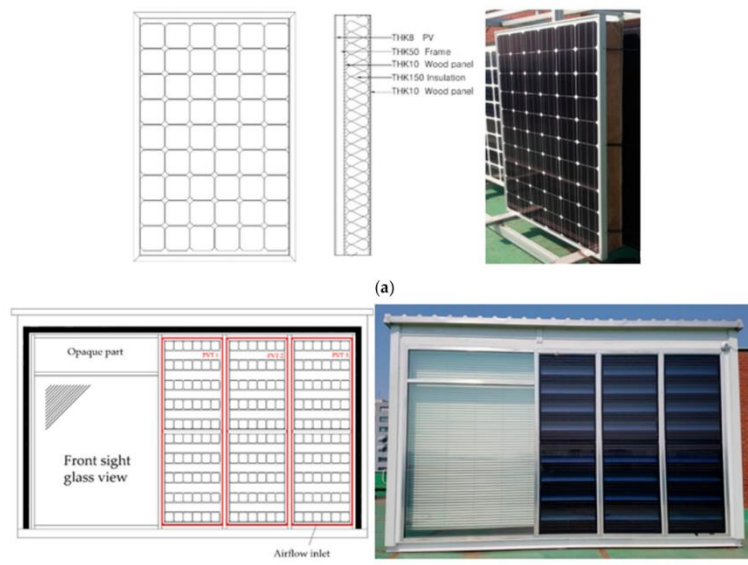


Figure 19:1 Experimental house: (a) BIPV system; (b) Experimental house with BIPVT system (Kim, Kim & Kim 2021)

The second stage: The solar panels are built on a piece of glass. Six air collectors also contain absorbers from the bottom and top that are exposed to outside air to allow passage through the collectors and help with cooling or warming. Through the outflow, warm air from the BIPVT collectors entered the AHU's supply air channel. There are two operating modes, and it was regulated by a fan and damper. The damper is locked to restrict the path between the PVT collector and the AHU anytime space heating is not needed, and the warm air is expelled outside.

Another experiment study has been used pressurized solar cells were used inside a glass facade, where the basic unit measurements were 76 centimeters by 83 centimeters, 24 monocrystalline silicon heterojunction bifacial half-cells in series set out in 4 rows and 6 columns. Along with concrete wall was likewise placed and instrumented back the PV façade in a south orientation. The FACT tool is a two-story modular test facility with ten cells that are located at the CEA site in Le Bourget du Lac in France and is specifically used for testing envelope elements (2.3 m of width, 3.3 m of height, and 3.9 m of length). The outdoor climate of the test is considered summers are warm and dry, while the winters are pleasant near the installation location. The experiment lasted for about a year between December 2018 and December 2019, a test campaign was conducted to assess the thermal behavior, electrical output, and test cell energy consumption for heating and cooling. Taking into consideration of the performance ratio after the micro-

inverter Prac (-), the final yield I_f (kWh/ kWp), and the electrical efficiency PV, which are all supplied by equations, were the three major parameters employed for the study of the recorded electrical data. Lastly, an observation made between the reference 20 cm thick cast concrete wall and the PV facade test cells' overall energy usage for heating and cooling while taking into account the cold and warm seasons (Assoc et al. 2021).

Piccolo et al. (2018) included a combination of two methodologies, the first: Experiment, was a 42cm x 44cm box with 12 cm window of EC DGU shown in Figure 20. One of the characteristics of the glass used is that it is reversibly transformed from transparent to opaque with a value of ± 2.5 volts. The measurements were taken on the roof of a university in Italy under a clear sky condition to the south for two days in June and four days in July, while the west was two days in July for eight hours a day. The second one was a numerical simulation: it was simulated on a two- story apartment building for a family of two people.

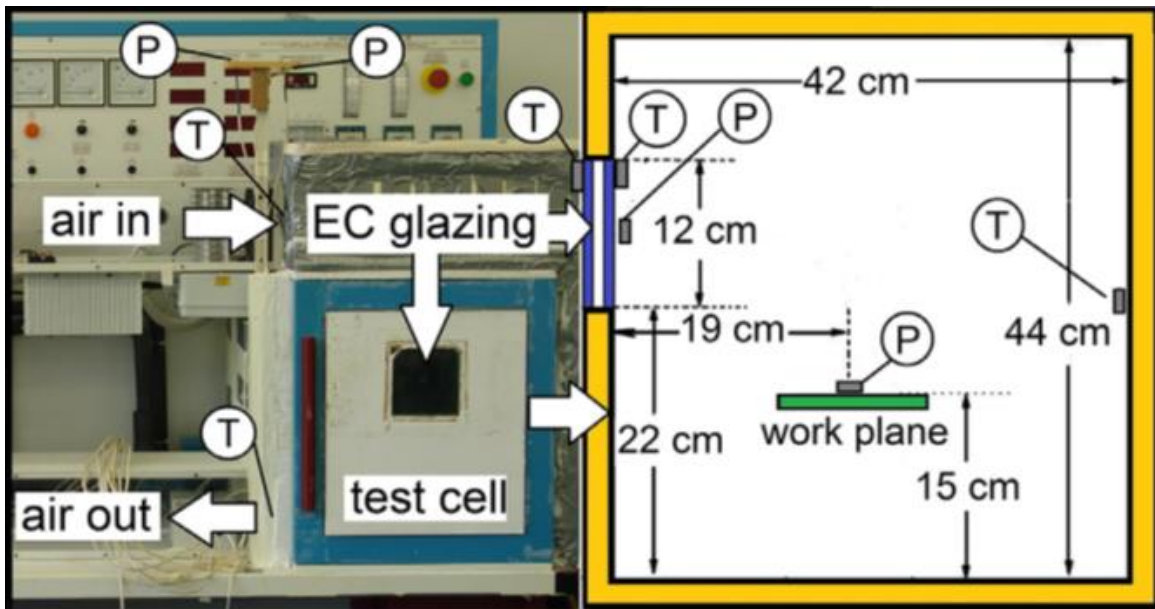


Figure 20:photographic view of the test rig (left side). Schematic cross section of the test-cell (right side) (Piccolo et al. 2018)

Taking into account the operation of the lighting system and air conditioning according to use through a standard profile. The specifications of the EC DGU are the same specifications that were used during the experiment for the double type, while for the first type, the thickness of the glass was 4 mm and the air space in between was 12.7 mm(Piccolo et al. 2018).

Another study(Somasundaram et al. 2020) has two methods, based on experiment and simulation. The experiment was conducted in a room in a building in Singapore. The room measures approximately 10.65 meters in length, 5.95 meters in width, and 4.95 meters in height from floor to surface. The internal height of the ceiling included 1.65 m. An internal window of Low-E glass was installed with an unsealed air gap where the room contains three window facades located in the directions SE, SW, and NW, and there are fixed sun blinds over the facade of SW and NW, and a darkening wall directly to the northeast. As for the simulation method, a program was used to build the room by Design-Builder interface, along with Energy Plus as the background engine. Where the same properties and material in test work are applied in modeling simulation.

3.5 Methodologies Pros and Cons

Every research should include a literary review as a key tool for gathering more data and elucidating the full picture of the chosen subjects. The review's affordability is one of its benefits. It also helps to recognize the gap as well as be aware of it based on previous knowledge, whether for a specific place, a particular region, or worldwide. Nevertheless, utilizing literary analysis as the only approach has certain limitations, especially time and findings. where choosing and organizing research articles takes a lot of work. When identifying gaps or restrictions and no numerical data or tangible outcomes were employed, there will also be verbal suggestions for future papers.

Regarding the simulation approach, its benefits include low cost and quick performance in addition to these. The function of its flexibility in dealing with the intended findings in the studies comes from both the speed of change to the tests and the inclusion of modifications in terms of variables or results. In addition to the building feature and simulating the investigated case without using the actual building for research, the simulation is presently also characterized by weather files, operations, and definitions to achieve the requisite precision, which makes it easier to get the outcomes. The absence of costly investigation supplies and manpower, as well as the short time frame, play a part in cost since they allow the study to be expanded and provide more opportunities to look into other factors and variables. The simulation still has certain limits since some systems do not yet account for all new materials, sophisticated techniques, or

intricate analytical techniques that call for somewhat realistic outcomes in particular situations that require higher mobility.

Coming to the experimental method used in previous studies is assumed to be one of the most accurate approaches for obtaining results based on real-life experiences under actual climatic conditions both with relation to the accessible parameters, though it is recognized that experiments may vary depending on the reachable resources. Regardless of how long the research takes or how the information is organized, it is expensive to use the resources for study purposes. Studies often last a year and often longer. In addition to locations or places of experience where it is not always accessible, it also required effort and a budget. Considering also that data collecting depends on an observer, data collector, and records throughout the specified period an unintended error may exist. Additionally, the experiment has limitations from a climatic perspective since the locations have different features as well as the weather, which might make the experiment difficult. The utilization of residential or other structures where people are present may have an impact on the statistics. As for the mixed methodology, they are still insufficient in terms of simulation and experimentation. It provides good results, somewhat real, nevertheless, the limitations still overcome them, as the studies were carried out inside the laboratory with the use of simulation, and therefore it may not be sufficient in terms of covering the required parameters or modifying from a broader side and repeating the experiment. It is difficult to access simulation programs that work with a connection to experience, as they are not available to everyone and because of the cost also for programs besides the experiment.

3.6 Methodology Selection and Tools

Since the research includes a study on the performance of dynamic solar panels for facades in addition to its impact on lighting and energy, based on previous methodologies review, and knowledge of the advantages and limitations associated with each of them, the modeling approach compared to other types is considered the most appropriate in this study. Where the simulation method is characterized by a wider scope in terms of flexibility and control of parameters regardless of location or place and measurement. Existing programs can analyze based on climate, locations, and solar conditions sufficiently to give a visualization and valuable information about the project before implementation, which also facilitates Work on future sites

and avoid errors as much as possible. Simulations can be improved by repeating experiments more than once and comparing them with realistic results to achieve the desired level and deepen the knowledge of the use of software capabilities.

The aim of using simulation in the research is to investigate the performance of the panels in terms of moving angles during the year and to determine the absolute angles for each month of the year to generate energy that covers the needs of the office. As well as its impact on shading and interior lighting, which helps in the future to know the vertical angles of the facades of buildings that will help in the pre-design stage. Where the results of the research will be wide-ranging in terms of the impact of the panels on interior lighting, energy consumption, and energy production during the year in detail to study the settings and angles of the panels and determine the absolute scenario for the best results. Besides, to reach the maximum results that can be applied to increase the efficiency of buildings built with wide curtain walls, as well as a view of future buildings in the United Arab Emirates.

Choosing a simulation tool should refer to several aspects, starting with the accuracy of controlling the panels based on the sun's directions for the climate of the UAE, specifically Dubai during the year. And the availability of building materials and glass windows that will be studied next to the panels. Where the focus on comparing and studying the results of the parameters in terms of lighting, power generation, and energy consumption for each (air conditioning, lighting) is essential for choosing the simulation.

The program will be used starting from the office building modeling, taking into account parameters such as the orientation of the panels, window materials, panel angles, and several panels, taking into account the building materials, thermal properties, and lighting. Also, the validation stage will be to check the efficiency of the software used and compare the results with the actual electricity bills. In addition to saving energy consumption, internal lighting systems and how to control them will be taken into account in the advanced settings, along with the external lighting that the program will provide. Finally, besides dynamic shading devices and providing them with photovoltaic panels to produce electricity during the year with the priority of determining the angles and absolute direction.

Simulation software offers trust, and the researchers discovered that all dynamic systems and the suggested control are successful, while also time-saving (Al-Masrani & Al-Obaidi 2019).

Several researches-based simulations study the effect of facades on building energy, lighting, and the effect of shaded panels on energy production. Starting from (Marzouk & Atwa 2020) studied the PV horizontal shading system and their performance due to lighting, energy consumption, and energy production by Rhino\Grasshopper software. To improve the energy of the building from the large glass facades. While (Qadir, Haddad & Hamdan 2019) used Revit simulation software to achieve the Estidama Green Building Assessment System of Abu Dhabi. That enhanced building energy performance and generated energy by installing solar panels on the roof. Another study adopted the Revit program was used to analyze the total energy consumption from the thermal and electrical energy, besides PVSYST program to choose the best location to install the BIPV interface system to reduce the cooling load and increase the production of electrical energy (Salameh et al. 2020). For dynamic shading investigation (Shi, Abel & Wang 2020) used Rhino\Grasshopper software to aim to get an appropriate absolute design solution with different motion strategies. while another study with the same software plus a DIVA plugin, to assess the energy, thermal performance, and lighting, as the use of a PDSD (passive dynamic shading device) reduced the total energy and increases daylight (Alhazzaa 2019)

3.7 Software Simulation Process

The previous part explained the research papers used for Rhino\Grasshopper and DIVA software, which was established on programming engineers, architects, and energy engineers. The Software is characterized by the specifications of a dynamic environmental analysis of the building developed by Harvard University. along with the ARCHSIM plug which is based on energy plus software. Moreover, the plug-in facilitates the analysis of the environment within the necessary environmental conditions.

The climate file for the Emirate of Dubai was downloaded and entered into the software first, through the format EPW. This is to ensure that the climate condition of the site is existing, which improves the efficiency of the analysis. Then the building was modeled with its true dimensions and the building settings were adjusted from building materials and glass to windows by adjusting the thermal location of the ARCHSIM in the Grasshoppers for the stage of validate the efficiency of the software and comparing the data with the actual electricity bills.

After this significant step, the settings for the studied scenarios are determined. And adjusting the settings of the sun through DIVA by choosing the sun path and linking the settings of the sun with the solar panels in a complex way thus it easy to deal with the movement of the panels based on the directions of the sun during the full year.

In addition to analyzing lighting, using a sensor tool (dimming setting) to control based on the number of cd/m^2 (Lux) in the indoor space used. Thus, to know the visual comfort and how the panels affect the sensor's work. As for the energy consumption analysis tool with cooling load energy, electrical energy, and lighting energy, this was done with the ARCHISM and Energy Plus tool, thus linking it also with the tools of movable solar panels during the year, based on the control of each of the studied scenarios as shown in Figure 21.

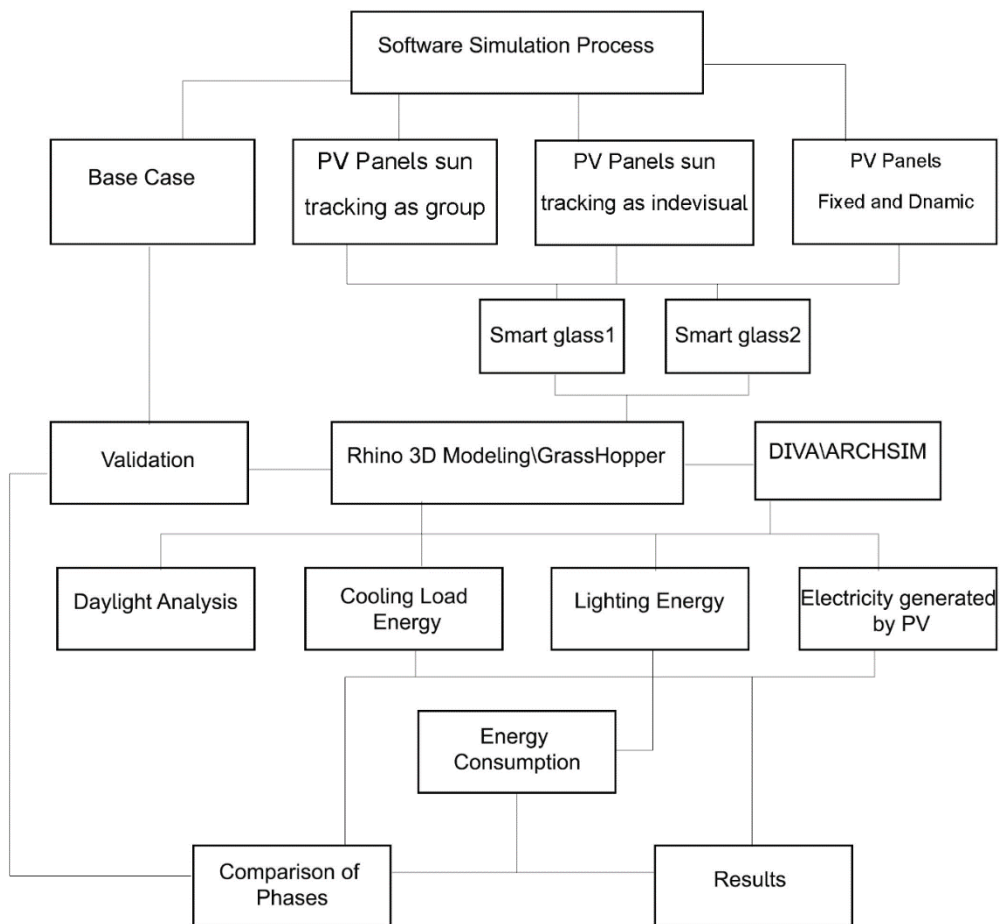


Figure 21:Software Simulation map process (Author,2022)

CHAPTER 4 : BUILDING SIMULATION MODELS OVERVIEW

4.1 Overview

Base case modeling is one of the most important steps throughout the study. Where modeling preparation will be presented in this chapter in terms of scenario configurations, starting from drawing the actual building to applying the proposed scenarios. The selection of the Base Case for the study and validation of energy consumption will also be mentioned in order to verify the efficiency of the program's work in terms of simulation and energy. Taking consecration to the program was verified by using the actual electricity bills of the office and comparing them with the simulation results of energy consumption in the program.

4.2 Base Case Description Building

As mentioned in Chapter 1, Numerous studies show that the usage of glass facades in office buildings, in particular, has resulted in the use of more than 40% of energy. Especially in the UAE, where the construction sector consumes 80% of the total energy demand(Najini et al. 2020). Based on that, the type of building was selected as an office in the United Arab Emirates, the selected case study is basing on the availability and accessibility to the energy bills. The law office is located on 10th street of OUD MITHA in Dubai city which the second-largest city in UAE as shown in Figure 22.

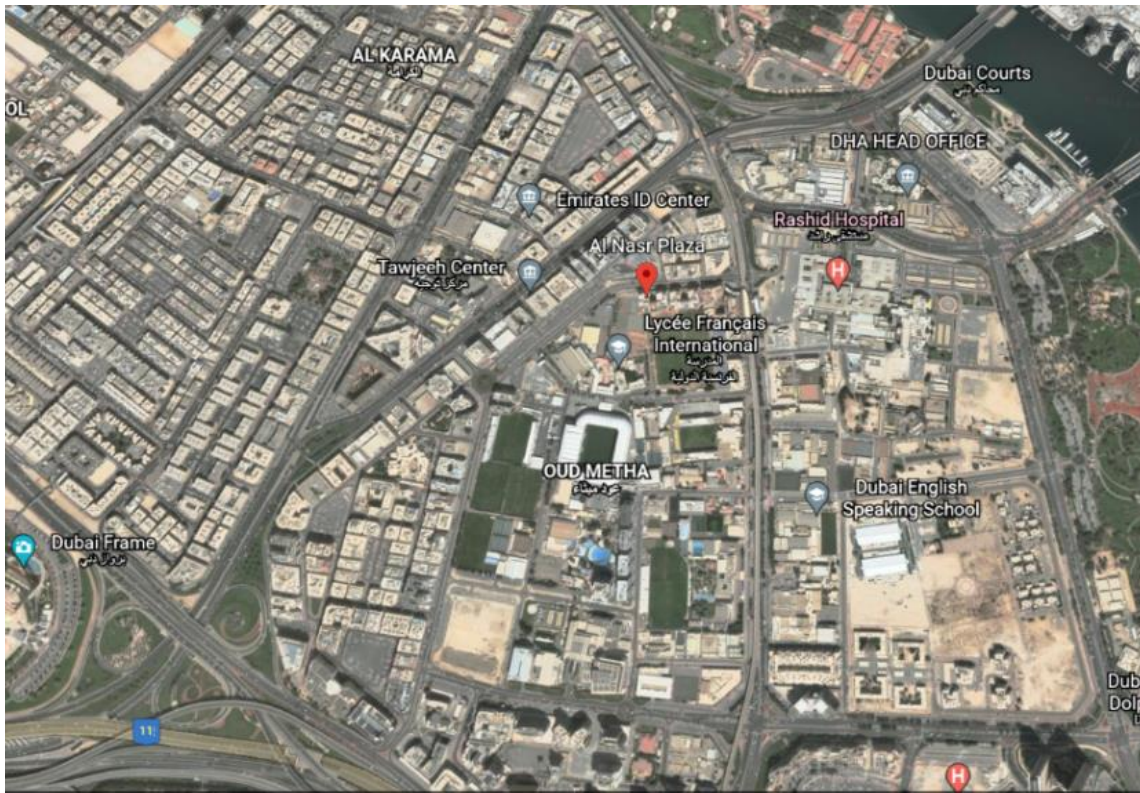


Figure 22: The law office location (case study) google earth (Earth 2021)

The office is on the first floor with two large windows (1.8m high and 3m wide) with a total space of 306 m² and 2.7m high facing the southwest. Also, the office contains four private small offices shown in Figure 23, reception space, kitchen, and storeroom. The construction materials that have been used to build the office are illustrated through the (fig), where the floor and walls, and roof from concrete, in addition to the use of insulation in between. As for the window, clear single glass 12mm thickness was used with light aluminum frames.

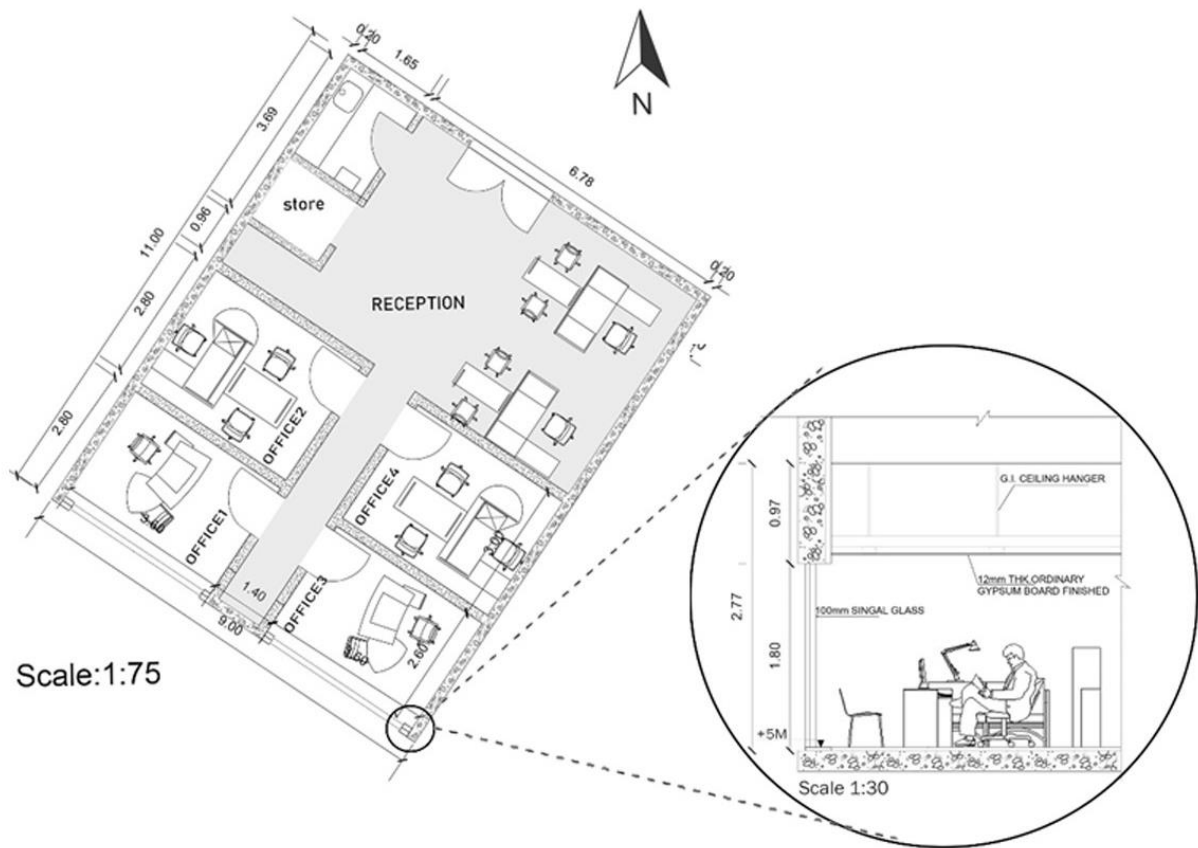


Table 1:Simulation model construction materials

	Material used	Thickness(mm)	Density (Kg/m ²)	Conductivity(kg/m ³)	Category	U-Factor [W/m ² -K]
Roof construction	Concrete	200	2100	1.4	concrete	0.276
	Insulation	120	-	-		
Slab construction	Cast concrete	200	1200	0.4	concrete	0.8191
External floor	Concrete	200	2100	0.4	concrete	
	Screed	30	1200	0.4100	screed	
	Parquet flooring	3.2	112	0.11	Wood flooring	
External walls construction	Concrete	200	2100	1.4	concrete	0.276
	Insulation	120	-	-		
Partition construction	Gypsum	12	950	0.16	plaster	1.366
	Solid wood	78	510	0.12	wood	
	Gypsum	12	950	0.16	plaster	
	Material	Thickness(mm)	Glass Visible Transmittance	Glass SHGC	Inside reflectance	U-Factor [W/m ² -K]
External window	Single glass layer	100mm	0.914	0.905	0.080	5.84

4.4 Office Actual Electricity Bills

Electricity bills for the year 2019 were provided by the office in Figure 24, However there were missing numbers of bills for the rest of the months, thus contacting Dubai Electricity & Water

Authority (Dewa) to provide the rest of the bills. The bills include a summary of the overall electricity consumption from lighting, air conditioning, and electrical equipment for the 12 months. And those bills will use for the validation of the simulation model.

Green Bill
Tax Invoice

Invoice: 100300899623
Issue Date: 10/01/2019
Month: January 2019
Period: 09/12/2018 to 07/01/2019
DEWA VAT No.: 100027620200003

Account Number
2011852544
This number can be used for EasyPay

Account Type
Commercial

Business Partner
10485195

AL SUWAIDI ABIN DHANI ADVOCATES
AL NASR SPORTS CLUB
OFFICE-105 (E&W-SUB METER)
319/3 ST. OUD METHA
Premise Number: 319056171
Premise Type: OFFICE
PO Box: 28523, Dubai, UAE

Page 1 of 3

Bill Summary
Due before 24/01/2019

Dubai Electricity & Water Authority	
Electricity	167.13 AED
Water	23.25 AED
Total	190.38 AED

Dubai Municipality	
Housing	0.00 AED
Sewerage	4.40 AED
Total	4.40 AED

Additional charges: 0.00 AED
Current month total: 194.78 AED
Previous bill balance: 189.10 AED
Adjustments: 0.00 AED
Payments received: 0.00 AED

Figure 24:Law office Electricity bills of the office (Author 2021)

The number of employees in the office is approximately 12 people, so the energy use differs in some months Table 2, especially in June, where energy use was relatively low in the summer and due to relatively less work, the summer vacations for the employees and also in December for the New Year's vacation.

Table 2:Actual electricity bills (Author 2021)

Month	Energy consumption (kWh)
January	2095.04
February	2119.68
March	2266.19
April	2248.35
May	2474.32
June	2287.29
July	2638.43
August	2743.77
September	2684.40
October	2741.01
November	2466.86
December	1997.31

4.5 Base Case Model Validation

The simulation program DIVA 4, which is an energy simulation plugin to Rhinoceros program, was used with Grasshopper and Archsim. The figures below, are showing the setting of the thermal and construction office modeling according to the previous plan and the detailed section that is described for the office. Where the weather file for the city of Dubai was first determined, and then the office was built on the Grasshopper. The thermal profile of the building is the first step that was adjusted as shown in Figure 25 using Archsim, where it included the number of people (12) where the number is divide to the total area (306 m²), in addition, determine the type of space for the electrical equipment and lighting.

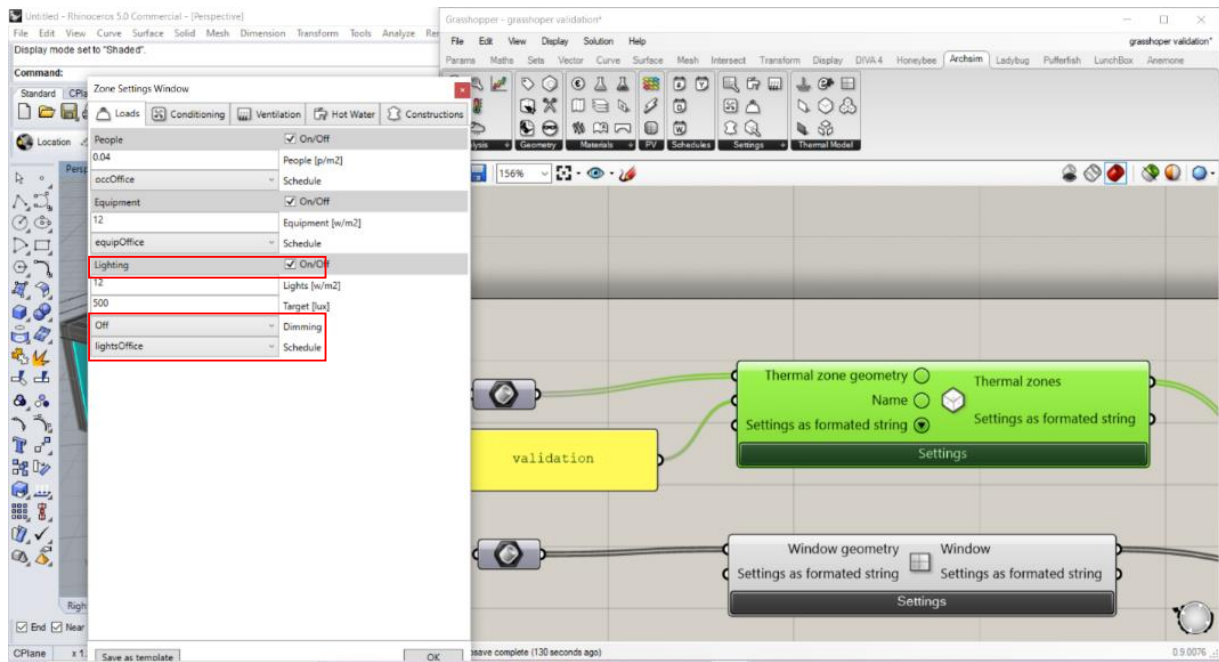


Figure 25: Archism\Grasshopper thermal profile and zone setting (Author 2021)

The Indoor lighting level target is set as 500 LUX in offices and commercial buildings (Talip et al. 2021) and this according to CIE standard which in general rooms the level exceeds 300 LUX however not exceeding 750 LUX (Bunjongjit & Ngaopitakkul 2018). The Dimming is off for this setting since the office is not supplied with it. The construction materials and window setting showing in Figure 26 where have been set according to the detailed section where also, the interior partitions are made of gypsum and wood and single glass clear for the window glazing construction. The final step is to start the energy simulation for the whole year by the energy plus after selecting the output variables (lights electric energy, equipment electric energy and cooling load energy).

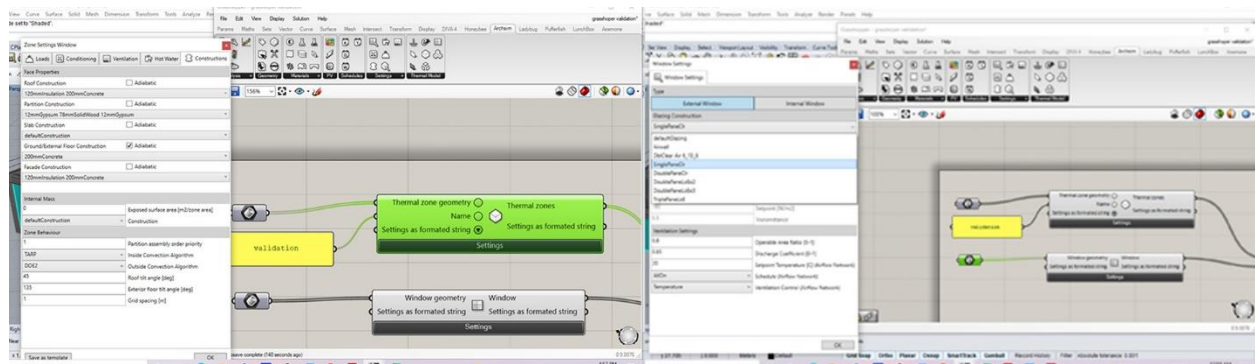


Figure 26:Construction material and energy plus setting (Author 2021)

As mentioned before some of the months has less activity and energy consumption regarding the actual bills so the three months (June, and December) were done with special editing for the thermal where the adjustments of the zone setting included fewer people using the space and less electrical equipment usage. The below Figure 27 showing the data of the validation energy consumption. where the results are almost near from the actual energy bill consumption. since it uses a simulation program, it must to calibrated its performance.

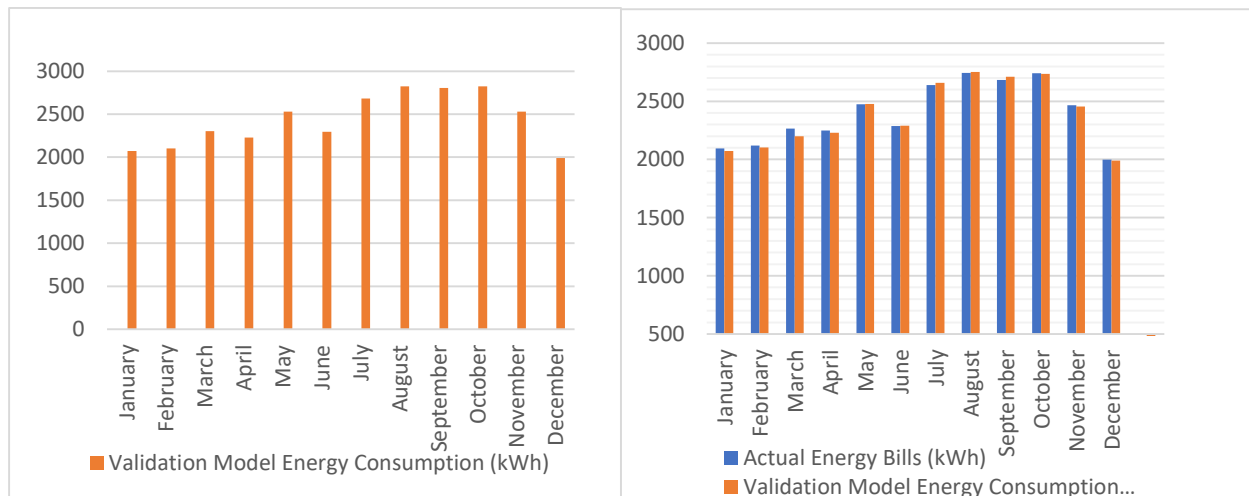


Figure 27:Validation data and comparison with actual energy consumption (Author 2021)

According to ASHRAE 14, section 4.3.2.4 explains how to Compliance the requirements for the entire -Building Calibrated Simulation Performance Path. where the computer validation

model must have CV(RMSE) and NMBE. The CV should have $\pm 15\%$ and NMBE of $\pm 5\%$ proportional to monthly calibration data (ASHRAE Guideline 2014).

Where this is might be useful especially for evaluate the energy building performance of the simulation model. Where Normalized Mean Bias Error is the (NMBE) and the Coefficient of Variation of the Root Mean Squared Error is (CVRMSE) (Cooke 2018).

The formula $NMBE = \frac{\sum_{i=1}^n (y_i - \hat{y}_i)}{(n-p) \times \bar{y}}$ used to calculate as shown in Figure 28 (NMBE) (ASHRAE Guideline 2014) where:

n = numbers of total data

p = number of parameters model, considered to p=1 in this equation

y_i = independent variables which represent the actual data

$\hat{y}_i$ = simulation data

$\bar{y}$ = Mean values of actual data

Note: The equations multiply by 100 to get the percentage

months	actual data	simulation data
January	2095.04	2072.993
February	2119.68	2103.534
March	2266.19	2199.543
April	2248.35	2229.67
May	2474.32	2477.161
June	2287.29	2290.367
July	2638.43	2658.498
August	2743.77	2752.611
September	2684.4	2709.752
October	2741.01	2734.965
November	2466.86	2454.959
December	1997.31	1990.125
SUM	28762.65	28674.18
MEAN	2396.888	

$$\begin{aligned}
 NMBE &= \frac{\sum_{i=1}^n (y_i - \hat{y}_i)}{(n-p) \times \bar{y}} \times 100 \\
 &= \frac{\sum_{i=1}^n (28762.6 - 28674.1)}{(12-1) \times 2396.8} \times 100 \\
 &= \frac{88.5}{26364.8} \times 100 \\
 &= 0.335\%
 \end{aligned}$$

$$\begin{aligned}
 CV(RMSE) &= \frac{\sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{(n-p)}}}{\bar{y}} \times 100 \\
 &= \frac{\sqrt{\frac{\sum (28762.6 - 28674.1)^2}{(12-1)}}}{2396.8} \times 100 \\
 &= \frac{\sqrt{\frac{(88.5)^2}{11}}}{2396.8} \times 100 \\
 &= \frac{26.68}{2396.8} \times 100 \\
 &= 1.13\%
 \end{aligned}$$

Figure 28:NMBE and CV(RMSE) calculation steps (Author 2021)

Also, the formula $CV(RMSE) = \frac{\sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{(n-p)}}}{\bar{y}}$ with the same values of the NMBE formula (ASHRAE Guideline 2014). To solve the equation, the calculation was done manually using the CASIO calculator where the NMBE value 0.33% and the CV(RMSE) value 1.1%. for the value of the $y_i \hat{y}_i \bar{y}$ (mean and sum) for the actual data was done by using excel sheet. As a result, the values achieve the ASHRAE range standards for the calibration of the simulation computer model. Table 3 indicates the percentage difference for each month.

Table 3:Monthly error different percentage (Author 2021)

Months	Actual bills energy consumption(kWh)	Simulation energy consumption(kWh)	Different percentage (%)
January	2095.04	2072.993	1.06
February	2119.68	2103.534	0.77
March	2266.19	2199.543	2.95
April	2248.35	2229.67	0.84
May	2474.32	2477.161	-0.11
June	2287.29	2290.367	-0.13
July	2638.43	2658.498	-0.76
August	2743.77	2752.611	-0.32
September	2684.40	2709.752	-0.94
October	2741.01	2734.965	0.32
November	2466.86	2454.959	0.49
December	1997.31	1990.125	0.36

4.6 Weather data and Profile Setting

Like any energy simulation program, DIVA contains a weather data file based on the country or city climate data file that is included before starting the simulation. The weather data analysis falls under the Archsim plug in Rhino\grasshopper in cooperation with Energy Plus. The tool was used to generate the sun path diagram related to the climate of Dubai and its location in relation to the selected building. As the Figure 29 shows, the side of the windows is exposed to sunlight in particular towards the south and southwest.

The software is made to display the Sun's motion through the sky on any date as seen from any

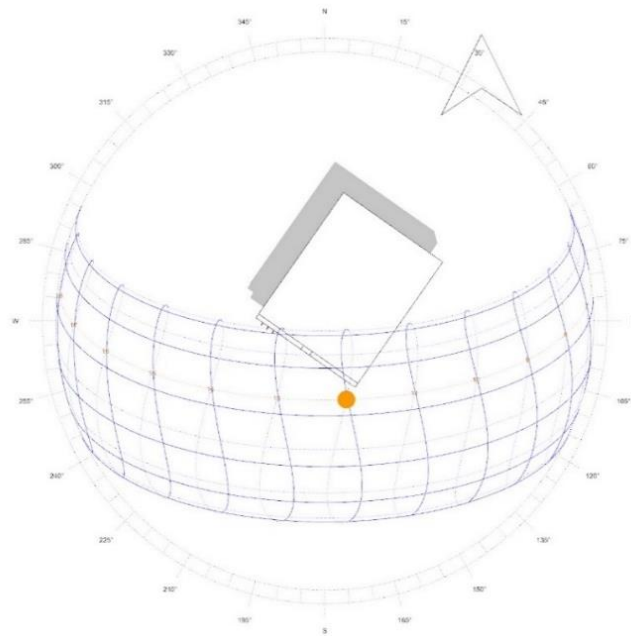


Figure 29:Sun path diagram of Dubai\UAE (DIVA2021)

location on the surface of the world. The observer's latitude and longitude, as well as the time and date of the observation, are the elements that influence the apparent route. Degrees of azimuth and degrees of altitude are used to describe the Sun's location. The user can choose the duration throughout which the path is presented. Since the panels are vertical, the panels move due to the azimuth of the sun. The simulations were done annually.

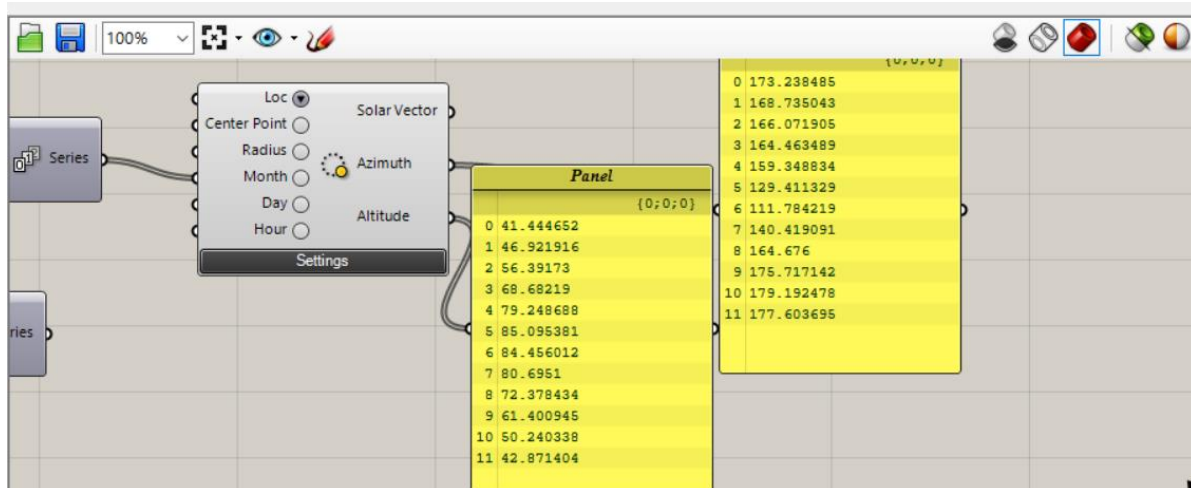


Figure 30:Setting of Dubai sun path (DIVA2021)

The temperature of the dry bulb, as shown Figure 31, is high for the Dubai climate in the summer season, and after the hours of the month of May, where the red color indicates the number of hours during the month in which the temperature exceeds 40C, as in July, by examining 8670 hours during the year.

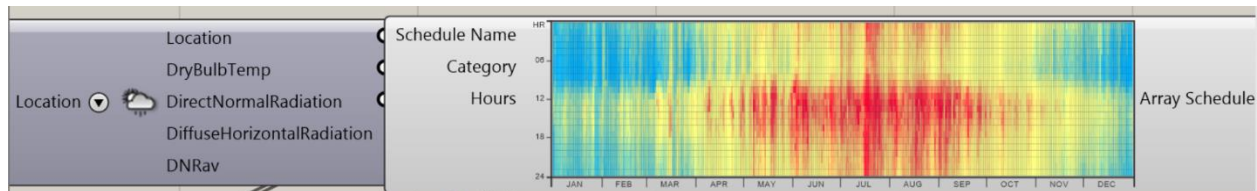


Figure 31: Dry Bulb Temperature of Dubai (DIVA2021)

The Figure 32 shows the exposure of Dubai to direct and indirect sunlight. Where during the year all months, it is exposed to more direct solar radiation between the hours of seven in the morning until three in the afternoon. As for the diffuse solar radiation, its strength increases, as shown in some hours of the spring season (March, April and May). The colors indicate the intensity of the solar radiation, where blue (0 Wh/m^2) and yellow ($20\text{-}100 \text{ Wh/m}^2$) and red ($>600 \text{ Wh/m}^2$).

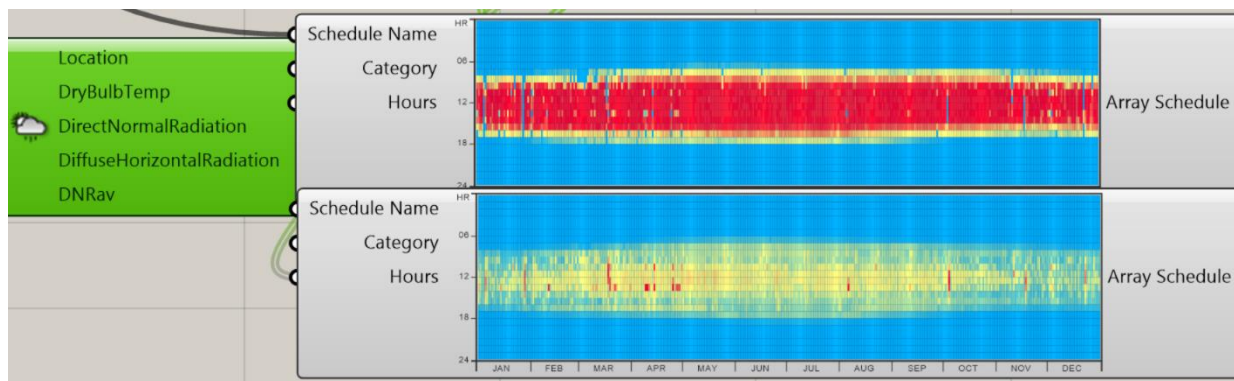


Figure 32: Direct and diffuse solar radiation of Dubai (DIVA2021)

As setting done in Base Case validation stage in Figure 33, the profile selected in thermal zones setting where office thermal zone has been selected which already set the operating system of the office in terms of the consumption of artificial lighting, electrical equipment and air

conditioning during the day and hour, as weekend days are not calculated and the simulation starts from office hours (8 am to 5 pm).

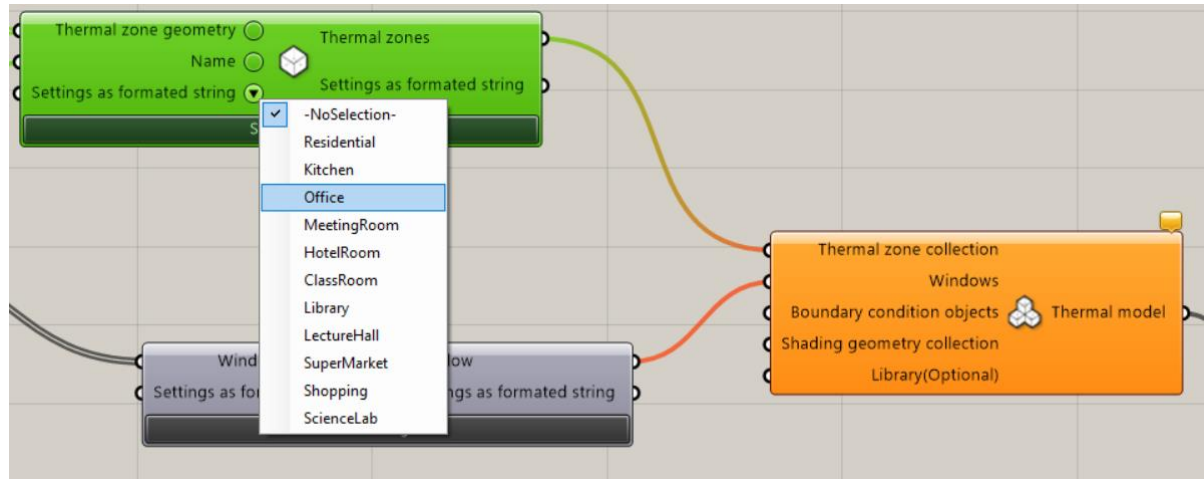


Figure 33: Thermal zone setting (DIVA-Author2021)

4.7 Scenario's Model Setting

The scenarios were selected based on the literature review conducted previously through the research in Chapter 2. Where the type of glass for the windows was chosen to use modern smart glass to reduce the heat gain as shown in Table 4, which is a modern way to reduce the energy consumed by the facades of the buildings. In addition to using solar panels as building facades, glass material is an important step to reduce the heat emitted into the building. Based on the availability of subjects in the program, the selection is qualitative as described below.

Table 4: Glazing properties for simulation (Rhino\Grasshopper2021)

Glass material	Thickness(mm)	Shading Coefficient	Glass SHGC	Glass Visible Transmittance	Glass U-Factor [W/m ² -K]
LowE glass	120	0.60	0.649	0.77	1.507
Tinted Ec 30	120	0.39	0.34	0.43	0.28

Regarding to the PVs panels used, the type of Monocrystalline Silicon was chosen based on the most widely used type currently, as mentioned previously in Chapter 2. The weight of the panels was taken into account, as the type of light weight available in the market was chosen with the

measurements below. Moving to the number of panels, it was based on the size of the window (width 3.6m) and was divided by the size of the panel (width 0.54m). Therefore, the output was 7 panels for each window.

As Figure 34 indicates, the building has a part of building extension of 32cm in around the windows and some parts of the building, as it was used to install the panels, and a sufficient distance was taken between the panels and the window in order to enhance the entry of air for cooling.

Shadows were taken into account during the simulation of the upcoming scenarios, as there was no shadow of a building covering the window. The land Infront the two offices is an open football field. The shadows of the panels were also taken into consideration during the simulation. The panels move with the horizontal direction of the sun from east to west during the year which the panels move within a range of 180 degrees. The angle of 180 is the angle that the panels take when they are in a straight position, completely closed. The arrangement of the panels comes from the right side, the panels of the southern office (1,2,3,4,5,6,7,) and the western office (8,9,10,11,12,13,14).

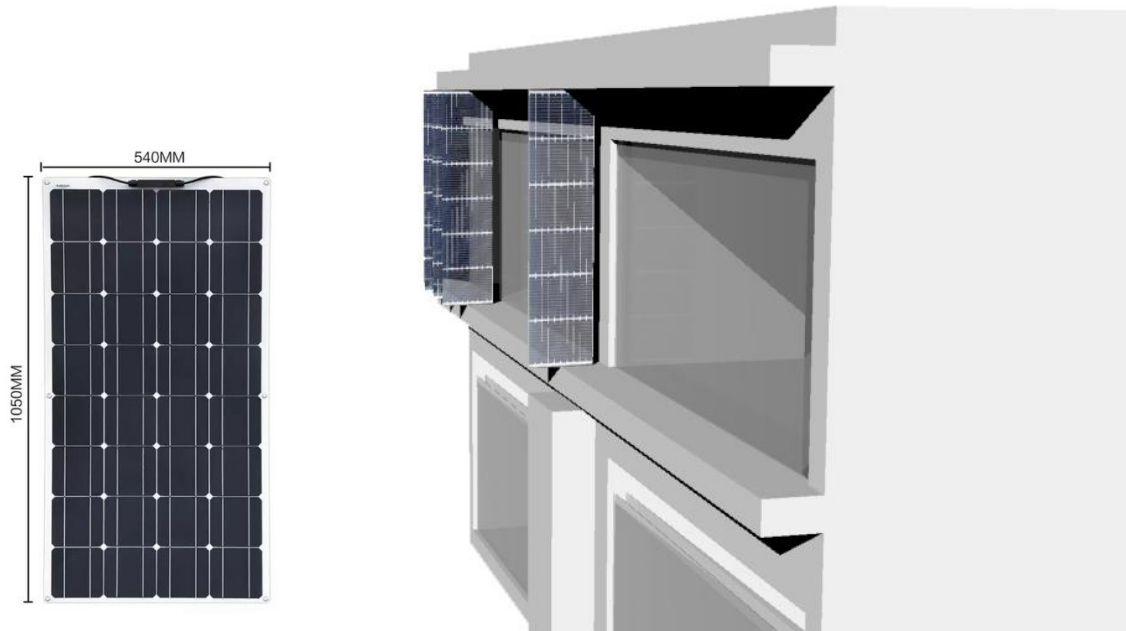


Figure 34:Base Case modeling with PV panels *(Author 2021)*

4.7.1 Scenario 1: PV panels tracking the sun as a group

In this scenario Figure 35, the fourteen panels were set as one layer, meaning that all panels follow the sun's azimuth in a unified system. All panels were set with one layer and were connected to the sun file.

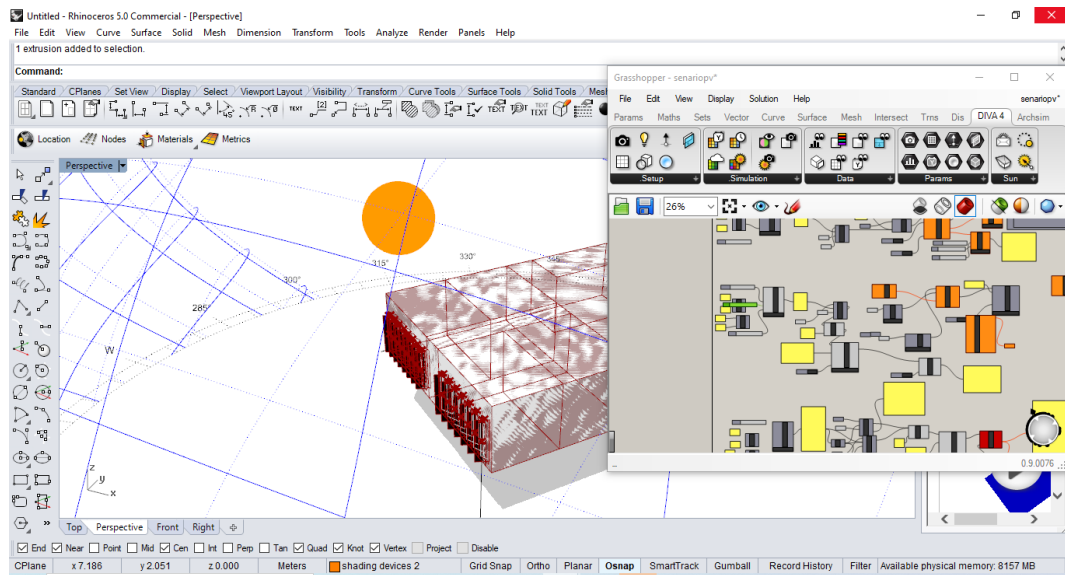


Figure 35: Scenario 1: PV panels tracking the sun as a group (Rhino\Grasshopper2021)

4.7.2 Scenario 2: PV panels tracking the sun as Individual

For the second scenario in Figure 36, the solar panels were reset as individual panels, as they have a single control to follow the sun's azimuth.

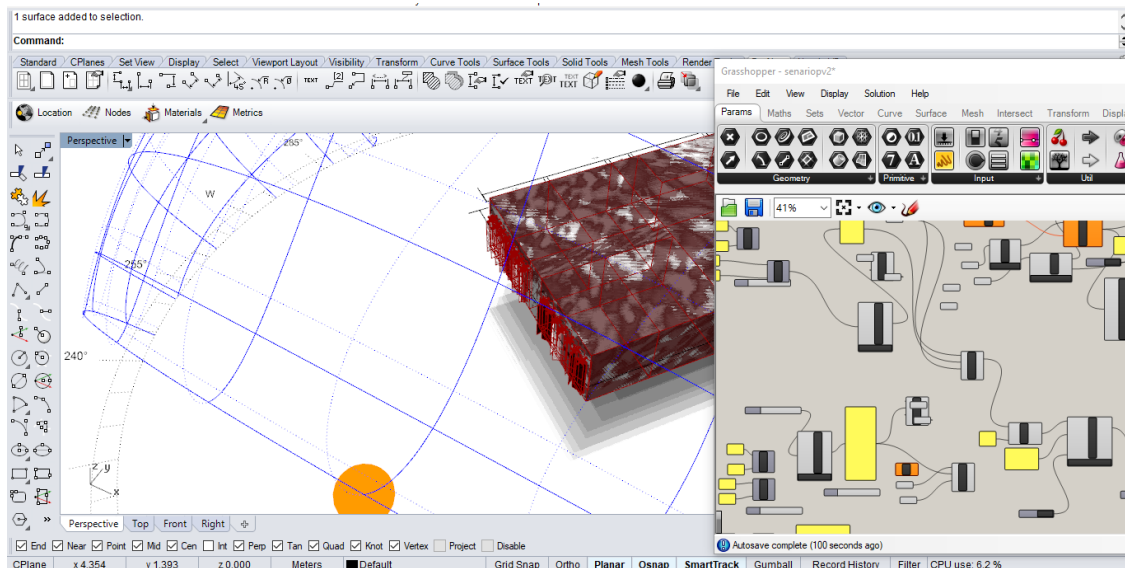


Figure 36: Panels tracking the sun as Individual (Rhino\Grasshopper2021)

4.7.3 Senario3: Fixed and dynamic PV panels

The last scenario, set based on single panels but with fixed angles for some months. The scenario was based on the most frequent angles for the months for the second scenario during the year.

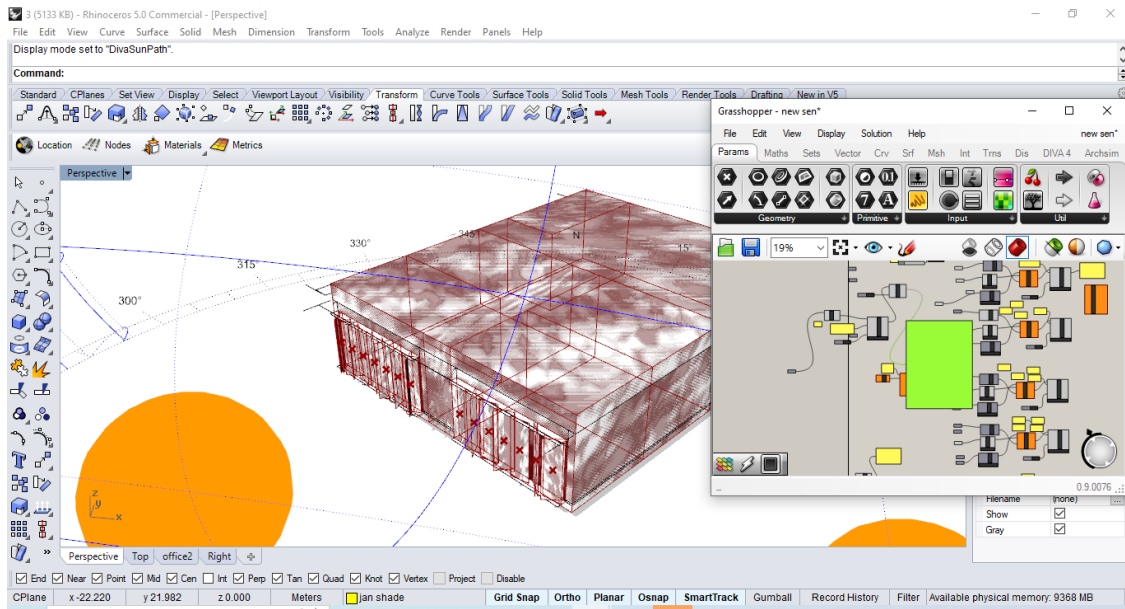


Figure 37: Fixed and dynamic PV panels (Rhino\Grasshopper2021)

4.8 Simulation Scenarios Configuration

The performance Simulation Scenarios Configuration of the panels was verified through five aspects of the performance of the solar panels and their impact on the performance of cooling energy, lighting and electricity generation, in addition to the use of smart glass for windows by studying different situations as shown in Table 5. The difference between states is made possible by changing the following variables:

- Office window orientation
- Panel angles and numbers
- The type of glass

The simulation runs for a full year based on monthly profile. Creating monthly profiles for the calculation of cooling and electricity capacity. As for the luminance study, the analysis was done for a peak day and hour of each month. Where the days and hours were determined according to the program for the brightest hours of the day.

Note: The lighting control system (Diming system) was operated throughout the simulation, except in the Base case, no control was used.

Table 5:Simulation case matrix (Author2021)

		South Office				Southwest Office			
All months		Base Case	Scenario 1 LowE glass	Senario2 LowE glass	Senario3 LowE glass	Base Case	Scenario 1 EC tinted glass	Senario2 EC tinted glass	Senario3 EC tinted glass
Winter	luminance	x	x	x	x	x	x	x	x
	Lighting energy	x	x	x	x	x	x	x	x
	Cooling load	x	x	x	x	x	x	x	x
	Energy Consumption	x	x	x	x	x	x	x	x
	Generate Energy		x	x	x		x	x	x
spring	luminance	x	x	x	x	x	x	x	x
	Lighting energy	x	x	x	x	x	x	x	x
	Cooling load	x	x	x	x	x	x	x	x
	Energy Consumption	x	x	x	x	x	x	x	x
	Generate Energy		x	x	x		x	x	x
summer	luminance	x	x	x	x	x	x	x	x
	Lighting energy	x	x	x	x	x	x	x	x
	Cooling load	x	x	x	x	x	x	x	x
	Energy Consumption	x	x	x	x	x	x	x	x
	Generate Energy		x	x	x		x	x	x
Autumn	luminance	x	x	x	x	x	x	x	x
	Lighting energy	x	x	x	x	x	x	x	x

	Cooling load	x	x	x	x	x	x	x	x
	Energy Consumption	x	x	x	x	x	x	x	x
	Generate Energy		x	x	x		x	x	x

CHAPTER 5 : SIMULATION RESULTS AND DISCUSSION

This Chapter presents the results from all the stimulation of the configurations outlined in the previous Chapter.

The first section will discuss the results from the six BIPV Facade test cases mentioned in chapter four. A discussion of these findings will form the reasoning of the selection process and the final model chosen for the comparison of the six modeling in terms of comfort visualization, lighting energy, cooling load, and electricity generated by PVs.

5.1 Comfort visualization

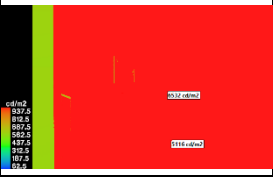
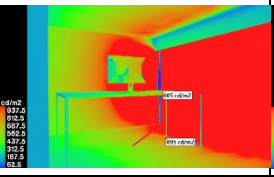
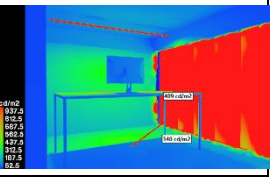
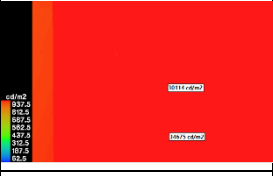
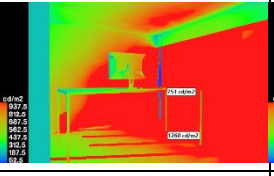
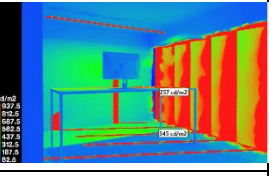
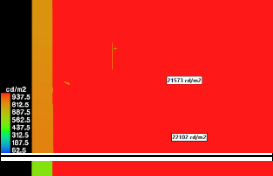
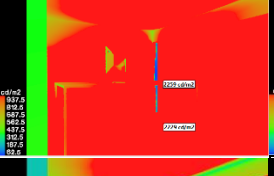
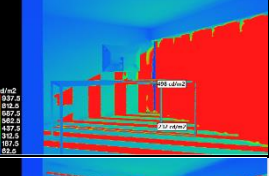
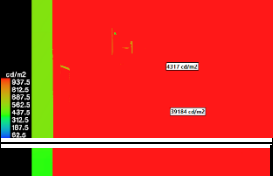
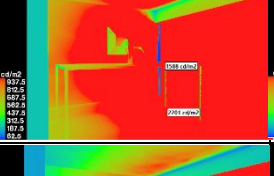
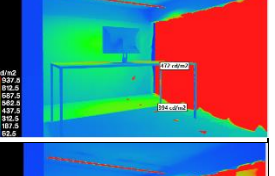
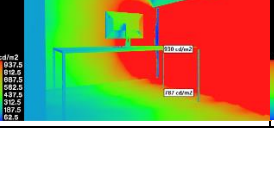
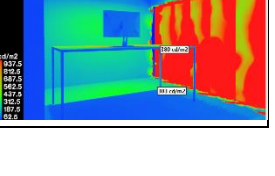
Daylight illuminance is one of the most important factors that affect visual comfort. Where the daylight varies according to the design, the space, and the external and internal environment. In this section, the daylight results of the building will be verified for each of the two offices. Although particular illuminance values for daylighting have so far to be specified. However, there is enough evidence in the literature to suggest that illuminances in the 100-3000 lux range are likely to result in significant reductions in electric lighting usage (Andersen 2014). Where the 300-3000 lux range is acceptable illuminance for daylight, yet exceeds the range need to use exterior devices to control glare (Ji 2020). For visual tasks, CIBSE recommends that light levels should not be exceeding 1000lux whereas office places required 300-500lux(Andersen 2014). There are four degrees of glare discomfort that experimental research findings where the discomfort luminance starts above 1000cd/m² and the high level of luminance are 10,000cd/m²(Fotios & Kent 2021). Since the office space is small in relation to the size of the window, the window formed an uncomfortable glare in relation to the scope of work inside the office, and therefore the internal space will be analyzed in terms of the glare effect from daylight windows for three different scenarios and glazing materials. Also, the Diming system has been used in this simulation.

5.1.1 South Office Scenario 1: PV panels tracking the sun as a group

The Table 6 shows All luminance maps to evaluate glare that values to for the Base Case months are high, as they exceeded 1000cd/m², whereas the highest luminance was in December. The brightness decreased more than 50% after using the dynamic PV blinds, as it recorded for

December values suitable for visual comfort within the range 300-500cd/m² in both glass materials, while for March, April, July, August, October, and November the values exceed 1000cd/m² in the area near the window for Low E glass case. For EC Tinted glass the high glare of the window was also reduced better than the first case, as shown. Where the lighting was distributed to the entire office in a better way, due to use Diming system besides daylight. The lights switch off in the first glass case while on in the second case. The range of values for most of the months was between the level of 300-600cd/m² expect march and November which record 800 cd/m². In addition to a high level of glare reflected on the wall and floor.

Table 6: Visual comfort and Glare for Scenario 1 South office (Author2022)

Visual comfort and Glare for Scenario 1 South office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	Low E glass	EC Tinted 30 glass
January	27	16	154.2°			
February	01	12	52.2°			
March	14	16	86.4°			
April	16	17	116.3°			
May	11	15	49.9°			

June	22	14	151.4 ₀	
July	05	16	76.3 ₀	
August	28	15	55.7 ₀	
September	28	17	105.6 ₀	
October	30	17	39.1 ₀	
November	22	17	173.6 ₀	
December	04	17	84.9 ₀	

The glare reduction percentage over base case showed in Table 7 that the reduction of Low E glass and PV scenario 1 ranked between 20% to 90% The values were taken from the work area (office table). Where December reduction percentage 92.4% and June for 88.7%. However, for March and November 24.5% -26.2% reduction, while Tinted glass reduction ranked more than 70% for all months. Starting with January and April reduction by 89.7%- 89% followed by May and December 91.3%-91.5%. As most of the months during the year recorded the values of the

optical comfort visualization which not exceeding luminance 500 cd/m^2 and not less than 300 cd/m^2 for case Tinted 30 glass.

Table 7:South office Scenario1's Luminance levels (Author2021)

South office of Scenario1's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m2)	Low E glass levels(cd\m2)	EC Tinted 30 glass levels(cd\m2)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16p m	4000	895	409	77.62%	89.77%
February	01	12p m	3000	1260	345	58%	88.50%
March	14	16p m	2994	2259	898	24.54%	70.00%
April	16	17p m	4300	1588	472	63.06%	89.02%
May	11	15p m	4380	787	380	82.03%	91.32%
June	22	14p m	3022	339	443	88.78%	85.34%
July	05	16p m	4000	1600	480	60.00%	88.00%
August	28	15p m	3921	1581	517	59.67%	86.81%
September	28	17p m	3400	974	419	71.35%	87.67%
October	30	17p m	2500	1408	600	43.68%	76.00%
November	22	17p m	4000	2951	800	26.22%	80.00%

December	04	17p m	4551	343	383	92.46%	91.58%
Average			3672.33	1332.08	512.16	62.28%	85.33%

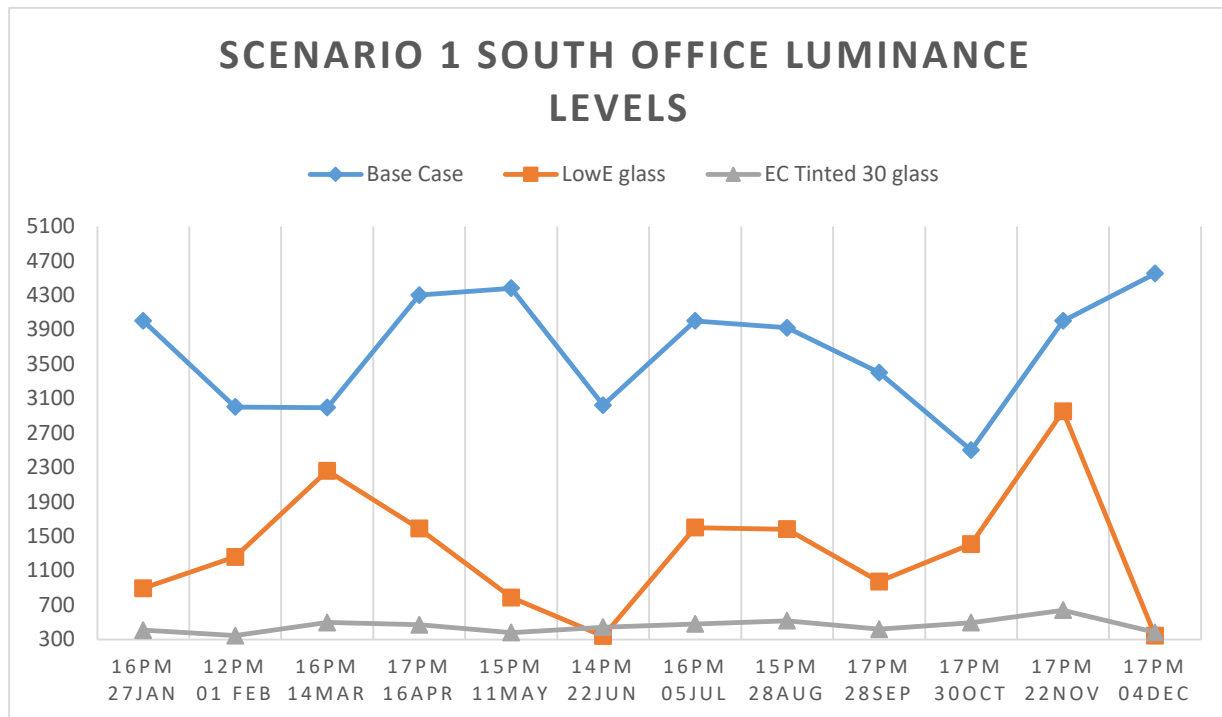


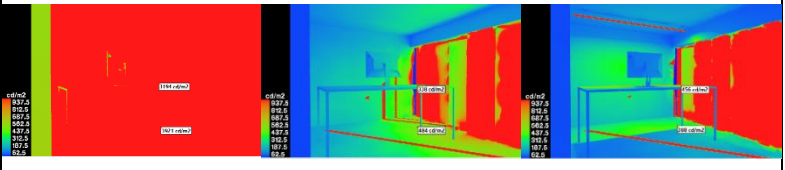
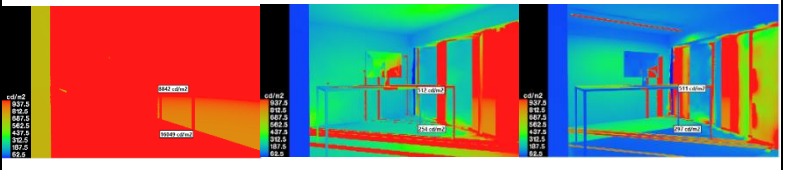
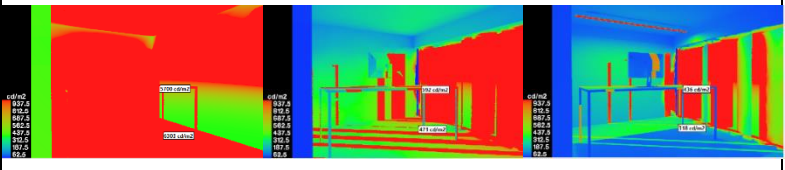
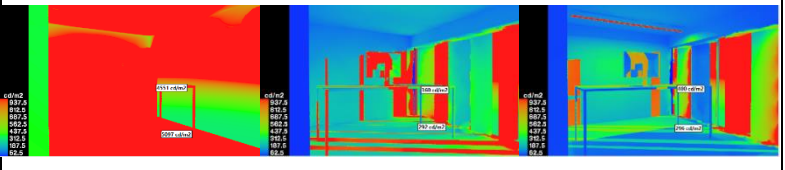
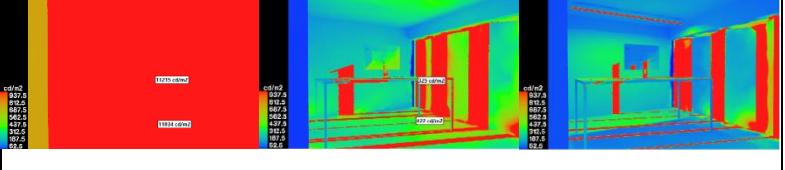
Figure 38:South office diagram of scenario1's Luminance levels (Author2021)

5.1.2 South Office Scenario 2: PV panels tracking the sun as Individual

Moving to scenario 2, the visualization glare maps showed better results where the level of glare is significantly reduced comparing to Base case for both cases, especially for case LowE glass. Maps indicate that the glare in most months of the year is within the required level (not exceeding 1000 cd/m²) for visual comfort. However, there are some months that reflected high glare on the floor as September and October. For the second glass case, the value of glare on the window has been reduced compared to the first case as well. Consequently, most of the months were within the required level of visual comfort. High glare reflection has also been reduced for both September and October.

Table 8: Visual comfort and Glare for Scenario 2 South office (Author2021)

Visual comfort and Glare for Scenario 2 South office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	Low E glass	EC Tinted 30 glass
January	27	16	49.0°			
			91.0°			
			168.1°			
			66.5°			
			154.5°			
			3.34°			
			16.9°			
February	01	12	101.4°			
			15.0°			
			175.9°			
			125.2°			
			26.4°			
			107.1°			
			21.2°			
March	14	16	133.6°			
			8.3°			
			42.1°			
			62.4°			
			112.1°			
			131.5°			
			175.9°			
April	16	17	26.9°			
			58.4°			
			180°			
			121.4°			
			61.3°			
			68.3°			
			2.2°			
May	11	15	86.4°			
			147.1°			
			86.8°			
			87.6°			
			67.5°			
			118.0°			
			30.1°			
June	22	14	180.0°			
			139.1°			
			167.6°			
			49.3°			
			128.0°			
			83.0°			
			164.5°			
July	05	16	2.1°			
			44.9°			
			175.8°			
			151.8°			
			63.0°			
			158.1°			

			166.5°	
August	28	15	92.4°	
			2.7°	
			170.8°	
			114.1°	
			104.9°	
			32.2°	
			13.1°	
September	28	17	158.8°	
			59.3°	
			155.7°	
			43.7°	
			97.5°	
			137.3°	
			169.1°	
October	30	17	94.4°	
			115.9°	
			47.2°	
			97.8°	
			109.5°	
			149.1°	
			2.6°	
November	22	17	130.7°	
			174.3°	
			167.7°	
			8.4°	
			87.9°	
			142.6°	
			172.6°	
December	04	17	9.2°	
			72.2°	
			173.4°	
			142.9°	
			138.5°	
			46.2°	
			11.7°	

As for the Table 9 below, it shows the values that were taken from a source close to the window for the work area. Whereas, the values of the first case of glass formed a noticeable decline compared to the basic case, due to the movement of the panels in a single way, which facilitated the control of daylight reflecting on the glass, as the ratios ranged between 70%-90% In addition, as is the case in the first scenario, the first glass case, the lights were not turned on during the simulation. The highest decrease was observed of July, followed by May, with a value of 91.4%-88.6%. As for the second glass, all the values during the year did not exceed 550cd/m² at the

work area, and the glare was completely controlled in the office area, and the percentage compared to the Base case was between 80%-90%.

Table 9:South office Scenario2's Luminance levels (Author2021)

South office of Scenario2's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m2)	LowE glass levels(cd\m2)	EC Tinted 30 glass levels(cd\m2)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16pm	4000	712	436	82.20%	89.10%
February	01	12pm	3000	813	308	72.90%	89.73%
March	14	16pm	2994	937	472	68.70%	84.23%
April	16	17pm	4300	568	479	86.79%	88.86%
May	11	15pm	4380	499	426	88.60%	90.27%
June	22	14pm	3022	400	358	86.76%	88.15%
July	05	16pm	4000	344	378	91.40%	90.55%
August	28	15pm	3921	530	456	86.48%	88.37%
September	28	17pm	3400	687	600	79.79%	82.35%
October	30	17pm	2500	900	536	64.00%	78.56%
November	22	17pm	4000	700	400	82.50%	90.00%
December	04	17pm	4551	582	450	87.21%	90.11%
Average			3672.33	639.33	441.58	82.44%	87.92%

The Figure 39 for the second scenario below indicates the difference between the values of the base case and the first and second glass cases, where the glare was significantly reduced by using different angles for each solar panel of the office façade. The summer and spring seasons achieved visual comfort values for each of the two glass cases, while the values in the first glass case (Low E glass) were more than 550cd/m² for the autumn, January and February of winter seasons.

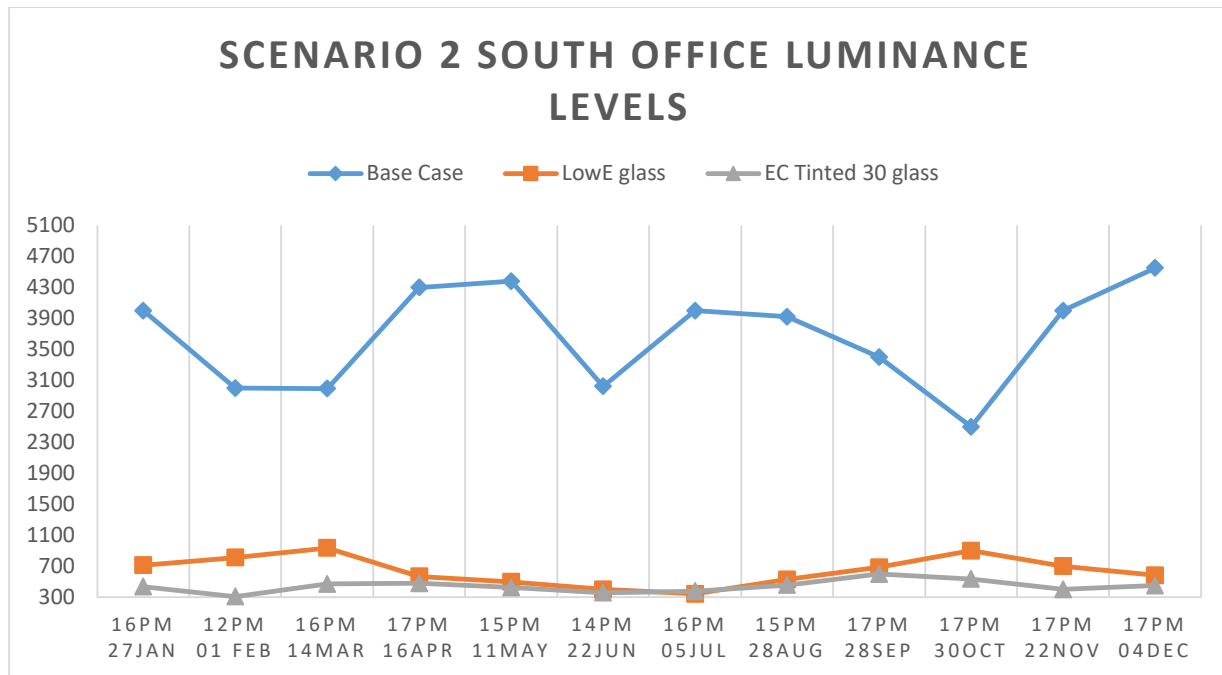


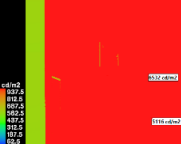
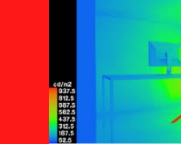
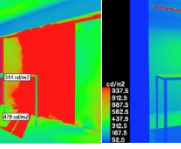
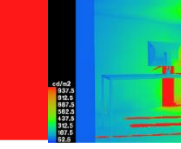
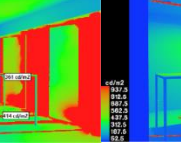
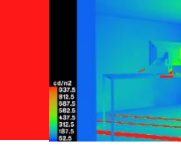
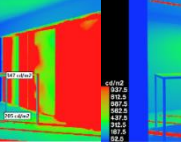
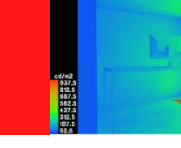
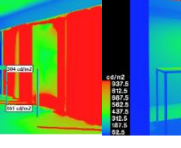
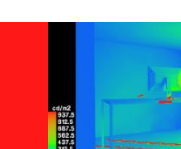
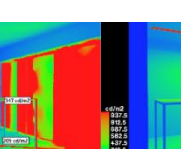
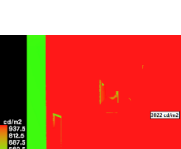
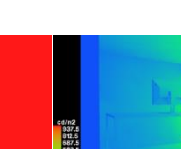
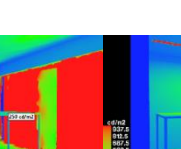
Figure 39:South office diagram of scenario2's Luminance levels (Author2021)

5.1.3 South Office Senario3: Fixed and dynamic PV panels

In this scenario, due to the use of fixed panels with moving panels during the year, the glare of the first glass case was within the required range for visual comfort for all months which not exceeding the 550cd/m², in addition to significantly reducing the glare on the window in both cases. Glare has been reduced compared to the original case, as shown in Table 10. The maps of the two glass cases are shown with a degree of convergence of the results from the visual point of view, where the work area for the first case is very good in terms of daylight as artificial lighting was not used, nevertheless in the second case the lamps were turned on to maintain the extent of visual comfort in a manner distributed over the office space. In addition, there is a high

glare reflected on the work areas in the fall season for the Lowe glass case, as it was reduced in the EC Tinted 30 glass case.

Table 10: Visual comfort and Glare for Scenario 3 South office (Author2022)

Visual comfort and Glare for Scenario 3 South office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	Low E glass	EC Tinted 30 glass
January	27	16	133.6°			
			58.4°			
			173.4°			
			125.2°			
			164.3°			
			68.3°			
			175.9°			
February	01	12	133.6°			
			58.4°			
			173.4°			
			151.8°			
			63.0°			
			30.2°			
			175.9°			
March	14	16	9.2°			
			44.9°			
			175.9°			
			49.3°			
			158.9°			
			160.1°			
			175.9°			
April	16	17	9.2°			
			44.9°			
			150.7°			
			49.3°			
			30.1°			
			160.1°			
			175.9°			
May	11	15	9.2°			
			44.9°			
			170.5°			
			49.3°			
			120.2°			
			160.1°			
			175.9°			
June	22	14	133.6°			
			40.3°			
			170.5°			
			49.3°			
			37.8°			
			160.1°			
			175.9°			
July	05	16	180°			

			40.3°			
			170.5°			
			142.9°			
			37.8°			
			145.1°			
			175.9°			
August	28	15	9.2°			
			20.2°			
			170.5°			
			100.8°			
			20.8°			
			32.2°			
September	28	17	175.9°			
			165.3°			
			23°			
			170.5°			
			175.9°			
			22.4°			
October	30	17	158.1°			
			175.9°			
			165.3°			
			44.1°			
			89.8°			
			151.8°			
November	22	17	35.9°			
			170°			
			150.2°			
			160°			
			44.1°			
			168.1°			
December	04	17	151.8°			
			154.5°			
			170°			
			150.2°			
			160°			
			20.2°			
			168.1°			
			151.8°			
			159.3°			
			160.1°			
			175.9°			

The percentage in Table 11 of reduction compared to the Base case for both cases is more than 80%, as the table below indicates the values on the work area. The highest percentage of reduction was for the month of December, followed by sum August, April, July and September for the first glass case. As for the second glass case, the summer season, the percentage of reduction is also 90%.

Table 11:South office Scenario3's Luminance levels (Author2022)

South office of Scenario3's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m2)	LowE glass levels(cd\m2)	EC Tinted 30 glass levels(cd\m2)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16pm	4000	479	470	88.02%	88.25%
February	01	12pm	3000	562	495	81.26%	83.50%
March	14	16pm	2994	380	366	87.30%	87.77%
April	16	17pm	4300	361	388	91.60%	90.97%
May	11	15pm	4380	500	419	88.58%	90.43%
June	22	14pm	3022	400	459	86.76%	84.81%
July	05	16pm	4000	380	400	90.50%	90.00%
August	28	15pm	3921	300	381	92.34%	90.28%
September	28	17pm	3400	313	300	90.79%	91.17%
October	30	17pm	2500	440	447	82.40%	82.12%
November	22	17pm	4000	552	461	86.20%	88.47%
December	04	17pm	4551	312	400	93.14%	91.21%
Average			44068	414.91	415.50	88.24%	88.25%

The Figure 40 indicates the convergence of the results between the first glass case and the second case when using the third scenario, in addition to the comparison with the Base case. The values did not exceed 500cd\m2 throughout the year, as they were almost constant.

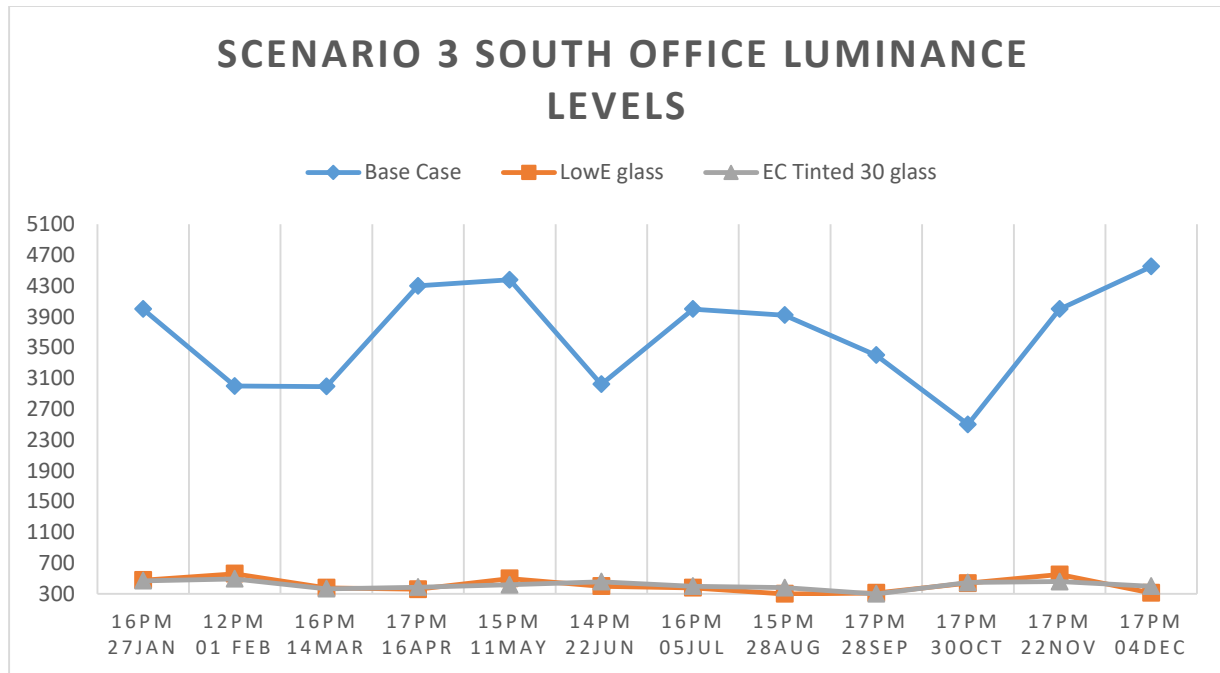
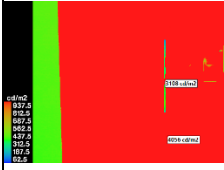
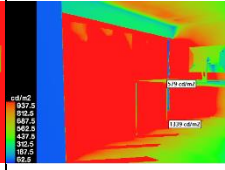
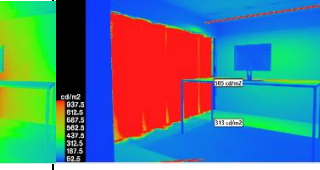
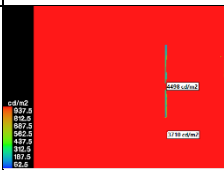
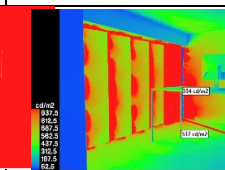
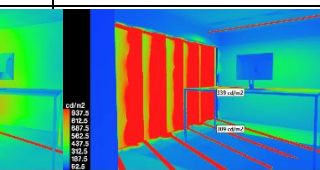
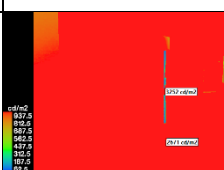
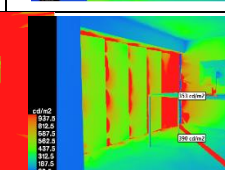
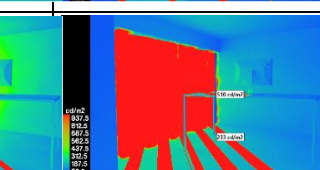
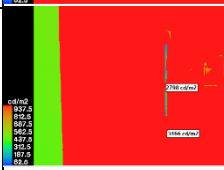
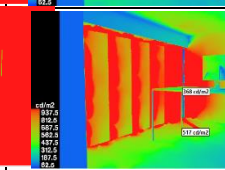
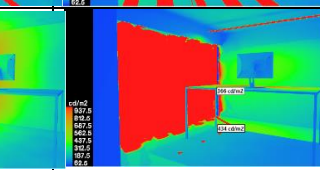
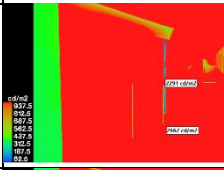
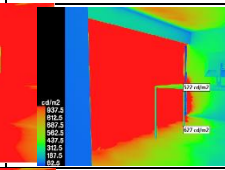
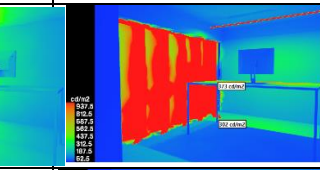
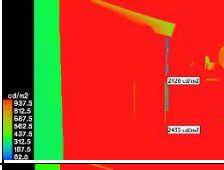
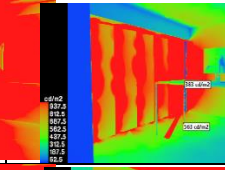
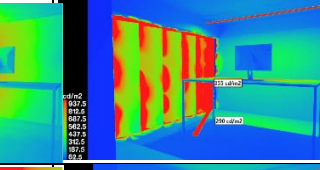
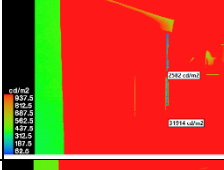
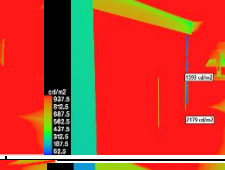
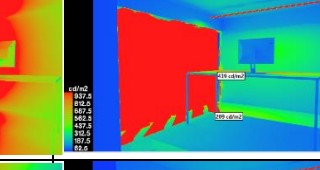
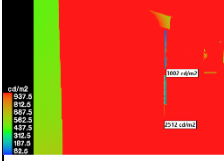
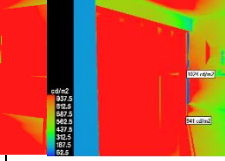
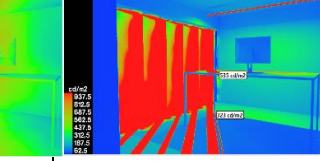


Figure 40:South office diagram of scenario3's Luminance levels(Author2022)

5.1.4 South West Office Scenario 1: PV panels tracking the sun as a group

For the southwest office, the glare was less for the first glass case than for the southern office, where the highest cases of glare that exceeded 1000cd/m² were observed in October, November, July, August, and January as shown in Table12. A high glare was also detected from the case window of the first glass of May. In the case of the second glass, the values of the work area do not exceed 1000cd/m², as most of the values are within the required level except March, August, followed by October, especially the area near the window. A high glare was also observed in the window area.

Table 12: Visual comfort and Glare for Scenario 1 South West office (Author2022)

Visual comfort and Glare for Scenario 1 South West office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	LowE glass	EC Tinted 30 glass
January	27	16	154.2°			
February	01	12	52.2°			
March	14	16	24.7°			
April	16	17	116.7°			
May	11	15	49.9°			
June	22	14	145.2°			
July	05	16	75.1°			
August	28	15	54.5°			

September	28	17	104.9°			
October	30	17	12.0°			
November	22	17	172.9°			
December	04	17	83.8°			

The Table13 below indicates the percentage of reduction with the Base Case. The lowest percentage of reduction is 13% for November in the first glass case, while the highest percentage of reduction is 87.79% for February followed by 84.10% for December. As for the second glass case, the reduction rate ranged from 73% to 88%. The lowest percentage of decline was 73.32% for October, followed by August. The highest percentage of decrease was in December, followed by February, at a percentage of 88.80% - 85.45%.

Table 13:South West office Scenario1's Luminance levels(Author2022)

South West office of Scenario1's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m2)	LowE glass levels(cd\m2)	EC Tinted 30 glass levels(cd\m2)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16pm	3018	900	505	70.17%	83.26%
February	01	12pm	4400	537	640	87.79%	85.45%
March	14	16pm	3252	600	800	81.54%	75.39%
April	16	17pm	3466	750	600	78.36%	82.68%
May	11	15pm	2261	627	373	72.26%	83.50%
June	22	14pm	2400	687	400	71.37%	83.33%
July	05	16pm	4020	1593	500	60.37%	87.56%
August	28	15pm	3002	1024	800	65.88%	73.35%
September	28	17pm	4900	1196	622	75.59%	87.30%
October	30	17pm	4228	1143	667	72.96%	73.32%
November	22	17pm	3000	2600	634	13.33%	78.86%
December	04	17pm	4021	639	450	84.10%	88.80%
Average			3487.33	1041.33	582.58	70.13%	83.29%

The chart shows the difference between before and after the use of solar panels for both types of glass. There are still values higher than 1000cd\m2 for the case of the first glass, such as the autumn months of September, October and November, in addition to the summer months of July

and August. While in the second case of glass, all values are under 1000cd/m², while there are only two months that recorded 800 cd/m², specifically March and August.

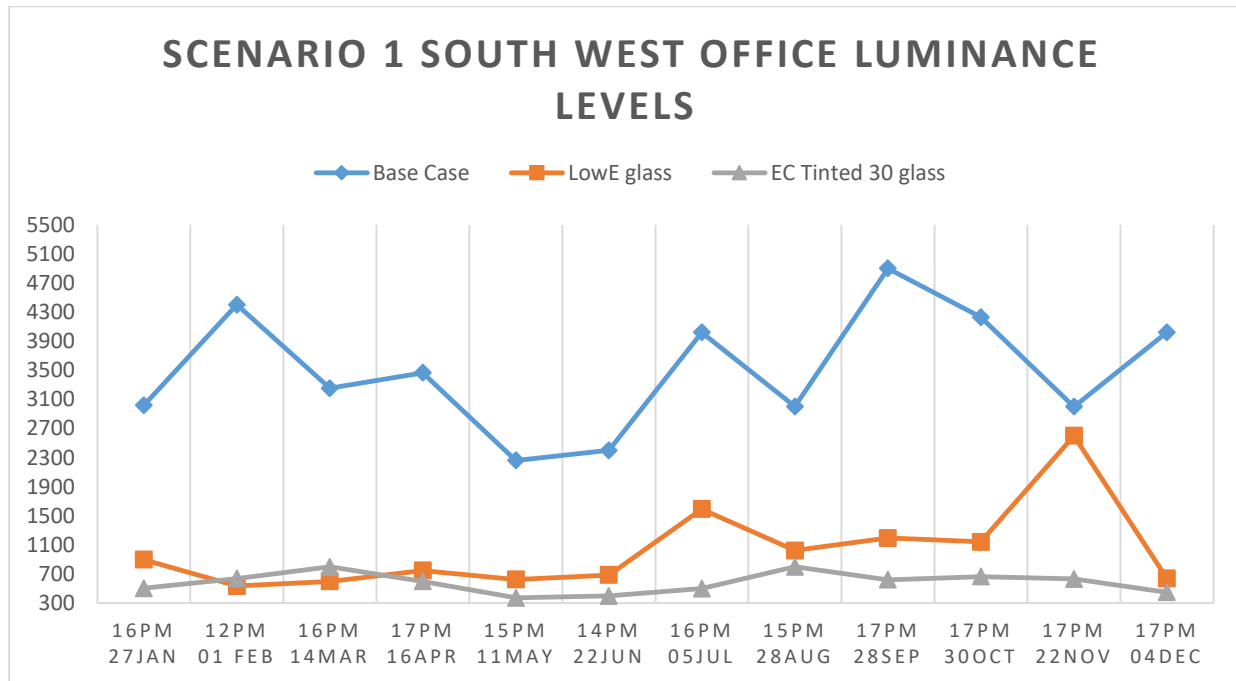


Figure 41: Southwest office diagram of scenario1's Luminance levels (Author2022)

5.1.5 South West Office Scenario 2: PV panels tracking the sun as Individual

Regard to this scenario Table14, the maps indicate that the results are almost comparable in both cases for glass, with some differences shown below. In the case of the first glass, the artificial lighting was not turned on, as daylight was relied upon, however there is a high glare on the floor for February, October and December, in addition to a high glare for the glass in most months. While the second case, the artificial lighting was turned on, as there is a good distribution of lighting over the entire office, in addition to reducing the reflection on the floor of the high glare and lowering it on the window. Except for February and May, where the glare on the glass was higher than the first case.

Table 14: Visual comfort and Glare for Scenario 2 South West office (Author2022)

Visual comfort and Glare for Scenario 2 South West office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	LowE glass	EC Tinted 30 glass
January	27	16	91.3°			
			169.2°			
			65.9°			
			154.2°			
			3.1°			
			129.4°			
February	01	12	16.9°			
			15.5°			
			177.2°			
			124.0°			
			26.4°			
			107.2°			
March	14	16	32.1°			
			20.7°			
			62.4°			
			114.5°			
			30.7°			
			51.2°			
April	16	17	20.1°			
			50.5°			
			175.3°			
			21.5°			
			173.4°			
			159.6°			
May	11	15	168.1°			
			144.7°			
			38.4°			
			157.8°			
			107.2°			
			139.5°			
			165.5°			

			138.1°			
			45.8°			
			145.9°			
			6.2°			
June	22	14	7.9°			
			101.5°			
			45.8°			
			3.4°			
			32.9°			
			100.5°			
			151.8°			
July	05	16	16.1°			
			23.5°			
			161.5°			
			78.6°			
			22.3°			
			134.6°			
			180°			
August	28	15	10.9°			
			165.9°			
			23.1°			
			133.2°			
			171.2°			
			24.5°			
			12.8°			
September	28	17	176.3°			
			95.9°			
			16.9°			
			57.9°			
			92.9°			
			180°			
			72.4°			
October	30	17	66.2°			
			149.3°			
			29.1°			
			70.1°			
			12.9°			
			104.5°			
			46.6°			
November	22	17	6.4°			
			60.9°			
			8.3°			
			63.1°			
			10.4°			
			152.2°			
			121.9°			
December	04	17	12.2°			
			95.2°			
			158.6°			
			147.2°			
			142.1°			
			36.2°			
			141.5°			

The percentage of glare reduction is shown in Table 15, as September achieved 90% for the first glass case and 93.20% for the second glass case. followed by October 90.06% and 91.01%. The lowest percentage is 70% for June, while in the case of the second glass it is 74.78% for May. The Figure 42 indicates that the results of the two cases of glass are somewhat similar, except for February and June, that the values of the first glass were more than 500. As for drawing the values of the second case, they are slightly constant between 300cd/m² and 500cd/m².

Table 15: Southwest office Scenario2's Luminance levels (Author2022)

Southwest office of Scenario2's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m ²)	LowE glass levels(cd\m ²)	EC Tinted 30 glass levels(cd\m ²)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16pm	3018	330	441	89.06%	85.38%
February	01	12pm	4400	900	600	79.54%	86.36%
March	14	16pm	3252	580	550	82.16%	83.08%
April	16	17pm	3466	540	505	84.42%	85.42%
May	11	15pm	2261	620	570	72.57%	74.78%
June	22	14pm	2400	720	523	70.00%	78.20%
July	05	16pm	4020	600	510	85.07%	87.31%
August	28	15pm	3002	500	568	83.34%	81.07%
September	28	17pm	4900	470	333	90.40%	93.20%
October	30	17pm	4228	420	380	90.06%	91.01%

November	22	17pm	3000	347	395	88.43%	86.83%
December	04	17pm	4021	680	570	83.08%	85.82%
Average			3487.33	558.91	495.41	83.97%	85.79%

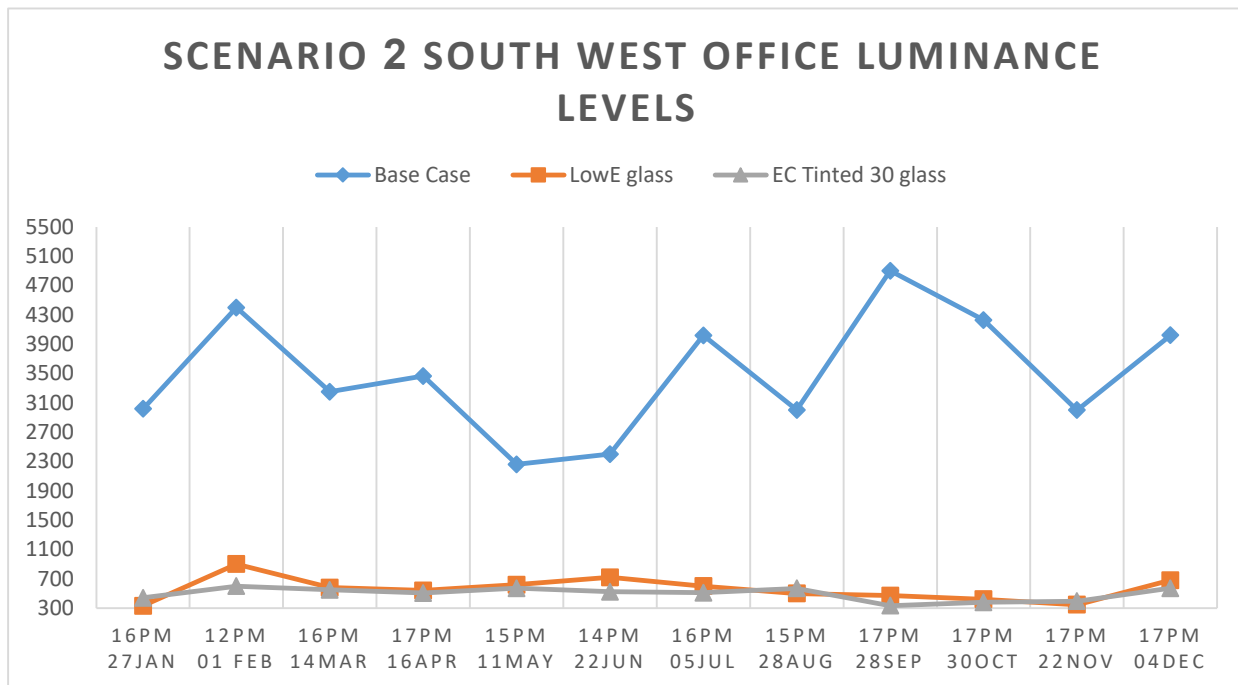
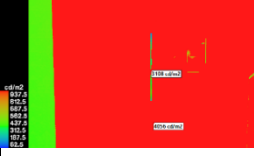
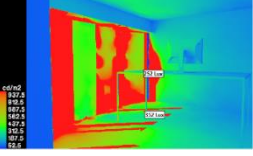
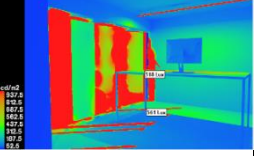
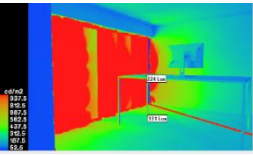
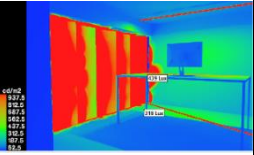
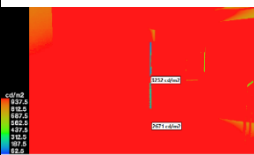
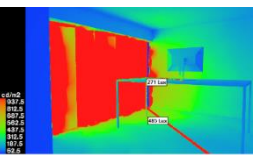
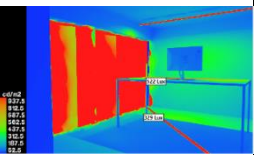
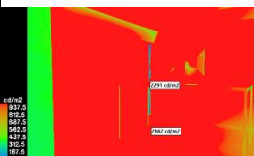
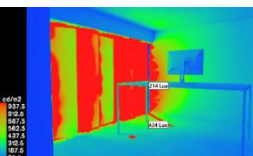
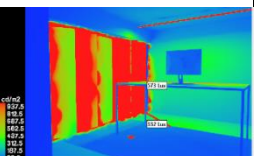
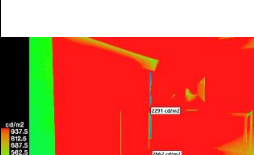
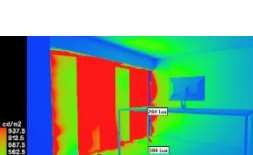
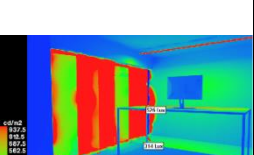
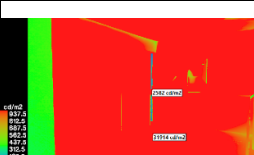
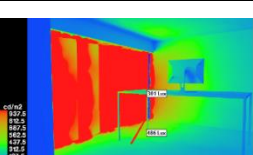
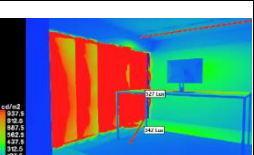
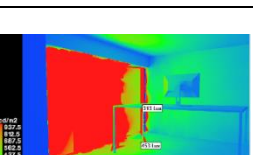
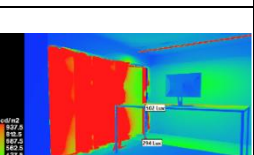


Figure 42:Southwest office diagram of scenario2's Luminance levels (Author2022)

5.1.6 South West Office Senario3: Fixed and dynamic PV panels

In this scenario, the glare maps are very similar, as the differences are in artificial lighting, lighting distribution, and window glare. In the first case in Table16, the lighting was not turned on due to the smart lighting system, as the glare is sufficient for visual comfort, which the lighting relied on daylight in this case. While in the second case, the lighting was turned on to reach the required level, that not less than 300cd\m2, as shown below. The glare of a window is less in the second case than in the first case.

Table 16: Visual comfort and Glare for Scenario 3 South West office (Author2022)

Visual comfort and Glare for Scenario 3 South West office						
Month	Peak Day	Peak Time (pm)	Pv Angle	Base case	LowE glass	EC Tinted 30 glass
January	27	16	166.3°			
			60.9°			
			95.1°			
			177.7°			
			13.9°			
			145.9°			
			46.6°			
February	01	12	166.3°			
			23.5°			
			29.1°			
			177.7°			
			20.1°			
			18.5°			
			46.6°			
March	14	16	166.3°			
			23.5°			
			29.1°			
			78.6°			
			20.1°			
			50.5°			
			46.6°			
April	16	17	166.3°			
			177.2°			
			29.1°			
			20.4°			
			171.2°			
			50.5°			
			46.6°			
May	11	15	166.3°			
			177.2°			
			29.1°			
			20.4°			
			90.1°			
			180			
			46.6°			
June	22	14	166.3°			
			73.2°			
			29.1°			
			20.4°			
			32.9°			
			100.5°			
			46.6°			
July	05	16	166.3°			
			23.5°			
			29.1°			
			78.6°			
			32.9°			
			145.9°			

			46.6°	
August	28	15	166.3°	
			60.9°	
			29.1°	
			78.6°	
			32.9°	
			152.2°	
			70.4°	
September	28	17	166.3°	
			60.9°	
			29.1°	
			78.6°	
			45.8°	
			180°	
			50.6°	
October	30	17	166.3°	
			95.2°	
			175.5°	
			78.6°	
			45.8°	
			38.4°	
			50.6°	
November	22	17	62.4°	
			95.2°	
			23.1°	
			49.2°	
			92.9°	
			38.4°	
			50.6°	
December	04	17	62.4°	
			177.2°	
			23.1°	
			49.2°	
			171.2°	
			38.4°	
			50.6°	

The percentage of reduction of glare from the Base Case was more than 70%, with the highest percentage of reduction being 92.04% and 91.65% for September for the two cases. In addition to 92.43% for October for the first case. While the lowest reduction percentage is 76.25% in June for the first glass case, and for the second glass case, 76.73% for May as shown in Table 17.

Table 17: Southwest office of Scenario3's Luminance levels (Author 2022)

Southwest office of Scenario3's Luminance levels							
Date	Peak Day	hour	Base Case levels(cd\m2)	LowE glass levels(cd\m2)	EC Tinted 30 glass levels(cd\m2)	Glare Percentage Decrease over Base Case (LowE glass)	Glare Percentage Decrease over Base Case (Tinted 30)
January	27	16pm	3018	522	518	82.70%	82.83%
February	01	12pm	4400	562	439	87.22%	90.02%
March	14	16pm	3252	550	522	83.08%	83.94%
April	16	17pm	3466	404	573	88.34%	83.46%
May	11	15pm	2261	516	526	77.17%	76.73%
June	22	14pm	2400	570	527	76.25%	78.04%
July	05	16pm	4020	500	502	87.56%	87.51%
August	28	15pm	3002	420	485	86.00%	83.84%
September	28	17pm	4900	409	390	91.65%	92.04%
October	30	17pm	4228	320	500	92.43%	88.17%
November	22	17pm	3000	370	505	87.66%	83.16%
December	04	17pm	4021	585	512	85.45%	87.26%
Average			3487.33	477.33	499.91	86.31%	85.66%

In the Figure 43 below, it shows the relationship between the values of the two cases compared to the Base Case that was taken from the work area (desk) near the window, where the values

did not exceed 700 cd/m², that is, between 300-500 cd/m², in addition to that they were very comparable.

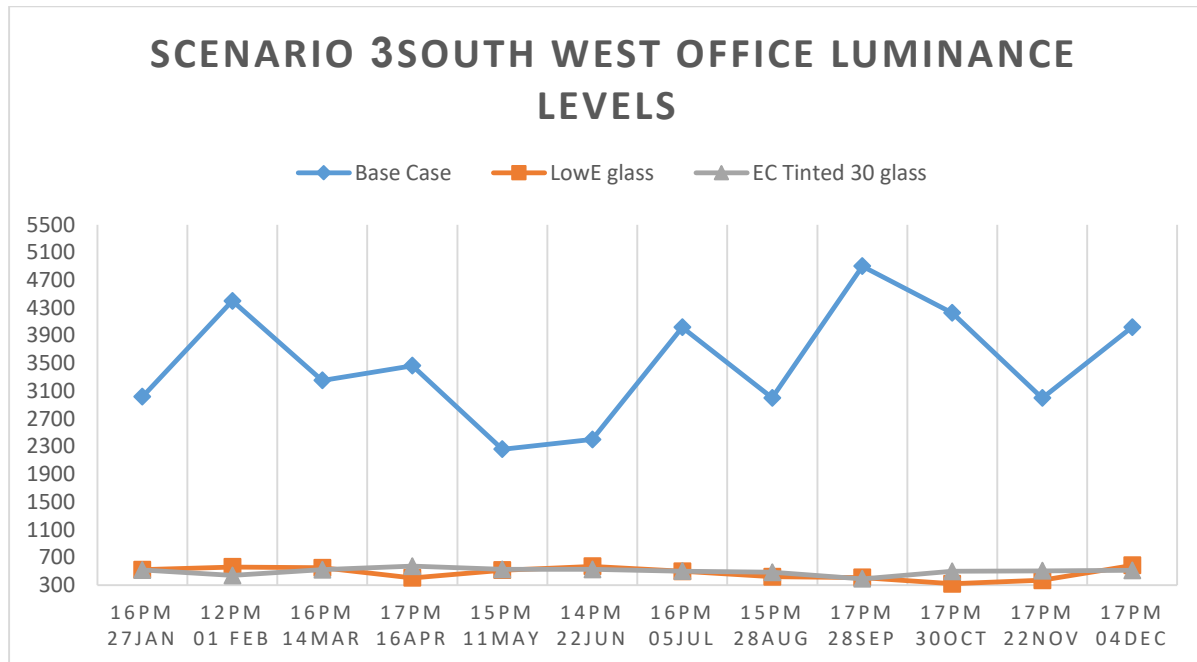


Figure 43: Southwest office diagram of scenario3's Luminance levels (Author2022)

5.2 Lighting energy

This section includes the light energy for each of the south and south west offices for the three scenarios, with the two glass cases, and compares it with the Base Case of the office, as the lighting controls (Diming system) were not used in the basic case, while they were used in the presented scenarios.

5.2.1 South Office Scenario 1: PV panels tracking the sun as a group

The simulation was done monthly, which is equivalent to the movement of the panels for 24 angles during the year for fourteen panels (two offices) in this scenario. The results in Table 18 below indicate the highest power consumption of lights for the base case in March, May and August, and the lowest power in December and June. After applying the scenario, more than 40% of lighting energy consumption was reduced for both types of glass. The highest reduction rate reached 91.10% for June in the case of the first glass and 90.56% for the same month for the second glass. While May was 85.70% for the second glass case and 82.56% for July in the

first glass case. As for the lowest reduction rate, it reached 47.91% for the second glass in October, and 59.84% in November for the first glass.

Table 18:South Office Electrical Lighting Energy Consumption of Scenario1(Author2022)

South Office Electrical Lighting Energy Consumption of Scenario 1					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	11.97	12.06	61.61%	61.32%
February	28.35	6.63	5.95	76.61%	79.01%
March	32.60	6.73	5.98	79.35%	81.65%
April	28.35	6.32	5.61	77.70%	80.21%
May	32.60	5.11	4.66	84.32%	85.70%
June	18.66	1.66	1.76	91.10%	90.56%
July	29.77	5.19	4.80	82.56%	83.87%
August	32.60	5.73	5.21	82.42%	84.01%
September	29.77	6.37	5.82	78.60%	80.45%
October	31.18	7.46	16.24	76.07%	47.91%
November	31.18	12.52	15.59	59.84%	50%
December	14.04	3.03	2.40	78.41%	82.90%
Total	340.28	78.72	86.08	76.86%	74.70%

As for the Figure 44, it shows a comparison of the Base Case with the application of the scenario for both glasses, where the most energy reduction occurred in the month of June, December, and then May. As for October and November, the case of the second glass was higher in terms of energy consumption compared to the first glass. As for the rest of the months, there is a convergence of consumption values for both glasses.

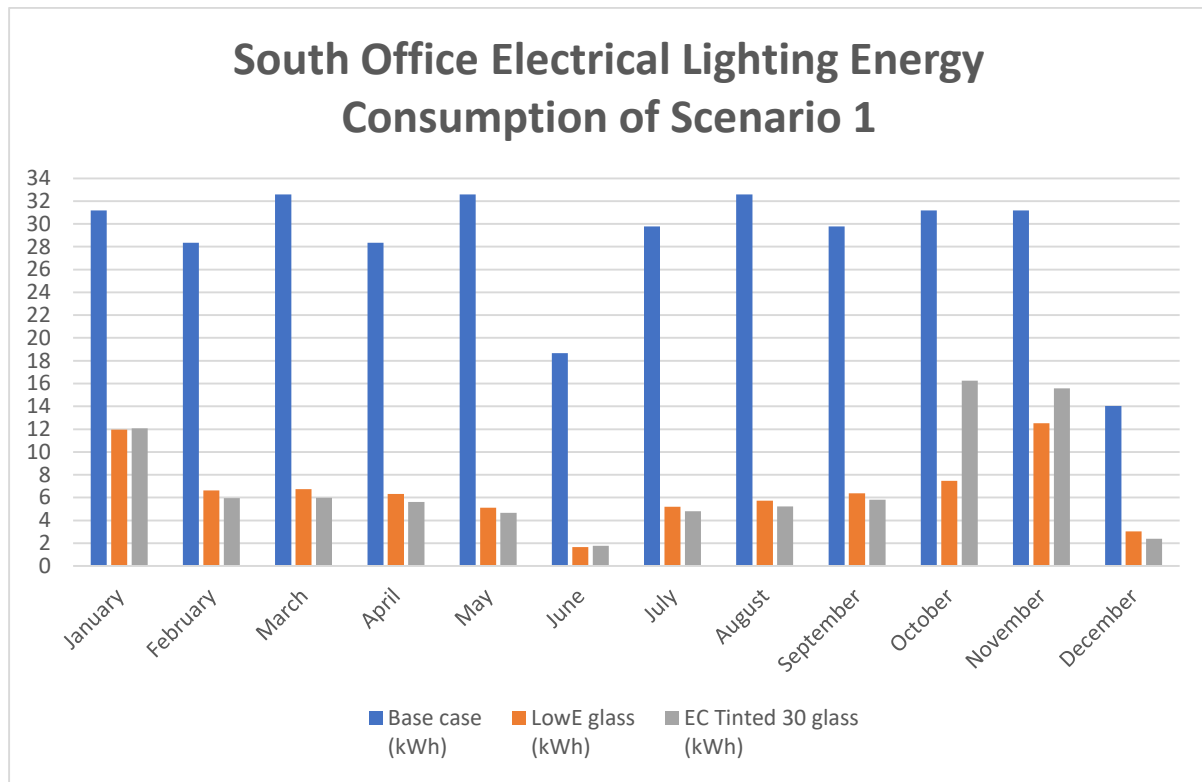


Figure 44:Base Case lighting Energy comparing with scenario 1(Author2022)

5.2.2 South Office Scenario 2: PV panels tracking the sun as Individual

This scenario presents the movement of solar panels during the year with 168 different angles in both offices, where 84 angles per office for 7 panels. The percentage of reduction shown in Table 19 below for the two cases of glass ranged from 62.70% to 88.69% compared to the Base Case. The highest reduction rate is 88.69% for the case of the second glass in June, followed by May at 85.30%, and the lowest rate at 69.69% for January. As for the first type of glass, the highest percentage reached 80.46% for March, followed by May with the same percentage, and the lowest percentage for January also with 62.70%.

Table 19:South Office Electrical Lighting Energy Consumption of Scenario 2(Author2022)

South Office Electrical Lighting Energy Consumption of Scenario 2					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	11.63	9.45	62.70%	69.69%
February	28.35	7.53	5.66	73.43%	80.03%
March	32.60	6.37	4.98	80.46%	84.72%
April	28.35	6.05	4.95	78.65%	82.53%
May	32.60	6.38	4.79	80.42%	85.30%
June	18.66	4.24	2.11	77.27%	88.69%
July	29.77	8.37	5.43	71.88%	81.76%
August	32.60	7.61	5.86	76.65%	82.02%
September	29.77	6.96	5.87	76.62%	80.28%
October	31.18	7.88	6.69	74.72%	78.54%
November	31.18	8.21	7.13	73.66%	77.13%
December	14.04	3.40	2.86	75.78%	79.62%
Total	340.28	84.63	65.78	75.12%	80.66%

The results indicate less energy consumption for the second type compared to the first type and the Base Case, as shown in the Figure 45 during the year. Where the least consuming months are June, followed by December, then March for the glass second type. As for the first glass type December, June and then April.

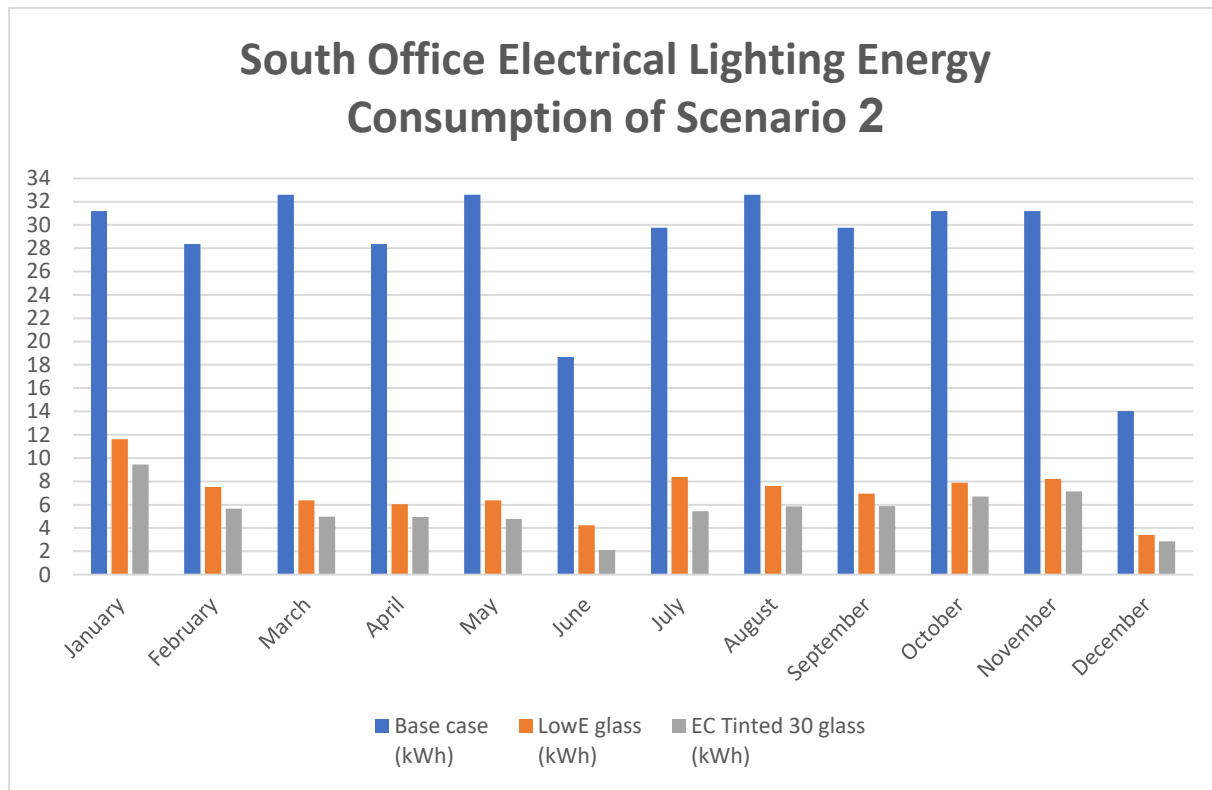


Figure 45:Base Case lighting Energy comparing with scenario 2(Author2022)

5.2.3 South Office Senario3: Fixed and Dynamic PV Panels

In this third scenario Table 20, fixed angles were used for some panels during the year, as the number of different angles during for both offices reached 85 angles. In this office the panels moved at 48 different angles per year. The table below shows a comparison of the percentage of electrical Lighting energy reduction for the scenario with the types of glass used. The percentage of reduction was more than 60% for both cases of glass. The highest percentage is 92.81% in June for the second type of glass, followed by 87.62% for the same month for the first type. In addition to the rate of 87.08% in May for the second type. Also, the second highest percentage for the first glass type is 83.17% for July. The lowest percentage is 63.09% between the two types for the month of March, which is within the percentages of the first glass.

Table 20:South Office Electrical Lighting Energy Consumption of Scenario 3(Author2022)

South Office Electrical Lighting Energy Consumption of Scenario 3					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	10.25	8.49	67.12%	72.77%
February	28.35	6.42	5.19	77.35%	81.69%
March	32.60	12.03	7.68	63.09%	76.44%
April	28.35	7.01	5.43	75.27%	80.84%
May	32.60	5.81	4.21	82.17%	87.08%
June	18.66	2.31	1.34	87.62%	92.81%
July	29.77	5.01	4.15	83.17%	86.05%
August	32.60	5.57	4.63	82.91%	85.79%
September	29.77	6.54	5.57	78.03%	81.28%
October	31.18	7.60	6.20	75.62%	80.11%
November	31.18	8.50	6.78	72.73%	78.25%
December	14.04	3.09	2.43	77.99%	82.69%
Total	340.28	80.14	62.1	76.44%	81.75%

As for the values of electrical energy consumption, the Figure 46below indicates a comparison between the Base Case and the third scenario, where the lowest values were recorded in June, December, and April for both glasses. In general, the second type of glass did not consume much energy, as all the values of the months are less than 8 kWh, while the second type had the most energy consumption month of 12 kWh is March.

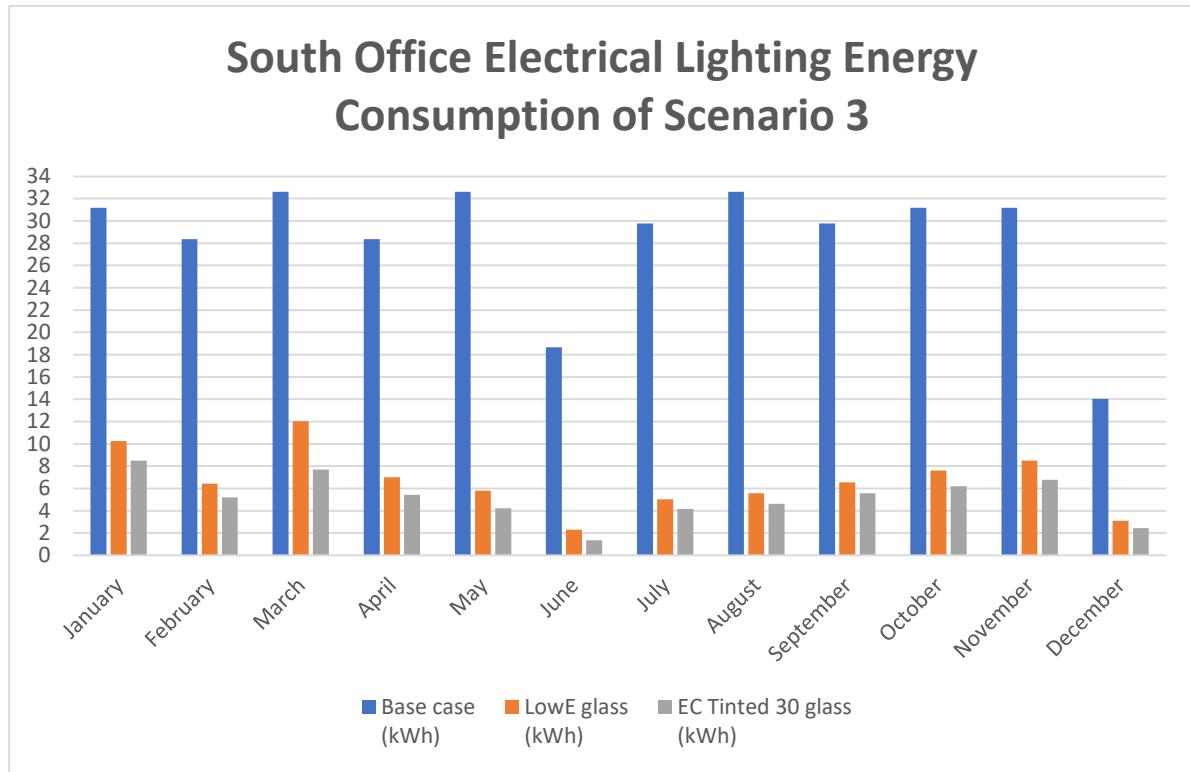


Figure 46:Base Case lighting Energy comparing with scenario 3(Author2022)

5.2.4 South West Office Scenario 1: PV panels tracking the sun as a group

The same angles were used in the south office in this scenario. The percentage of electrical lighting reduction in the first scenario ranged between approximately 23% to 89% in both glasses. The highest percentage of reduction in as shown Table 21 the first glass case is in June with 89.33%, while the second case had the highest percentage of 83.52% for August, followed by May and July. As for the lowest percentage, it is 23.60% in October for the second case, while the first case in January recorded 57.40%.

Table 21:South West Office Electrical Lighting Energy Consumption of Scenario 1(Author2022)

South West Office Electrical Lighting Energy Consumption of Scenario 1					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	13.28	18.29	57.40%	41.34%
February	28.35	6.69	6.22	76.40%	78.06%
March	32.60	8.31	9.66	74.50%	70.36%
April	28.35	6.89	5.99	75.69%	78.87%
May	32.60	5.33	5.43	83.65%	83.34%
June	18.66	1.99	3.20	89.33%	82.85%
July	29.77	5.33	5.04	82.09%	83.07%
August	32.60	5.77	5.37	82.30%	83.52%
September	29.77	6.69	6.16	77.52%	79.30%
October	31.18	7.70	23.82	75.30%	23.60%
November	31.18	12.48	15.43	59.97%	50.51%
December	14.04	2.98	2.36	78.77%	83.19%
Total	340.28	83.44	106.97	75.47%	68.56%

The values are shown in the Figure 47 below to show the extent of office consumption by the two types of glass in the first scenario, where the least consumption month during the year for both types is June, December, and then July. In addition, there is a discrepancy in the consumption values in some months, especially October, where the second type of glass consumed 60% more than the first type. Followed by January, when the second glass consumed more than 20% of the first glass.

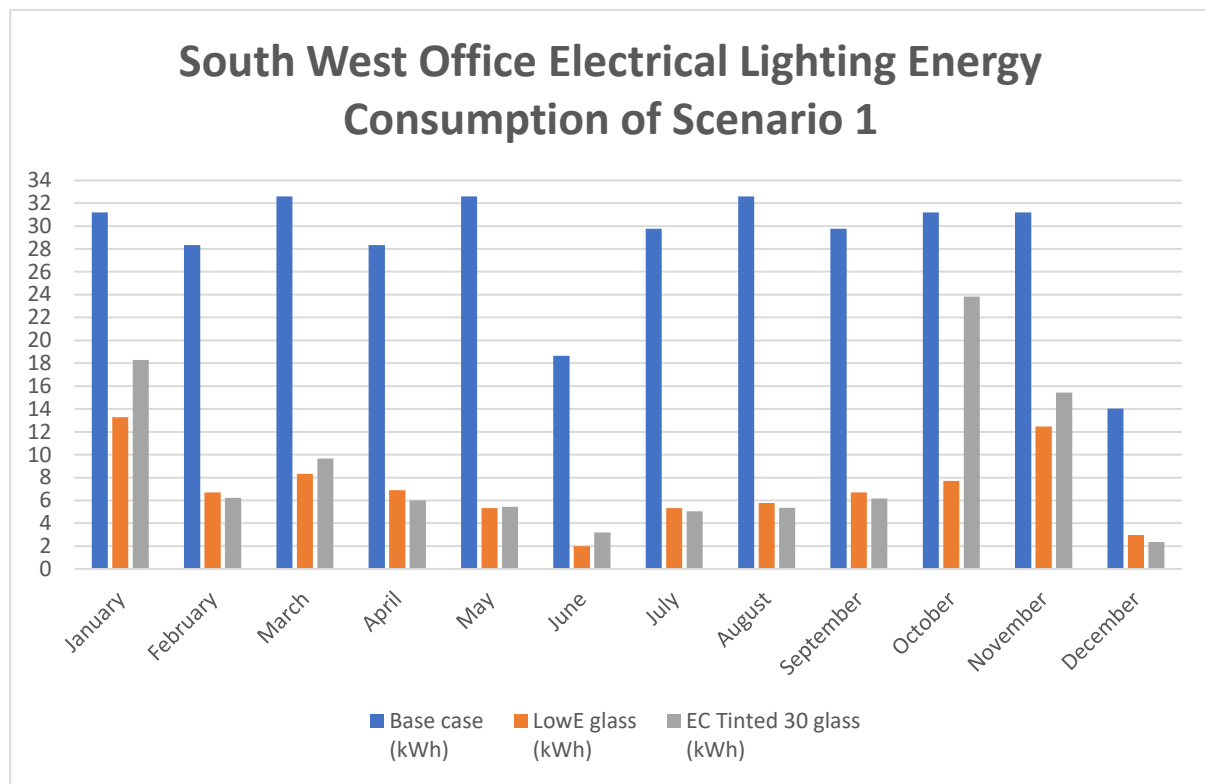


Figure 47:Base Case lighting Energy comparing with scenario 1(Author2022)

5.2.5 South West Office Scenario 2: PV panels tracking the sun as Individual

The number of angles of the solar panels in this office is the same as the number in the south office, however with different angle values, as they move individually in this scenario. The electrical lighting energy in Table 22 was reduced by more than 60% for the two glass cases over the Base Case. The highest percentage decrease is in June, at 90.51% for the second glass and 84.19% for the same month for the first glass. May also record the second-largest energy reduction percentage of 85.82% and 82.48% for the second and first glasses. While January recorded the lowest percentage reduction for the two cases, which is 66.16% and 71.80%.

Table 22:South West Office Electrical Lighting Energy Consumption of Scenario 2(Author2022)

South West Office Electrical Lighting Energy Consumption of Scenario 2					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	10.55	8.79	66.16%	71.80%
February	28.35	6.90	5.37	75.66%	81.05%
March	32.60	5.88	4.83	81.96%	85.18%
April	28.35	5.72	4.82	79.82%	82.99%
May	32.60	5.71	4.62	82.48%	85.82%
June	18.66	2.95	1.77	84.19%	90.51%
July	29.77	6.86	5.04	76.95%	83.07%
August	32.60	6.84	5.63	79.01%	79.01%
September	29.77	6.50	5.77	78.16%	80.61%
October	31.18	7.49	6.56	75.97%	78.96%
November	31.18	7.91	6.95	74.63%	77.71%
December	14.04	3.21	2.75	77.13%	80.41%
Total	340.28	76.52	62.90	77.51%	81.51%

The Figure 48 of the scenario presents the electrical lighting energy consumption. June comes in the first place with the lowest energy consumption for the two types of glass, followed by December, then April and March. In general, the values for both types of glass converge in terms of energy consumption, however the second type achieved the lowest cumulative value during the year.

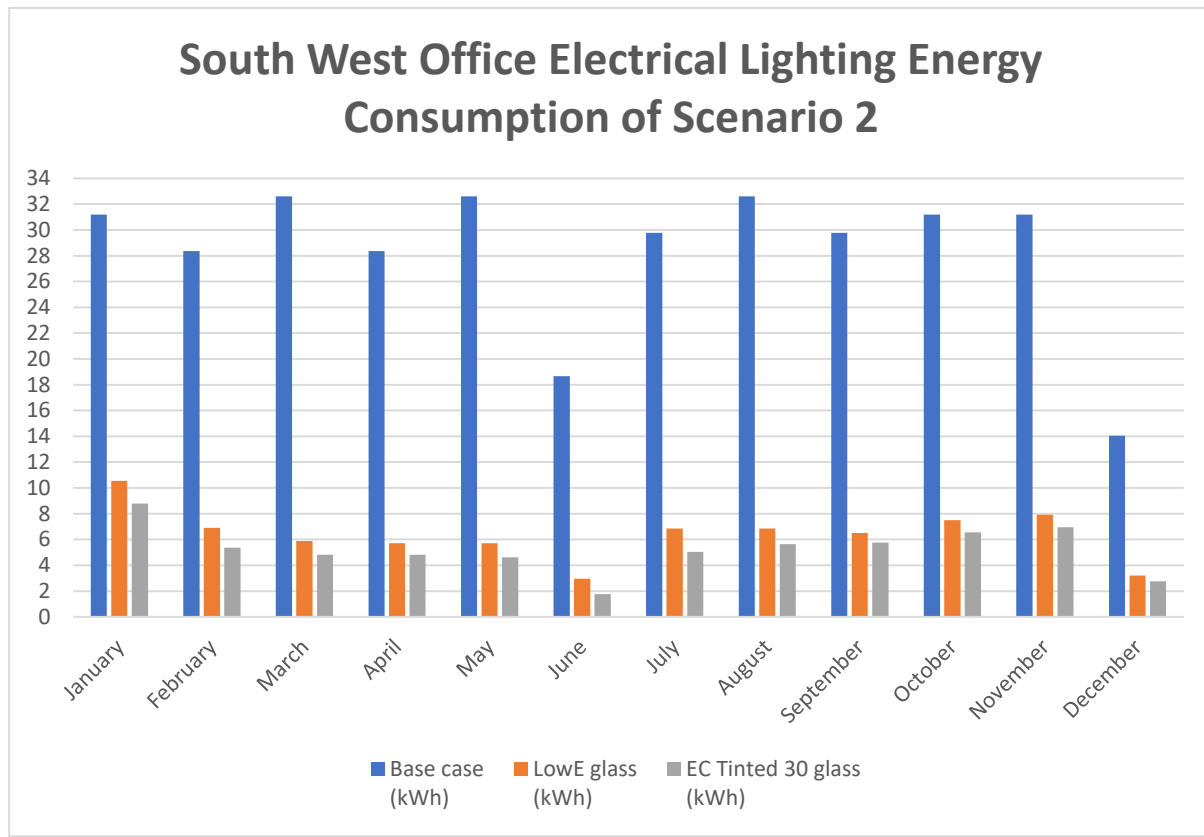


Figure 48 :Base Case lighting Energy comparing with scenario2 (Author2022)

5.2.6 South West Office Senario3: Fixed and dynamic PV panels

During the year in this scenario, the solar panels moved at 37 different angles. The Table 23 below indicates the range of energy reduction rates between 64.65% and 92.92%. Starting with the highest reduction rate for the second glass, with 92.92% for June and 88.21% for the first glass for the same month. May comes in the second month of the decrease by 86.96% for the second glass, followed by July and 85.85% for August. As for after June, for the first glass case July comes with 83.30%. October recorded the lowest reduction percentage for both glasses, with 64.65% for the first glass and 73.38% for the second glass.

Table 23:South West Office Electrical Lighting Energy Consumption of Scenario 3(Author2022)

South West Office Electrical Lighting Energy Consumption of Scenario 3					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	31.18	9.73	8.22	68.79%	73.63%
February	28.35	6.55	5.24	76.89%	81.51%
March	32.60	10.36	6.72	68.22%	79.38%
April	28.35	7.38	5.56	73.96%	80.38%
May	32.60	6.07	4.25	81.38%	86.96%
June	18.66	2.20	1.32	88.21%	92.92%
July	29.77	4.97	4.14	83.30%	86.09%
August	32.60	5.46	4.61	83.25%	85.85%
September	29.77	6.39	5.55	78.53%	81.35%
October	31.18	11.02	8.30	64.65%	73.38%
November	31.18	7.79	6.55	75.01%	78.99%
December	14.04	2.98	2.41	78.77%	82.83%
Total	340.28	80.9	62.87	76.22%	81.52%

The values of electrical lighting energy consumption in Figure 49 vary during the year in some months, where the consumption values for the first glass case in March and October are approximately 20% higher than second glass values, while January, February, April and May are higher by more than 10% approximately. June leads with the least energy consumption month, followed by December and July for both types of glass.

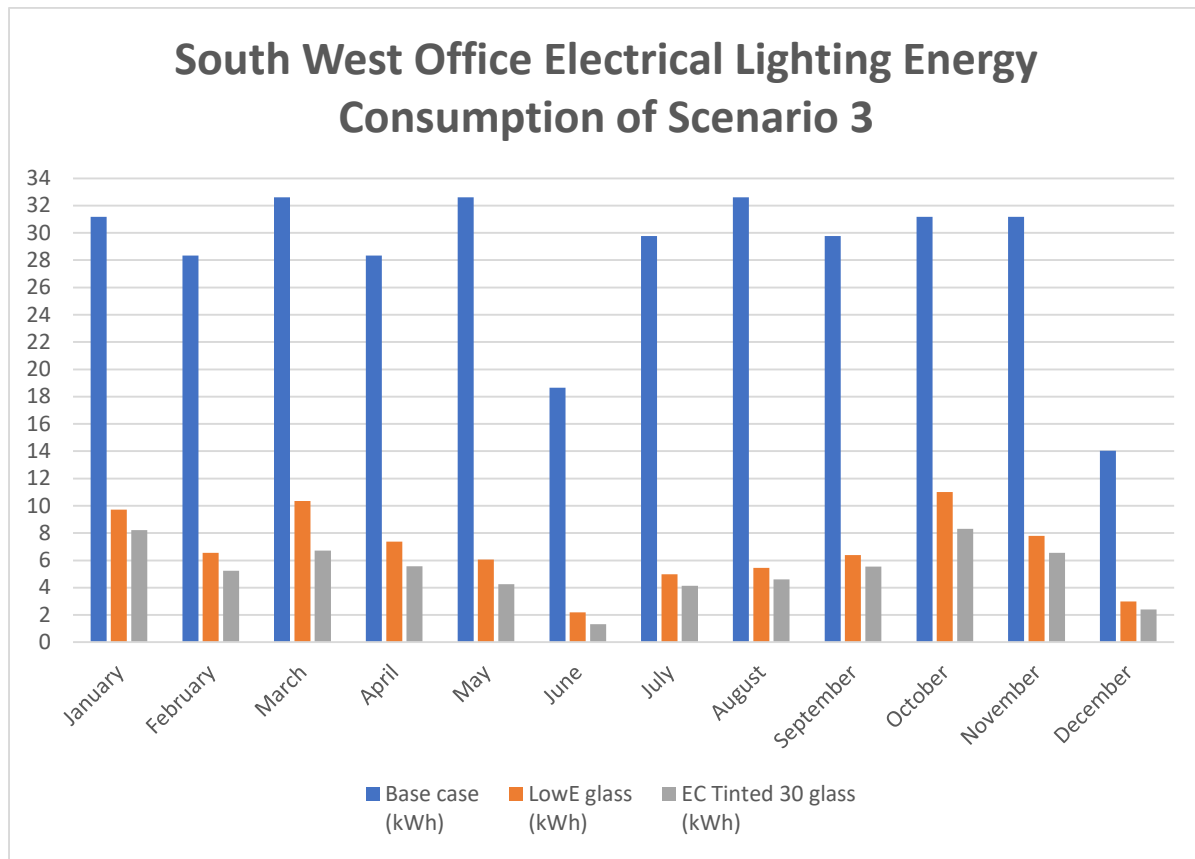


Figure 49:Base Case lighting Energy comparing with scenario 3(Author2022)

5.3 Cooling Load Energy

The results of the year's usage of air conditioning cooling energy for each of the two offices will be shown in this section. Along with the two different types of glasses, the simulation for three scenarios also considered the movement of the PV panels.

5.3.1 South Office Scenario 1: PV panels tracking the sun as a group

The Table 24 shows the results of the reduction for the first scenario with the two cases of glass, in terms of cooling load energy consumption over the Base Case. The lowest reduction rate is recorded in August, which is 31.60% for the second glass type, while the first glass recorded 46.51% in September. January achieved the highest reduction rate for both types of glass, with rates of 88.95% for the first glass and 94.61% for the second glass. In addition to March and February, they achieved the second highest percentage of reduction in the second glass type,

with rates of more than 89%. While in the first glass, October has the second highest rate of decrease after January, as it is 72.29% in October and 88.95% in January.

Table 24:South Office Cooling Load Energy Consumption of Scenario 1(Author2022)

South Office Cooling Load Energy Consumption of Scenario 1					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	521.05	57.57	28.08	88.95%	94.61%
February	508.54	233.74	53.37	54.03%	89.50%
March	551.69	205.34	55.39	62.77%	89.95%
April	521.89	226.00	155.32	56.69%	70.23%
May	556.02	223.43	205.26	59.81%	63.08%
June	499.21	238.20	305.14	52.28%	38.87%
July	620.18	283.65	398.28	54.26%	35.77%
August	669.32	336.38	457.79	49.74%	31.60%
September	712.30	380.95	398.28	46.51%	44.08%
October	739.91	205.01	306.87	72.29%	58.52%
November	662.71	297.66	152.89	55.08%	76.92%
December	553.76	280.92	138.66	49.27%	74.96%
Total	7116.58	2968.85	2655.33	58.28%	62.68%

The Figure 50 represents the values of each the Base Case of energy consumption with the two cases of the first scenario. The months values that record the highest consumption during the year are October, September and then November. The energy consumption values for both types of glass vary in this scenario, as in summer and autumn the values for the second glass for energy consumption are higher than for the first. While the rest of the months, the opposite occurs, that

is, the consumption values for the second glass are less than the first. The least consumption month after applying the scenario for both glasses is January.

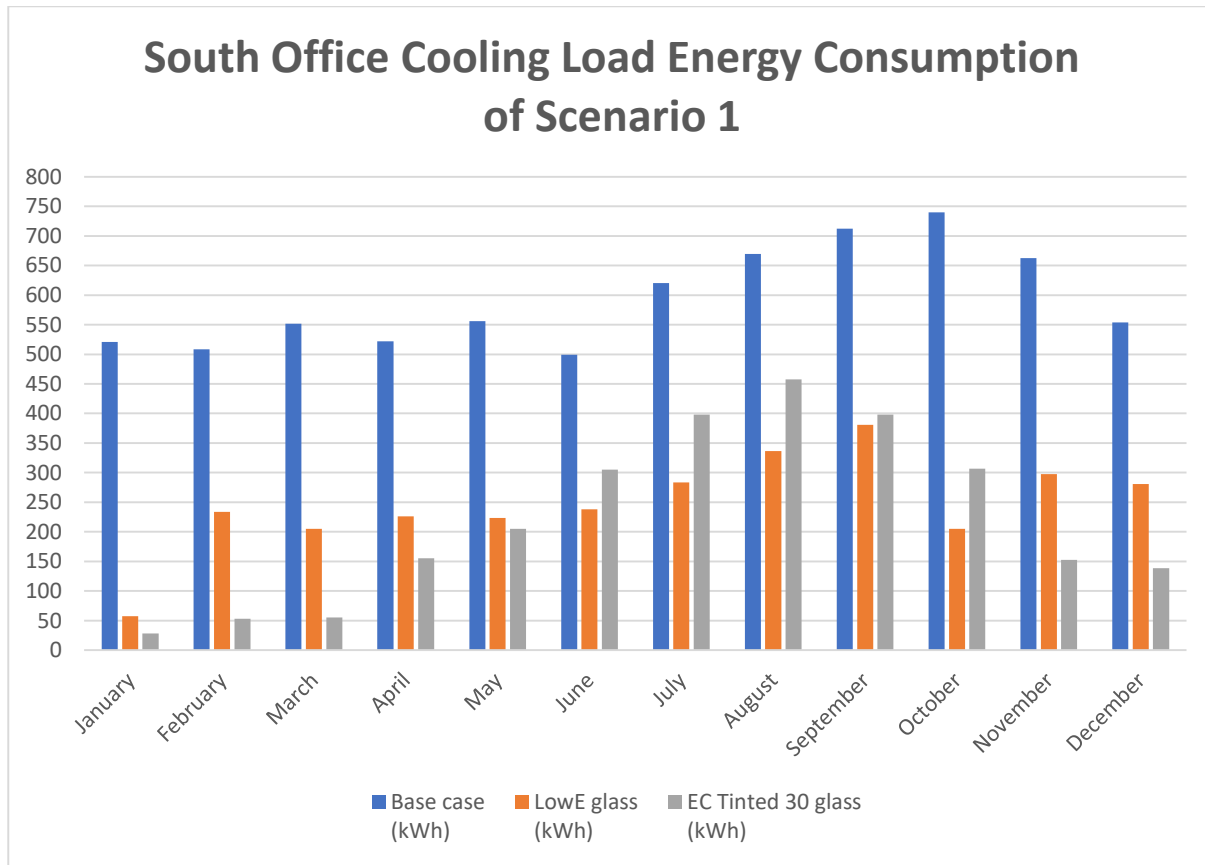


Figure 50:Base Case cooling Energy comparing with scenario 1(Author2022)

5.3.2 South Office Scenario 2: PV panels tracking the sun as Individual

Moving to scenario 2 in Table 25, June recorded the lowest rate of energy reduction for the first type, and the highest rate in December, with more than 50%. As for the second type, December recorded the highest rate of decrease, followed by January and February. The values for both glasses vary in the scenario where the performance of the second type is consumed by more than 20% less than the first glass during the year.

Table 25:South Office Cooling Load Energy Consumption of Scenario2(Author2022)

South Office Cooling Load Energy Consumption of Scenario2					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	521.05	239.92	115.71	53.95%	77.79%
February	508.54	239.16	114.47	52.97%	77.49%
March	551.69	266.87	145.13	51.62%	73.69%
April	521.89	275.54	170.48	47.20%	67.33%
May	556.02	286.02	206.81	48.55%	62.80%
June	499.21	291.64	224.46	41.57%	55.03%
July	620.18	359.5	288	42.03%	53.56%
August	669.32	394.14	310.86	41.11%	53.55%
September	712.30	415.7	300.26	41.63%	57.84%
October	739.91	417.97	286.99	43.51%	61.21%
November	662.71	317.49	191.3	52.09%	71.13%
December	553.76	252.14	122.57	54.46%	77.86%
Total	7116.58	3756.09	2477.04	47.22%	65.19%

The Figure 51 of the scenario presents the electrical lighting energy consumption. June comes in the first place with the lowest energy consumption for the two types of glass, followed by December, then April and March. In general, the values for both types of glass converge in terms of energy consumption, however the second type achieved the lowest cumulative value during the year.

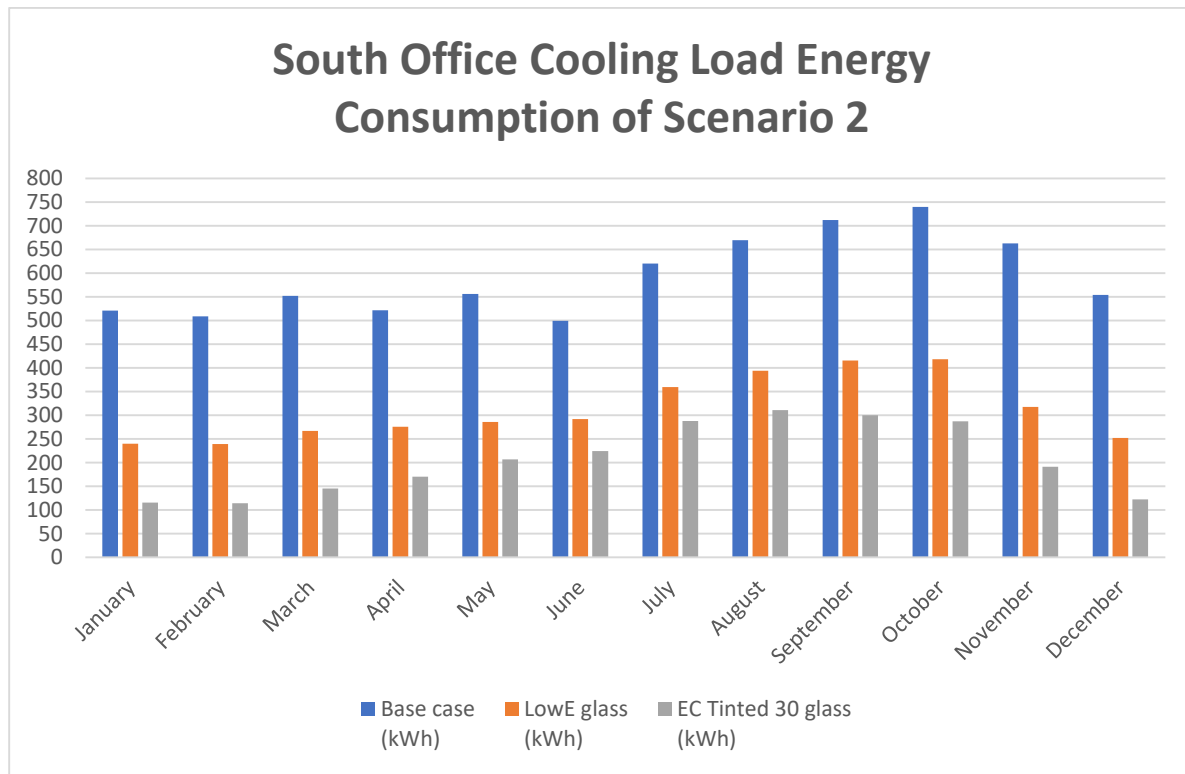


Figure 51:Base Case cooling Energy comparing with scenario 2(Author2022)

5.3.3 South Office Senario3: Fixed and dynamic PV panels

The percentage of energy reduction with the Base Case exceeded by more than 40%, the highest percentage recorded in December for both types of glass by more than 80% in Table 26. The lowest energy reduction percentage was 49.43% in August for the first type and more than 55% for the second type.

Table 26:South Office Cooling Load Energy Consumption of Scenario3(Author2022)

South Office Cooling Load Energy Consumption of Scenario3					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	521.05	117.78	78.94	77.39%	84.84%
February	508.54	106.95	72.4	78.96%	85.76%
March	551.69	153.37	112.27	72.20%	79.64%
April	521.89	180.59	139.73	65.39%	73.22%
May	556.02	235.97	193.03	57.56%	65.28%
June	499.21	233.89	126.8	53.14%	74.59%
July	620.18	303.33	262.25	51.09%	57.71%
August	669.32	338.43	292.77	49.43%	56.25%
September	712.30	295.57	253.79	58.50%	64.37%
October	739.91	285.53	237.65	61.41%	67.88%
November	662.71	189.75	148.43	71.36%	77.60%
December	553.76	107.18	73.46	80.64%	86.73%
Total	7116.58	2548.34	1991.52	64.19%	72.01%

Cooling energy consumption in Figure 52 during the year is less when using the second type of glass with the PVs third scenario, as it constitutes less than 20% of the consumption compared to the first type during the year, except for the month of June with more than 40%.

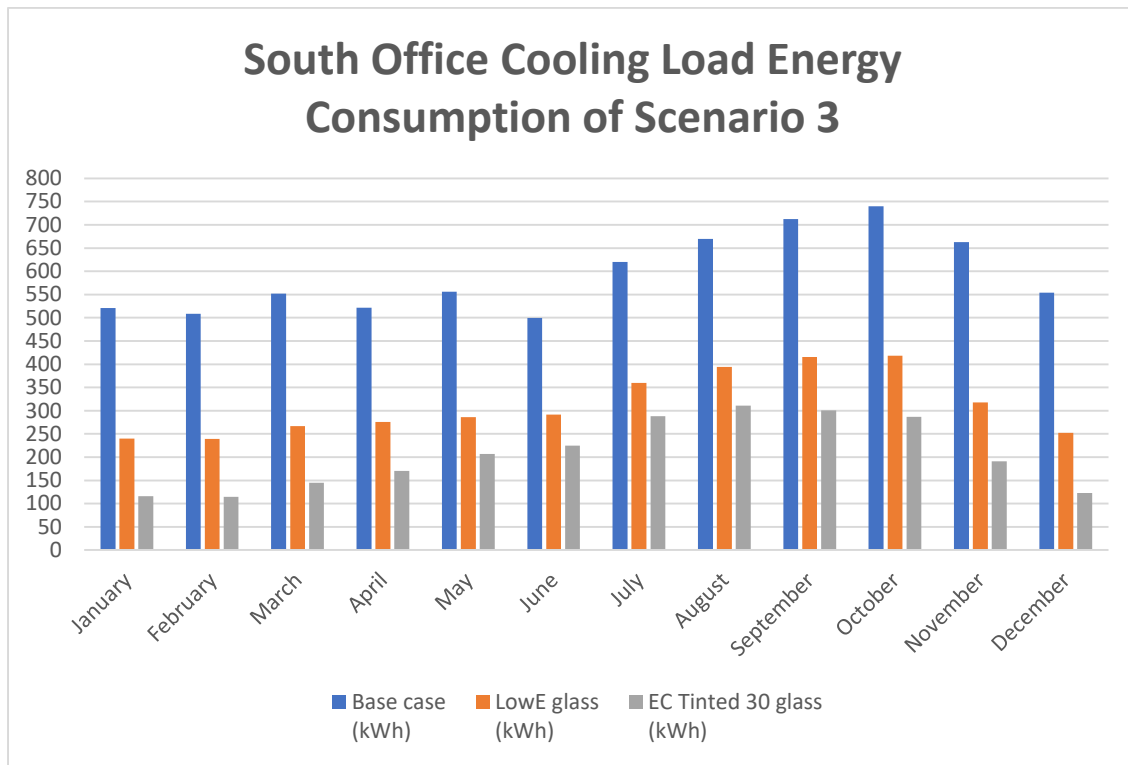


Figure 52:Base Case cooling Energy comparing with scenario 3(Author2022)

5.3.4 South West Office Scenario 1: PV panels tracking the sun as group

The cooling load energy consumption for the southeastern office Table 27 more than for the southern office. After applying the first scenario, the highest percentage of energy reduction is more than 85% for two glasses, as the month of January recorded the highest percentage of reduction. June recorded the lowest reduction rate, with 35.74% for the second glass and 46.12% in September for the first glass.

Table 27:South West Office Cooling Load Energy Consumption of Scenario1(Author2022)

South West Office Cooling Load Energy Consumption of Scenario1					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	525.41	60.65	30.07	88.45%	94.27%
February	511.92	240.08	57.54	53.10%	88.76%
March	554.16	210.20	57.89	62.06%	89.55%
April	523.98	230.79	157.94	55.95%	69.85%
May	556.95	225.41	206.61	59.52%	62.90%
June	499.27	244.09	307.05	51.11%	38.50%
July	620.44	285.31	398.64	54.01%	35.74%
August	670.37	338.07	459.13	49.56%	31.51%
September	714.78	385.07	401.15	46.12%	43.87%
October	743.52	214.19	309.87	71.19%	58.32%
November	666.36	300.60	155.88	54.88%	76.60%
December	557.45	284.89	141.87	48.89%	74.55%
Total	7144.61	3019.35	2683.64	57.73%	62.43%

The energy consumption values of the two types of glass range for the first scenario, as they are almost equal to September and May in Figure 53. While in the summer, the first glass exceeds consumption values by more than 15% compared to the second type. While in winter and November, the second type outperforms the lowest consumption by more than 50% over the first type.

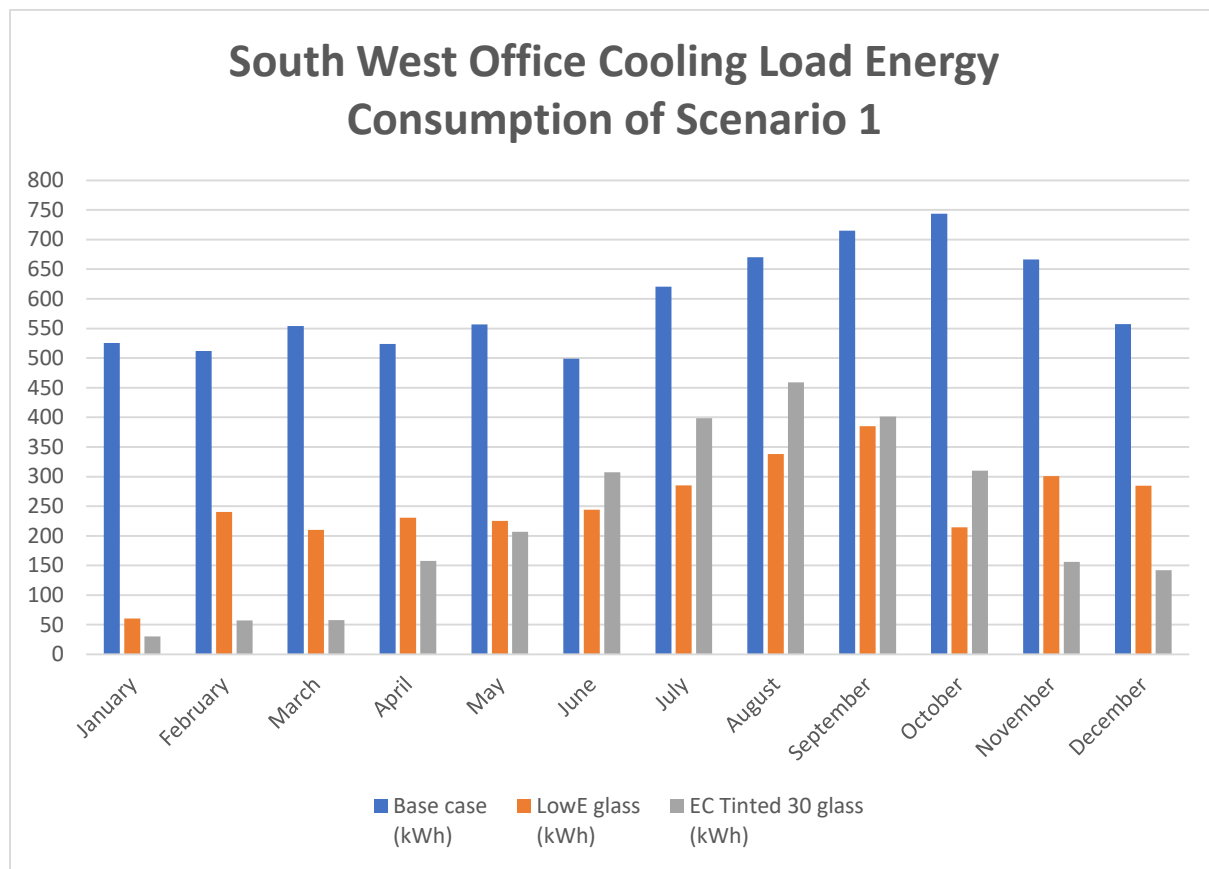


Figure 53:Base Case cooling Energy comparing with scenario 1(Author2022)

5.3.5 South West Office Scenario 2: Sun Tracking PV Panels as Individual

In the second scenario in Table 28, the lowest percentage of reduction exceeded 41% in August and September for both cases of glass, as shown. February recorded the highest rate of energy reduction by more than 70%, followed by December in the second glass type. As for the first type, the highest rate was 52.34% in December.

**Table 28:South West Office Cooling Load Energy Consumption of
Scenario2(Author2022)**

South West Office Cooling Load Energy Consumption of Scenario2					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	525.41	258.24	123.38	50.84%	76.51%
February	511.92	247.63	117.47	51.62%	77.05%
March	554.16	272.52	146.59	50.82%	73.54%
April	523.98	273.26	168.11	47.84%	67.91%
May	556.95	282.34	204.18	49.30%	63.33%
June	499.27	290.34	221.03	41.84%	55.72%
July	620.44	358.86	286.53	42.16%	53.81%
August	670.37	391.35	308.55	41.62%	53.97%
September	714.78	417.33	299.65	41.61%	58.07%
October	743.52	427.19	290.33	42.54%	60.95%
November	666.36	333.85	198.9	49.89%	70.15%
December	557.45	265.64	128.41	52.34%	76.96%
Total	7144.61	3818.55	2493.13	46.55%	65.10%

The values of energy consumption in both types of glass vary during the year, as the second type recorded consumption values of more than 20% less than the first type in Figure 54. lowest values recorded in December, January and February.

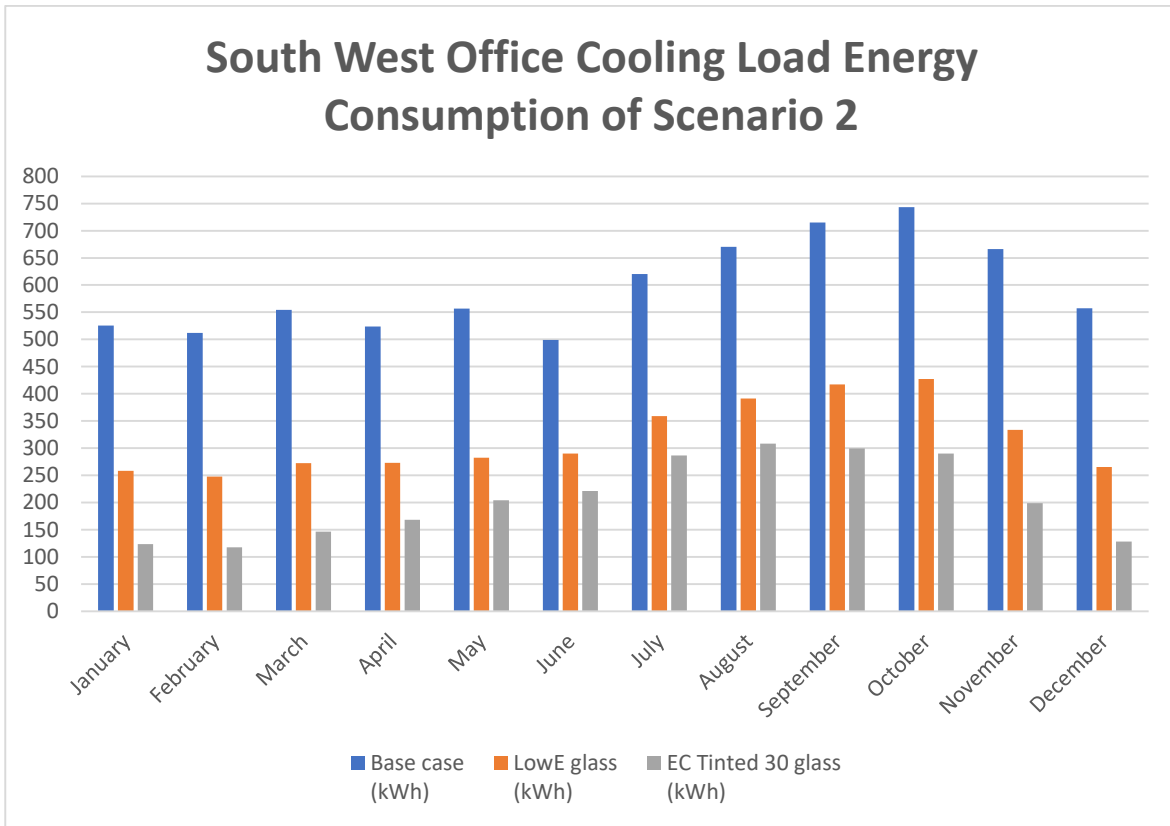


Figure 54:Base Case cooling Energy comparing with scenario 2(Author2022)

5.3.6 South West Office Senario3: Fixed and Dynamic PV Panels

February recorded the highest energy reduction percentage of more than 80% for both types of glass, followed by December as shown in Table 29. As for the lowest reduction rate, it exceeded 50%, and that was in July for the first type and August for the second type.

**Table 29:South West Office Cooling Load Energy Consumption of
Scenario3(Author2022)**

South West Office Cooling Load Energy Consumption of Scenario3					
Months	Base case (kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	525.41	117.78	78.37	77.58%	85.08%
February	511.92	99.17	67.38	80.62%	86.83%
March	554.16	152.14	110.42	72.54%	80.07%
April	523.98	176.53	137.06	66.30%	73.84%
May	556.95	231.75	190.34	58.38%	65.82%
June	499.27	233.9	196.8	53.15%	60.58%
July	620.44	301.66	258.99	51.37%	58.25%
August	670.37	339.15	292.76	49.40%	56.32%
September	714.78	307.28	261.75	57.01%	63.38%
October	743.52	289.45	241.27	61.07%	67.55%
November	666.36	215.46	165.7	67.66%	75.13%
December	557.45	121.71	82.63	78.16%	85.17%
Total	7144.61	2585.98	2083.47	63.80%	70.83%

In the scenario Figure 55 below, the consumption values of the second type are approximately 14% less than the first type, as shown during the year. The lowest values for energy consumption recorded in February, January followed by December.

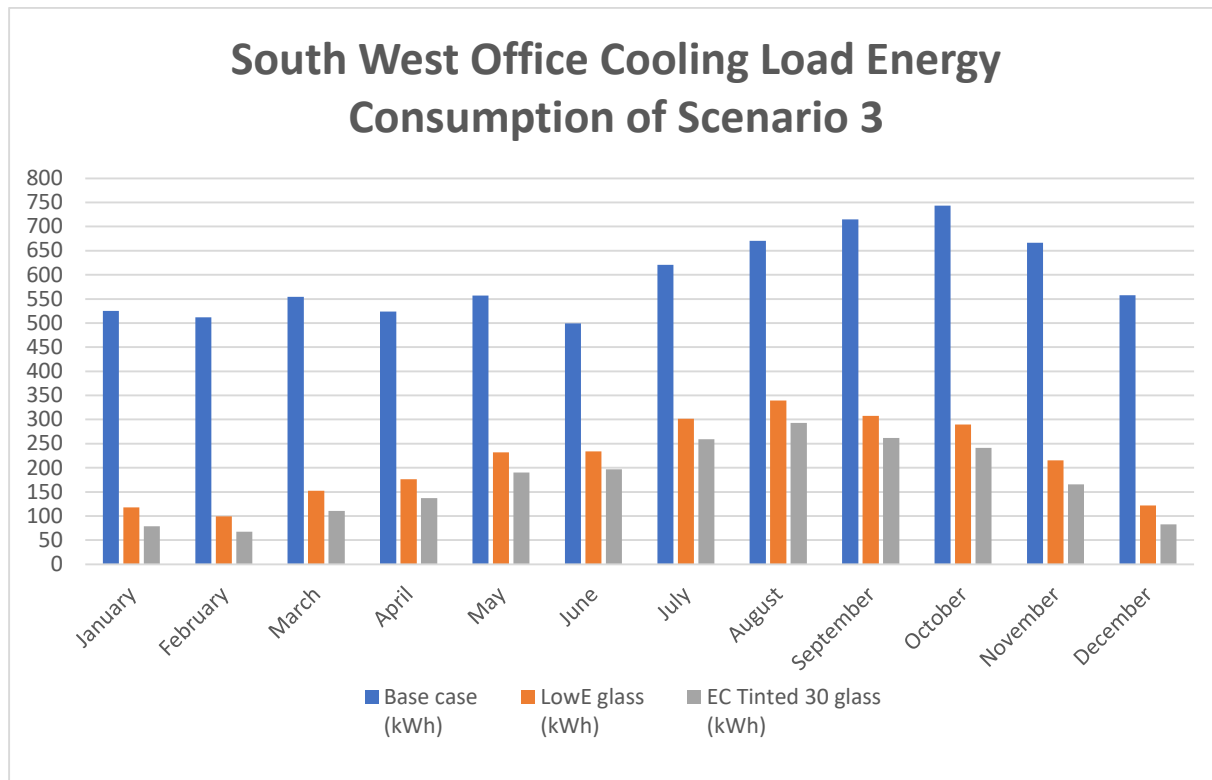


Figure 55:Base Case cooling Energy comparing with scenario 3(Author2022)

5.4 Electricity Generated by PV

This section will give the outcomes of three scenarios for the generation of electric energy for each solar panel within Fourteen panels for the southern and southwestern offices.

5.4.1 South Office Scenario 1: PV panels tracking the sun as a group

The results indicate that the months with the highest energy generation were February, December, and then June. Panel 7, recorded the highest amount of energy in February as shown in Table 30.

Table 30:Electricity Generated (kWh/m2) by Scenario 1's South Office PV Panels
(Author2022)

Electricity Generated (kWh/m2) by Scenario 1's South Office PV Panels									
Month	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Total	Angel
January	3.089	3.932	3.536	3.537	3.536	3.536	3.536	24.70	153.2 _o
February	15.056	15.527	15.525	15.528	15.528	15.525	17.279	109.9 ₆	53.4°
March	12.377	9.785	9.787	9.787	9.785	9.787	14.379	75.68	25.1°
April	11.751	9.548	9.55	9.55	9.55	9.55	13.589	73.08	117.9 _o
May	8.165	9.1	9.097	9.097	9.097	9.097	9.333	62.98	50.5°
June	11.204	11.337	11.337	11.335	11.336	11.337	12.804	80.69	146.4 _o
July	6.358	8.183	7.285	7.285	7.285	7.284	7.285	50.96	29.8°
August	8.827	9.755	9.755	9.756	9.756	9.755	10.088	67.69	166.3 _o
September	11.094	8.378	8.38	8.381	8.381	8.381	12.813	65.80	19.5°
October	12.013	8.586	8.587	8.587	8.587	8.586	14.445	69.39	13.5°
November	2.683	3.6	3.078	3.078	3.078	3.078	3.078	21.67	14.4°
December	13.074	15.236	14.939	14.941	14.941	14.941	14.94	103.0 ₁	144.7 _o
Total	115.69 ₁	112.96 ₇	110.85 ₆	110.86 ₂	110.8 ₆	110.85 ₇	133.56 ₉	805.61	

During the year in Figure 56, November recorded the lowest month for energy production, with a value of 21.67 kWh/m2, followed by January with 24.70 kWh/m2. During the year, most of the panels generate energy almost equally, except for panel 1 and panel 7 in March-April, September and October.

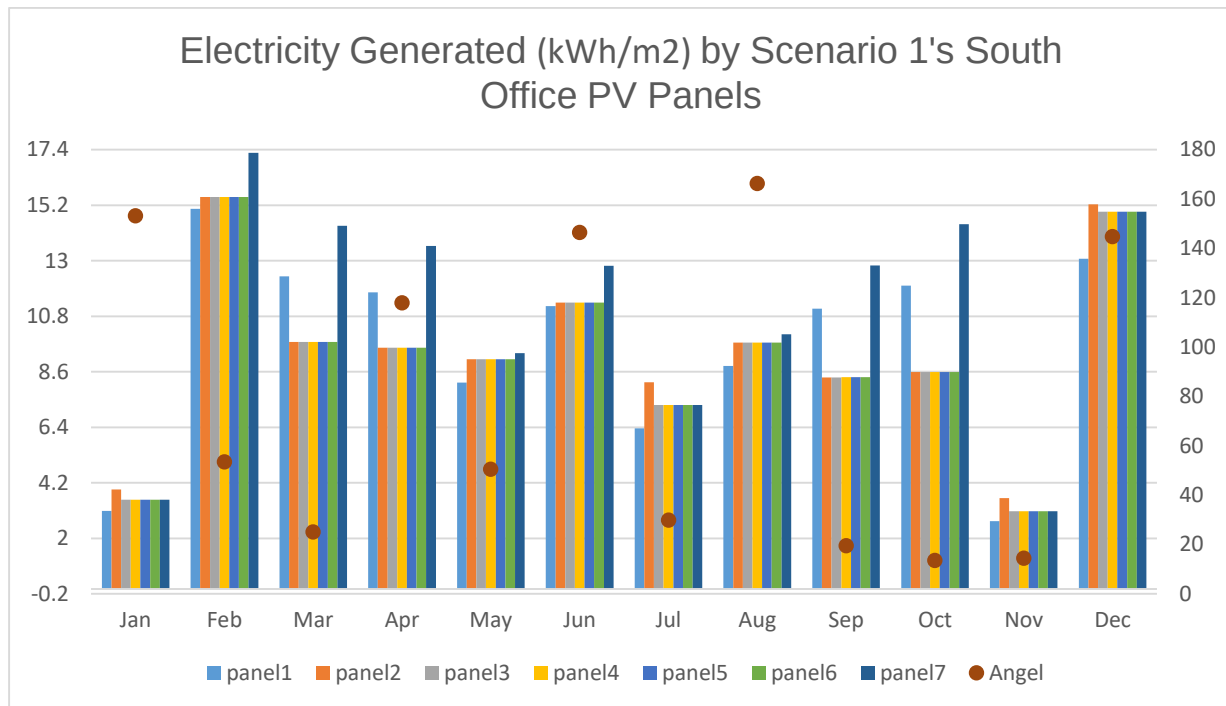


Figure 56:Electricity Generated of scenario 1(Author2022)

5.4.2 South Office Scenario 2: PV panels tracking the sun as Individual

In the second scenario in Table 31, the energy production for each month did not exceed 90 kWh/m², due to the panels moving individually at different angles, which creates shadows on some panels, thus reducing the exposure of the panel surface to direct sun radiation, and thus reducing electricity production. The highest amount of electricity was recorded in May, with the highest value during the year per panel 6, 15.232 kWh/m². Followed by June and July. While the least month for generating energy is December, with a value of 50.80 kWh/m².

The Figure 57 indicates that the highest months of energy generation are summer and spring. The panels vary in energy production values, as panel 4 recorded the highest individual production during winter and autumn, followed by panel 2.

Table 31:Electricity Generated(kWh/m2) by Scenario 2's South Office PV Panels
(Author2022)

Electricity Generated(kWh/m2) by Scenario 2's South Office PV Panels															
Month	panel 1	panel 2	panel 3	panel 4	panel 5	panel 6	panel 7	Total	Angel 1	Angel 2	Angel 3	Angel 4	Angel 5	Angel 6	Angel7
January	3.65	10.36 1	3.777	15.81	4.805	7.373	7.105	52.88	48.6	90	169.2	65.4	153.4	180	129.2
February	3.96	10.2	4.333	13.47	5.564	8.128	8.284	53.94	66.7	120	22.2	71.2	59.1	102.6	74.2
March	5.09	12.24 8	6.507	12.68	8.452	11.36 3	11.25 2	67.59	29.9	84.2	154.7	116.3	32.1	65.5	152.6
April	5.91	12.11 1	8.638	11.15	11.25 2	12.98 1	12.48 1	74.52	109.3	25.8	134.5	23.9	127.3	23.5	57.7
May	7.65	12.32	11.65 1	9.942	14.54 6	15.23 2	13.75 8	85.10	159	169.2	76.7	164.1	151.4	47.2	145
June	8.21	11.33 7	12.06 8	8.596	14.42 7	14.90 4	13.13 7	82.68	34.3	131.8	30.9	176.4	6.9	8.2	58.9
July	7.76	11.71	11.41	9.084	13.86 9	14.94	12.89	81.66	57.21	152.1	52.6	33.7	44.7	27.1	120.6
August	6.44	12.24 7	9.756	10.49 2	12.54 1	13.91 8	12.79 2	78.18	20.1	32.6	137.8	124.4	25	125	125.6
September	5.04	12.42 3	7.007	12.08 2	9.305	12.01 4	11.72 1	69.55	47.7	126.7	24.2	29	60.6	47.5	3.5
October	4.34	12.06	5.207	14.38 8	6.929	9.918	10.21 8	63.06	29.2	26.6	172.3	149.8	95.3	175.1	77.6
November	3.64	10.41 8	3.91	15.70 9	5.118	7.573	7.854	54.24	172.4 9	159.3	146.1	80.3	180	86.8	3
December	3.46	9.471	3.565	16.34 6	4.558	6.564	6.834	50.80	151.5	173.5	45.4	92.2	160.9	19.9	173.6
Total	65.1 5	136.9 0	87.82 9	149.7 4	111.3 6	134.9 0	128.3 2	814.2							

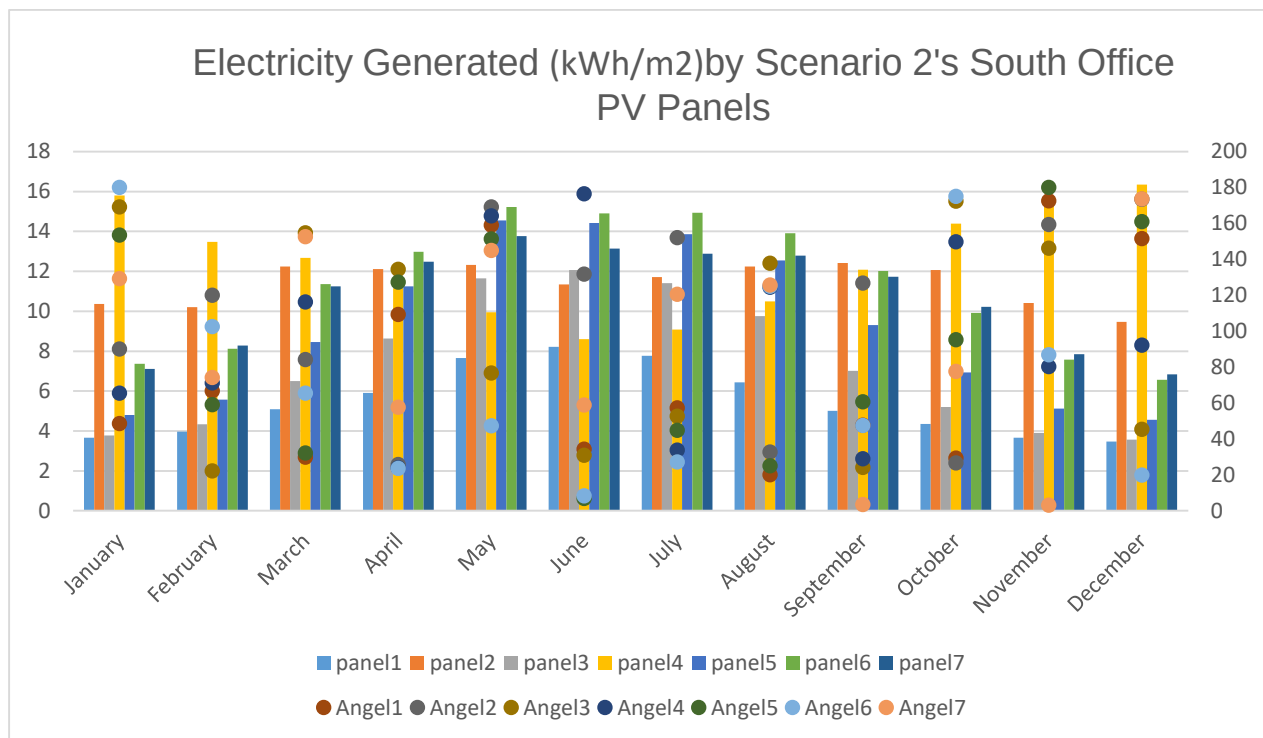


Figure 57:Electricity Generated of scenario 2(Author2022)

5.4.3 South Office Senario3: Fixed and Dynamic PV Panels

More than 100 kWh was generated from three months during the year as shown in Table 32. Where the highest month for electricity generation is December with 110.79 kWh/m2 and the lowest month with 64.69 kWh/m2. Panel1 for January was observed as the highest single panel for energy generation during the year, with 18.63 kWh/m2.

Table 32:Electricity Generated (kWh/m2) by Scenario 3's South Office PV Panels
(Author2022)

Electricity Generated (kWh/m2) by Scenario 3's South Office PV Panels															
Month	panel 1	panel 2	panel 3	panel 4	panel 5	panel 6	panel 7	Total	Angel 1	Angel 2	Angel 3	Angel 4	Angel 5	Angel 6	Angel7
January	18.63	15.480	16.937	14.545	11.227	15.223	16.355	108.39	137.3	50.9	173.1	127.7	173.9	58	180
February	12.237	15.388	13.606	15.972	10.842	15.354	15.972	99.37	137.3	50.9	173.1	153.8	68.9	26.1	180
March	12.758	13.901	12.542	14.122	12.905	11.194	13.107	90.52	10.7	37.7	172.5	47.6	165.4	166.3	180
April	13.873	11.298	12.456	9.31	13.46	11.632	11.521	83.55	10.7	37.7	144.9	47.6	40.9	166.3	180
May	14.306	12.86	11.291	9.012	7.958	10.588	8.37	74.38	10.7	37.7	172.5	47.6	120	166.3	180
June	10.158	11.119	8.802	10.067	6.778	6.985	11.768	65.67	137	33.3	172.5	47.6	44.3	166.3	180
July	13.578	9.764	9.576	8.474	11.938	5.723	5.646	64.69	180	33.3	172.5	141.1	44.3	140.3	180
August	8.651	11.493	12.128	10.376	11.101	10.658	12.533	76.94	10.7	24.5	172.5	109.4	16.4	29.7	180
September	10.6	10.872	13.816	13.151	13.662	13.268	14.083	89.45	172.3	27	172.5	180	18.2	161.9	180
October	17.305	12.265	13.69	15.241	14.491	15.869	12.192	101.05	172.3	45.4	99.7	159.9	42.2	180	146.3
November	17.908	16.107	16.494	17.27	11.17	15.907	9.881	104.73	170	45.4	170.7	159.9	152.2	180	146.3
December	17.725	11.624	17.416	16.425	15.848	16.194	15.562	110.79	170	25.4	170.7	159.9	167.2	162.2	180
Total	167.72	152.17	158.75	153.96	141.38	148.59	146.99	1069.53							

The Figure 58 refers to the highest months of energy generation distributed during the year between winter and autumn. The summer months recorded energy values higher than

60kWh/m². The highest single plate for energy production during the year is panel 1, followed by panel 3.

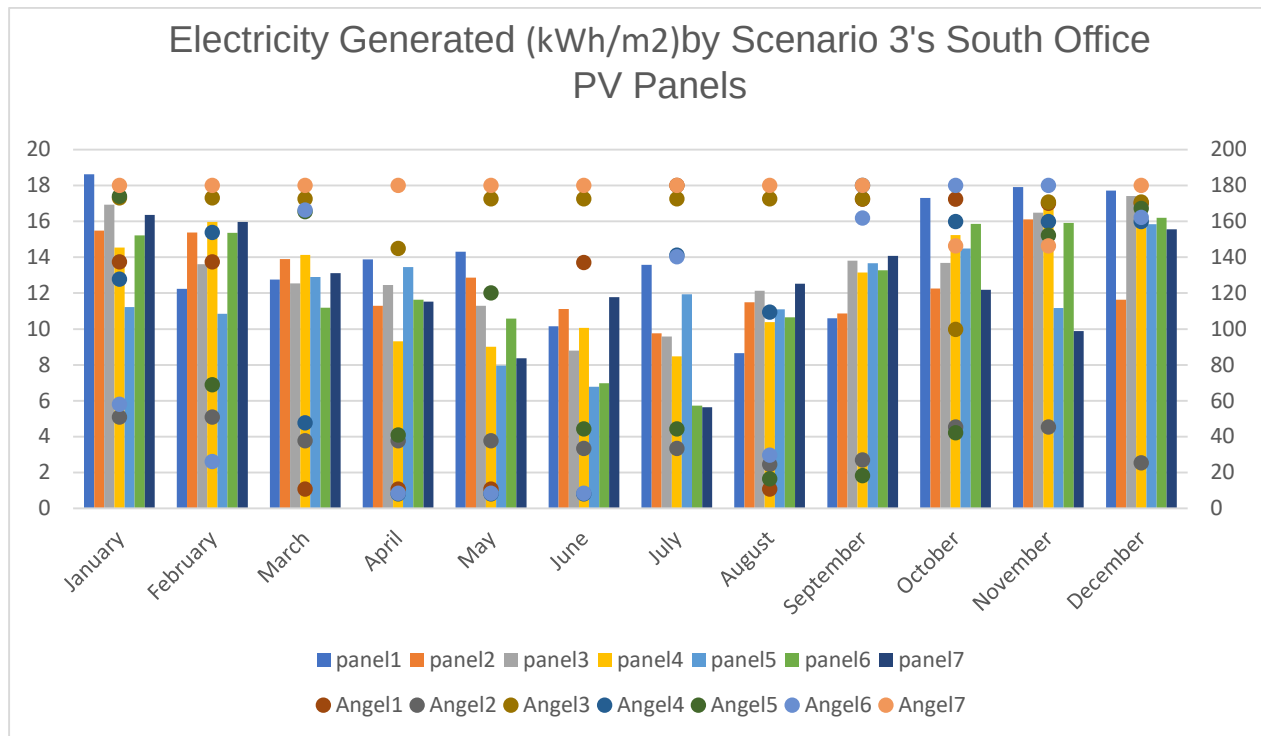


Figure 58:Electricity Generated of scenario 3(Author2022)

5.4.4 South West Office Scenario 1: PV panels tracking the sun as group

During the year, the highest month for energy generation is December with 94.90kWh/m2, followed by December with 91.75 kWh/m2 in Table 33. While the lowest month for energy generation is November, with 19.34 kWh/m2. The highest panels generated energy was panel1for February by 13.558 kWh/m2.

As for the individual power generation of the panels, all panels during the year produce the same energy for each month in Figure59.

Table 33:Electricity Generated (kWh/m2)by Scenario 1's South West Office PV Panels
(Author2022)

Electricity Generated (kWh/m2)by Scenario 1's South West Office PV Panels									
Month	Panel1	Panel2	Panel3	Panel4	Panel5	Panel6	Panel7	Total	Angel
January	3.443	3.09	3.09	3.09	3.09	3.09	3.443	21.98	153.2°
February	13.558	13.558	13.562	13.558	13.558	13.557	13.558	94.90	53.4°
March	8.37	8.37	8.373	8.37	8.37	8.37	8.37	58.59	25.1°
April	8.172	8.172	8.172	8.172	8.172	8.173	8.172	57.20	117.9°
May	7.955	7.955	7.957	7.957	7.954	7.954	7.955	55.68	50.5°
June	9.896	9.895	9.895	9.895	9.895	9.896	9.896	69.26	146.4°
July	7.249	6.358	6.358	6.358	6.358	6.36	7.249	45.39	29.8°
August	8.52	8.52	8.518	8.518	8.521	8.52	8.52	59.63	166.3°
September	7.164	7.163	7.163	7.164	7.164	7.164	7.164	50.14	19.5°
October	7.328	7.329	7.329	7.328	7.328	7.328	7.328	51.29	13.5°
November	3.248	2.683	2.683	2.683	2.684	2.684	3.248	19.34	14.4°
December	13.327	13.071	13.075	13.071	13.071	13.071	13.327	91.75	144.7°
Total	98.23	96.164	96.175	96.164	96.165	96.167	98.23	675.15	

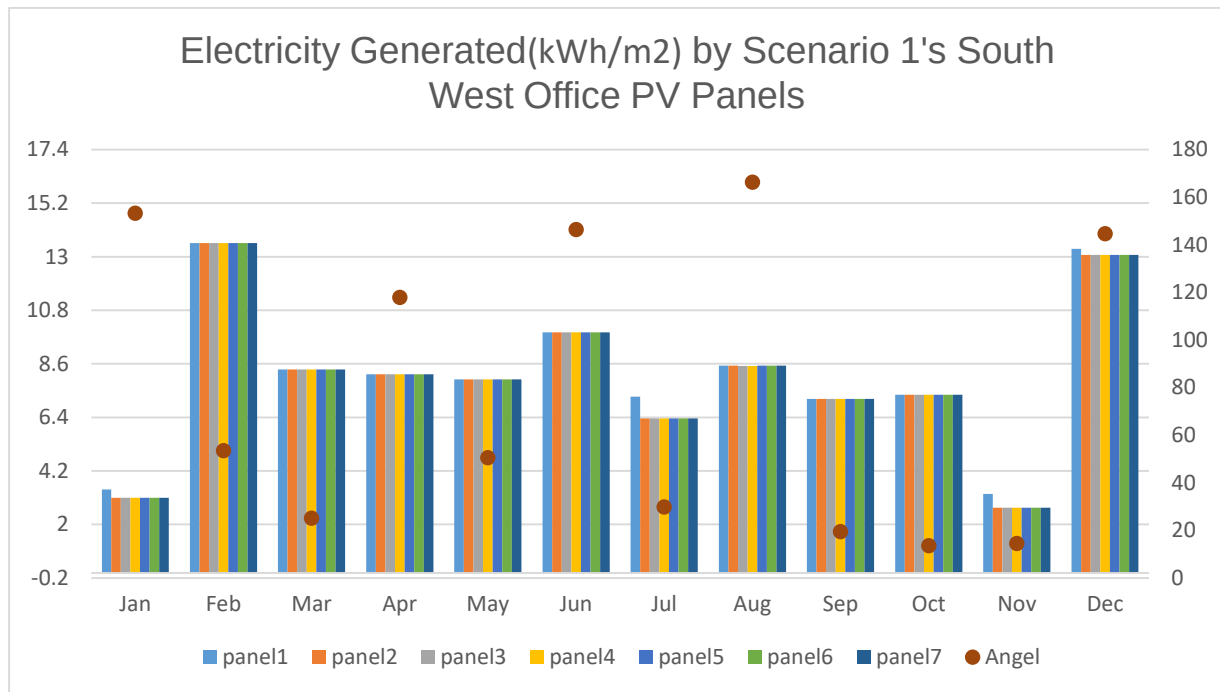


Figure 59:Electricity Generated of scenario 1(Author2022)

5.4.5 South West Office Scenario 2: PV panels tracking the sun as Individual

In the second scenario in Table 34, the highest month for energy generation did not exceed 90 kWh/m². Where the highest month for energy generation is May and then June. The lowest month for energy production is January with 45.9kWh/m².

Table 34:Electricity Generated (kWh/m2) by Scenario 2's South West Office PV Panels(Author2022)

Electricity Generated (kWh/m2) by Scenario 2's South West Office PV Panels															
Month	panel 1	panel 2	panel 3	panel 4	panel 5	panel 6	panel 7	Total	Angel 1	Angel 2	Angel 3	Angel 4	Angel 5	Angel 6	Angel 7
January	7.105	7.373	3.455	4.805	15.81	3.777	3.657	45.98	74.9	55	104.9	12.2	172.7	83	85
February	6.974	6.973	6.974	9.165	3.641	12.85 9	9.366	55.95	47.8	176	74.9	180	172.6	88.4	89.4
March	8.164	8.162	8.163	11.02 3	5.222	13.59 9	9.285	63.61	16.8	119	43.9	167.2	171	96.1	97
April	9.251	9.248	9.248	11.55 6	6.741	12.23 1	8.987	67.26	160.5	61.5	15.5	155	170.6	104.4	102.9
May	10.85 7	10.85 4	10.85 4	11.97 1	9.017	11.27 6	9.233	74.06	124	6.8	166.5	145	171.7	111	109.8
June	10.44 9	10.44 6	10.44 7	11.10 7	9.47	9.812	8.497	70.22	85.1	130.9	138.6	134.2	171.7	117.6	117.4
July	10.23 7	10.23 4	10.23 4	11.09	8.947	10.43 5	8.606	69.78	43.6	76.6	111.9	123.9	171.7	125.3	123.5
August	9.844	9.842	9.842	11.55 9	7.523	11.83 6	8.985	69.43	180	23.9	85.9	114.4	173.9	131.9	132
September	8.499	8.496	8.497	11.31	5.445	13.30 8	9.111	64.66	132	150.6	61.1	105	174.5	139.4	139.3
October	7.956	7.954	7.955	10.76 2	4.177	14.52 7	10.12 9	63.46	84.1	100.2	36.6	95.7	176.2	146.6	147.1
November	7.478	7.477	7.478	9.523	3.298	14.17 3	10.73 7	60.16	33.7	49.6	11.4	87.3	180	153.6	154.6
December	7.468	7.467	7.468	9.011	3.102	13.87 4	11.16 5	59.55	162.3	180	167.5	76.9	180	163	162
Total	104.2 8	104.5 2	100.6 1	122.8 8	82.39 3	141.7 0	107.7 5	764.12							

The Figure 60 shows the most energy production panels individually during the year. In most months, more than 12 kWh/m2 of energy were generated for panel 6 during the month.

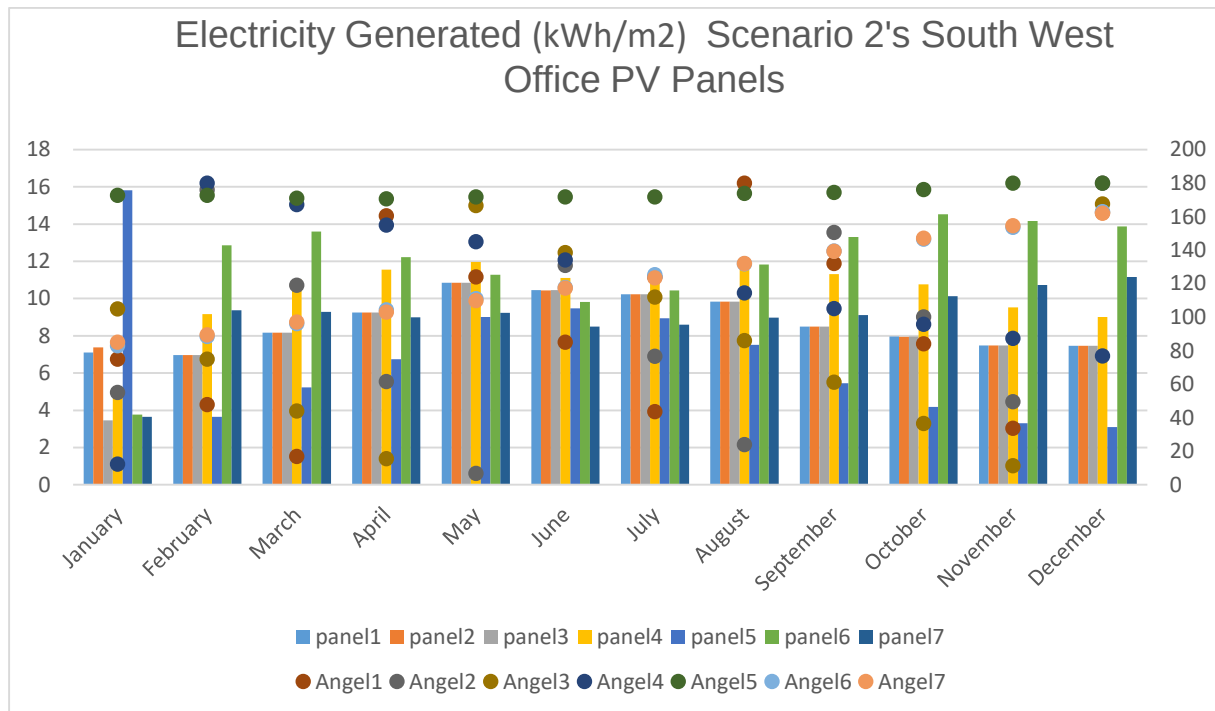


Figure 60:Electricity Generated of scenario 2(Author2022)

5.4.6 South West Office Senario3: Fixed and Dynamic PV Panels

In the third scenario in Table 35, all months did not produce energy less than 60kWh/m2. Where the highest month for energy production is February with 97.77kWh/m2, followed by September and March. The lowest month of energy production is July, with 64.09kWh/m2.

The energy production for each panel varies during the year for each month. Where the highest board that recorded more than 16 kWh/m2 during the year are panel7, panel 4, panel 6 and panel 1as shown in Figure 81.

Table 35:Electricity Generated (kWh/m2) by Scenario 3's South West Office PV Panels
(Author2022)

Electricity Generated (kWh/m2) by Scenario 3's South West Office PV Panels															
Month	panel 1	panel 2	panel 3	panel 4	panel 5	panel 6	panel 7	Total	Angel 1	Angel 2	Angel 3	Angel 4	Angel 5	Angel 6	Angel 7
January	7.076	14.56 5	4.927	17.10 5	6.338	11.22 3	18.87	80.10	151.1	65.3	101.2	180	18.9	141.9	42.2
February	13.08 4	13.99 6	12.85 7	17.93 5	8.746	17.84 2	13.31 6	97.77	151.1	25.3	31.2	180	23.9	16.9	42.2
March	13.36 1	12.62 9	14.81 5	10.16 1	12.43 8	12.93 7	13.22 3	89.56	151.1	25.3	31.2	87.6	23.9	51.9	42.2
April	12.71 3	11.12 3	11.14 4	11.37 7	13.07 5	10.70 4	11.91 1	82.04	151.1	180	31.2	17.6	180	51.9	42.2
May	9.469	10.76 5	12.64 2	8.383	12.69 9	7.315	11.10 1	72.37	151.1	180	31.2	17.6	93.9	180	42.2
June	9.687	10.67 9	5.796	5.975	12.80 4	9.944	13.70 6	68.59	151.1	80.3	31.2	17.6	33.9	91.9	42.2
July	7.986	12.11 7	12.24 4	9.836	5.67	6.194	10.04 9	64.09	151.1	25.3	31.2	92.6	33.9	141.4	42.2
August	10.74	10.72	13.29 2	8.195	13.44 5	11.68 1	10.23 9	78.31	151.1	65.3	31.2	87.6	33.9	151.8	62.2
September	13.01 8	13.19 5	13.49	11.87 4	14.47 8	13.45 1	13.27 7	92.78	151.1	65.3	31.2	87.6	58.9	180	57.2
October	6.295	11.31 2	11.23 2	14.95 8	11.95 6	16.29 3	10.15 4	82.2	151.1	90.3	180	87.6	58.9	36.9	57.2
November	17.21 5	11.51 5	9.802	10.59 2	12.92 2	9.439	10.95 3	82.43	56.1	90.3	21.3	42.6	88.9	36.9	57.2
December	8.221	16.11 6	12.11 1	10.56 2	16.21 8	9.843	8.178	81.24	56.1	180	21.3	42.6	180	36.9	57.2
Total	128.8 6	148.7 3	134.3 5	136.9 5	140.7 8	136.8 6	144.9 7	971.48							

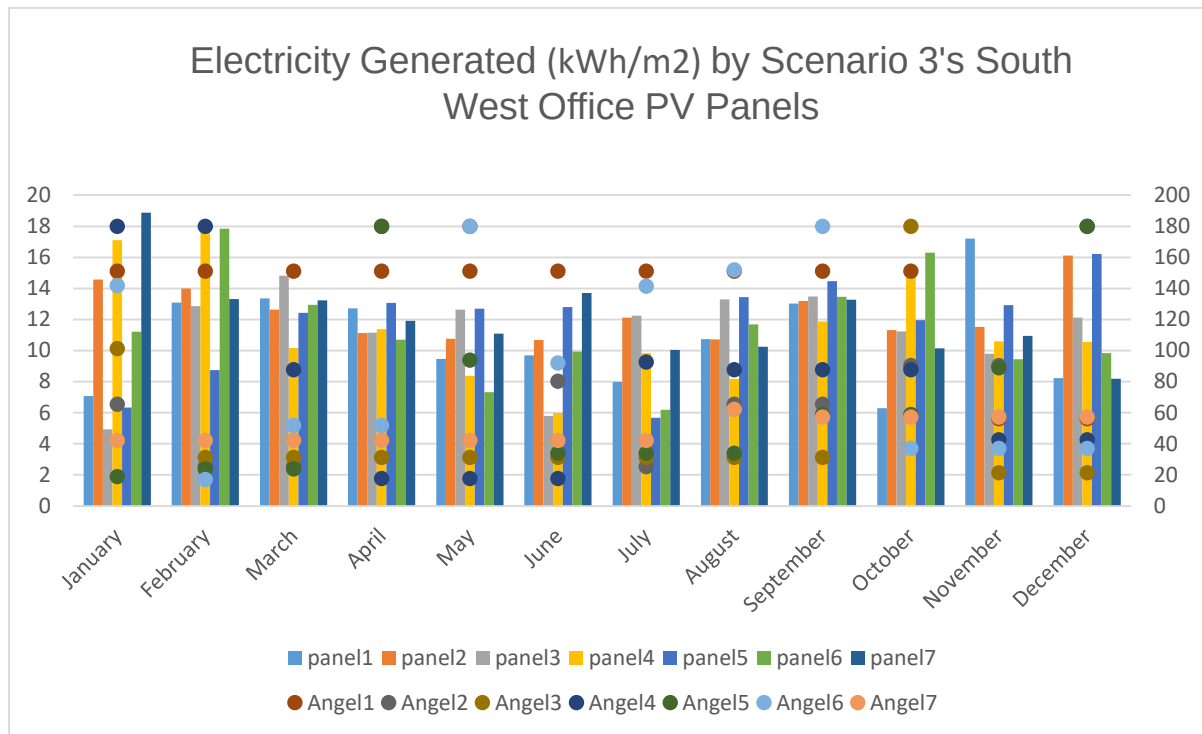


Figure 61:Electricity Generated of scenario 3(Author2022)

5.5 Energy Consumption

In this section, the results of the full energy of the office will be displayed in terms of the energy of electric lighting energy, cooling load, and electric equipment energy for the three scenarios along with two types of smart glass.

5.5.1 Scenario 1: PV panels tracking the sun as a group

Comparison with the Base Case indicates that the first scenario was reduced during the year by more than 30% of the total energy consumption in Table 36. The largest percentage of energy consumption was reduced in November, reaching 46.94% for the second type of glass. While the first glass had the highest rate of decrease in January, with 42.95%.

During the year Figure 62, most months did not consume more than 2300 kWh for both cases of glass. The second type consumed more energy than the first type of glass in the summer months.

Table 36:Energy Consumption of Scenario1(Author2022)

Energy Consumption of Scenario1					
Months	Base Case Energy Consumption(kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	2072.993	1182.621	1127.651	42.95%	45.60%
February	2103.534	1581.684	1217.624	24.80%	42.11%
March	2199.543	1496.548	1194.888	31.96%	43.19%
April	2229.67	1665.26	1520.12	25.31%	46.40%
May	2477.161	1795.738	1758.418	27.50%	29.01%
June	2290.367	1734.450	1865.961	24.27%	18.53%
July	2658.498	1995.754	2223.034	24.92%	16.38%
August	2752.611	2071.138	2312.688	24.75%	13.00%
September	2709.752	2057.017	2089.347	24.08%	24.09%
October	2734.965	1671.231	1893.671	38.89%	30.11%
November	2454.959	1734.485	1451.015	29.34%	46.94%
December	1990.125	1267.404	1080.874	36.31%	45.68%
Total	29187.664	20253.330	19735.291	30.61%	32.38%

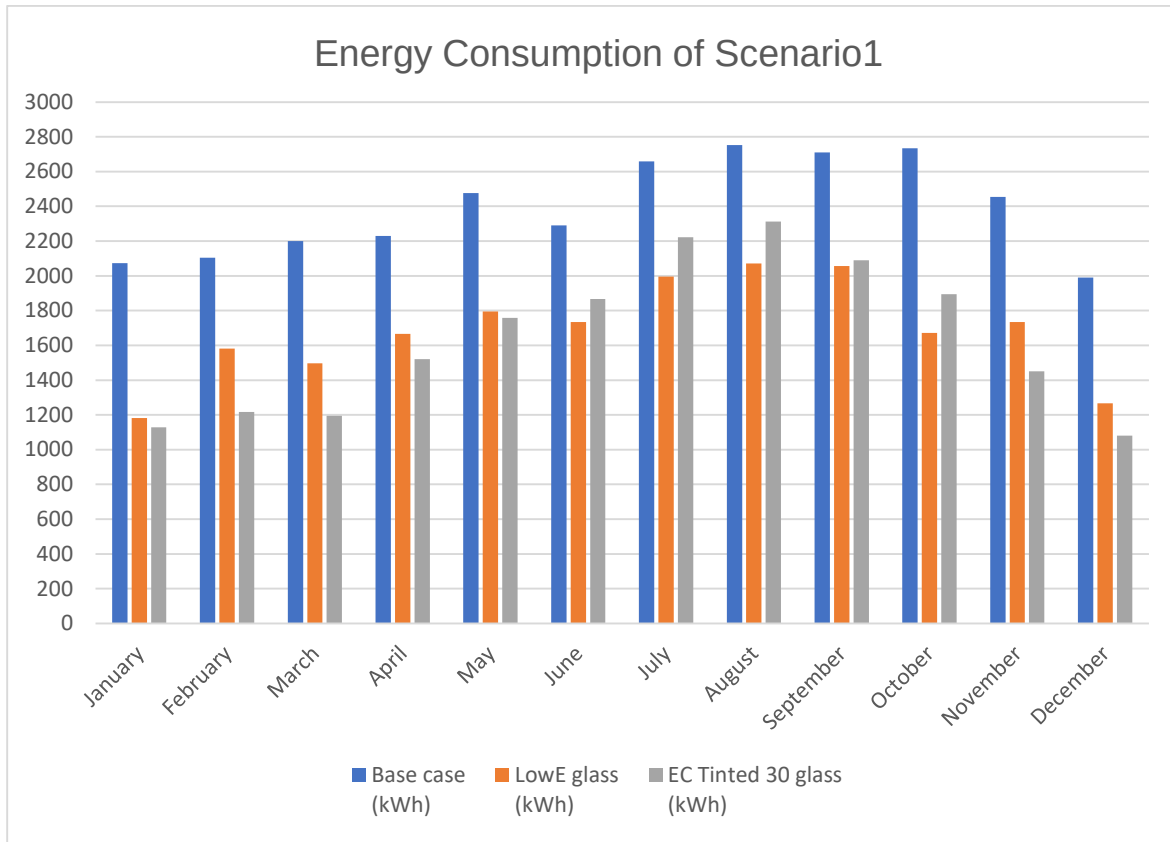


Figure 62:Energy Consumption of Scenario1 over Base Case (Author2022)

5.5.2 Scenario 2: PV panels tracking the sun as Individual

Moving to the second scenario in Table 37, the second type of glass achieved a reduction in the total energy consumed during the year by more than 33%. The highest energy reduction month for both types of glass is December, followed by November. The lowest energy reduction percentage was recorded in July for both glass cases.

Table 37:Energy Consumption of Scenario2(Author2022)

Energy Consumption of Scenario2					
Months	Base Case Energy Consumption(kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	2072.993	1559.491	1296.481	24.77%	37.45%
February	2103.534	1595.764	1337.514	24.13%	36.41%
March	2199.543	1617.608	1367.498	26.45%	37.82%
April	2229.67	1755.83	1543.62	21.25%	30.76%
May	2477.161	1916.908	1756.858	22.61%	29.07%
June	2290.367	1837.981	1698.181	19.75%	25.85%
July	2658.498	2149.864	2001.274	19.13%	24.72%
August	2752.611	2185.128	2016.088	20.60%	26.75%
September	2709.752	2124.427	1889.487	21.60%	30.27%
October	2734.965	2097.401	1827.441	23.31%	33.18%
November	2454.959	1778.685	1515.505	27.54%	38.26%
December	1990.125	1219.974	1002.174	38.69%	49.64%
Total	29187.664	21839.061	19252.121	25.17%	34.04%

Energy consumption during the year indicates a decrease, starting from the winter season, with a gradual increase in the summer season, and a return to decline during the fall. The consumption values for both types of glass vary, but the second type performs better in terms of lower consumption for all months as shown in Figure 63.

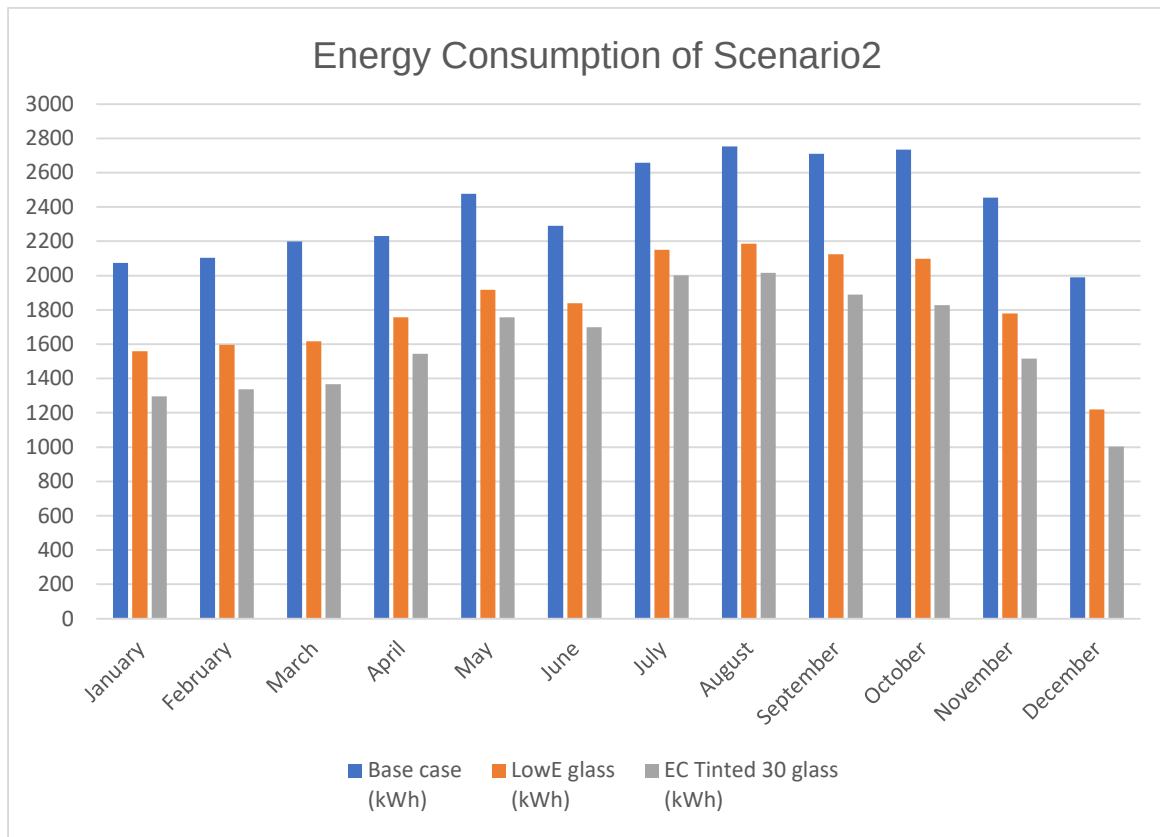


Figure 63:Energy Consumption of Scenario2 over Base Case (Author2022)

5.5.3 Senario3: Fixed and dynamic PV panels

In this scenario in Table 38, the energy consumption was reduced up to 37% during the year for the second glass type. Where the highest month for the percentage of total energy consumption reduction is December for both glass type with 56.96% for the second glass and 53.24% for the first glass, followed by January and November. The lowest percentage of reduction exceeded 20% in July for both glasses in Figure 64.

Table 38:Energy Consumption of Scenario3(Author2022)

Energy Consumption of Scenario3					
Months	Base Case Energy Consumption(kWh)	LowE glass (kWh)	EC Tinted 30 glass (kWh)	Energy Saving Percentage Over Base Case (LowE glass)	Energy Saving Percentage Over Base Case (Tinted 30 glass)
January	2072.993	1294.691	1213.171	37.54%	41.47%
February	2103.534	1313.634	1244.753	37.55%	40.82%
March	2199.543	1393.868	1303.058	36.62%	40.75%
April	2229.67	1566.77	1483.040	29.73%	33.48%
May	2477.161	1816.058	1728.28	26.68%	30.23%
June	2290.367	1720.81	1574.770	24.86%	31.24%
July	2658.498	2031.244	1945.804	23.59%	26.80%
August	2752.611	2073.798	1979.958	24.66%	28.06%
September	2709.752	1893.717	1804.597	30.11%	33.40%
October	2734.965	1830.471	1730.291	33.07%	36.73%
November	2454.959	1532.725	1438.684	37.56%	41.39%
December	1990.125	930.544	856.514	53.24%	56.96%
Total	29187.664	19398.33	18302.930	33.53%	37.29%

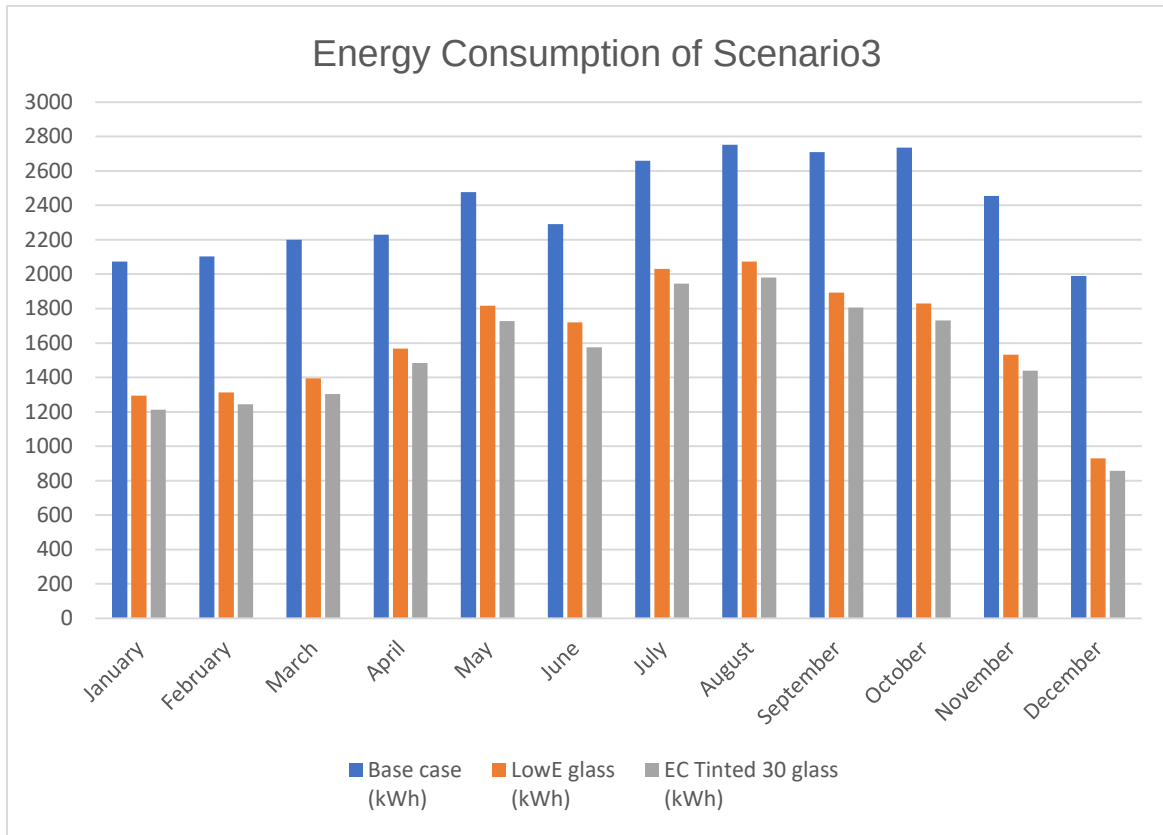


Figure 64:Energy Consumption of Scenario3 over Base Case (Author2022)

CHAPTER 6 : SUMMARY OF THE SCENARIOS COMPARISON

In this section, all results will be summarized for all the scenarios that were presented for the various types of testing in terms of energy consumption and PVs generated energy. The scenarios have been compared with each other, and the best scenario will be determined in terms of less energy consumption, compared to the actual bills of the building.

6.1 Comfort visualization

he third scenario Figure 65 achieved relatively stable results within the visual comfort of both types of glass for the south and southwest office, as the average value of glare did not exceed 600 cd/m^2 during the year.

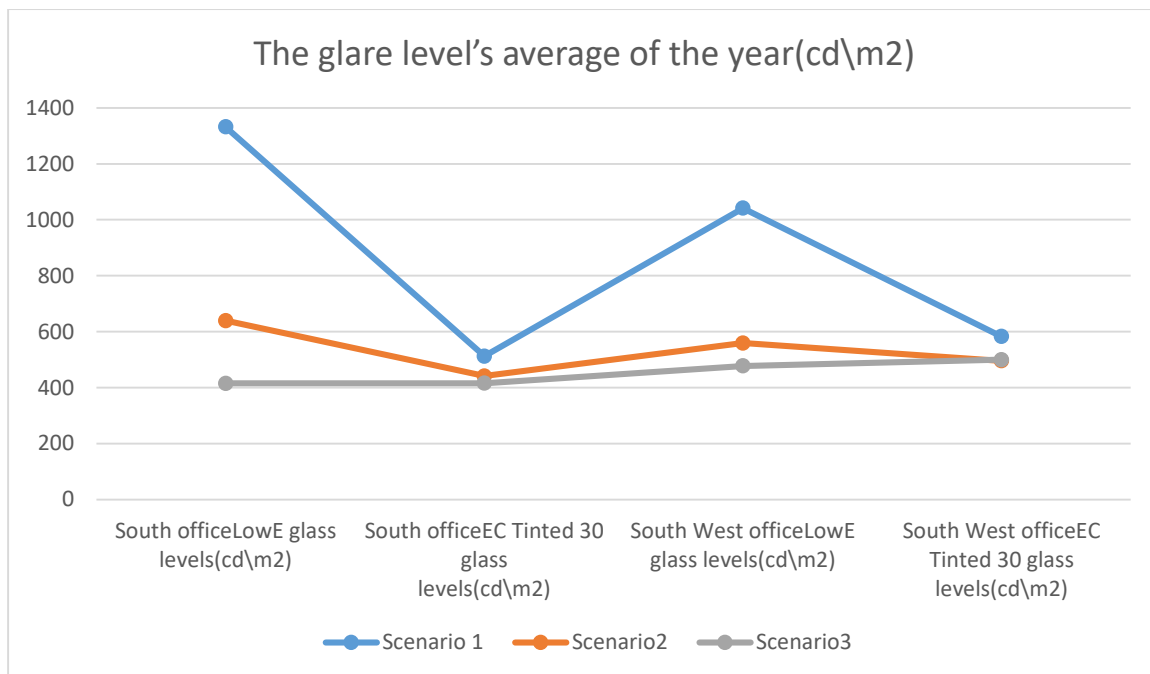


Figure 65:The glare level's average of the year(cd/m^2) of three scenario (Author2022)

6.2 Electrical lighting Energy

The Figure 66 below indicates a comparison of the percentage reduction of the scenarios with the Base Case of artificial lighting energy for both offices (south and southwest). The third

scenario, with the Tinted glass type, achieved the highest percentage 81.75% of energy reduction during the year. This is followed by the third scenario for the same type of glass, as the percentage of reduction is the second scenario for the same type of glass is presented after this because the decrease percentage is comparable.

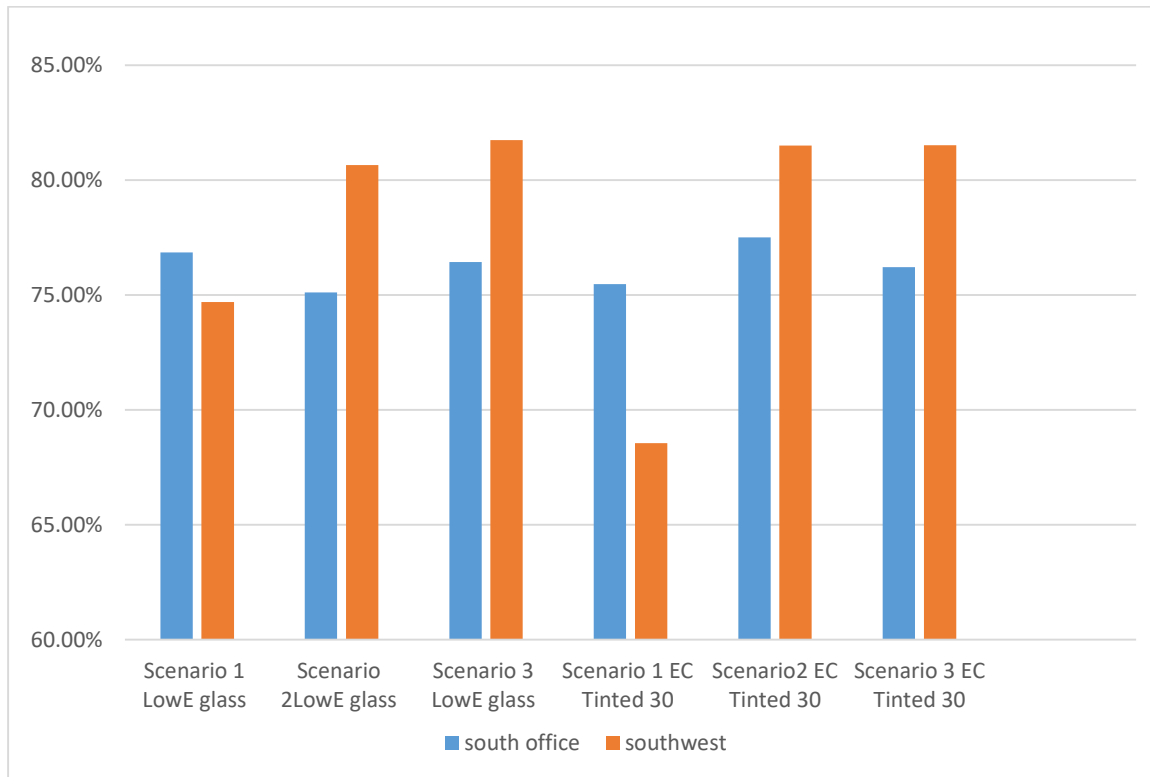


Figure 66: Three scenarios comparison of electrical energy reduction (Author2022)

6.3 Cooling load energy

As for the consumption of cooling energy in Figure 67, the highest percentage of energy reduction with the Base Case is also for the third scenario by 72.01% in lowE glass, where the two types of glass for the scenario achieved a close percentage and they are the highest compared to the other cases.

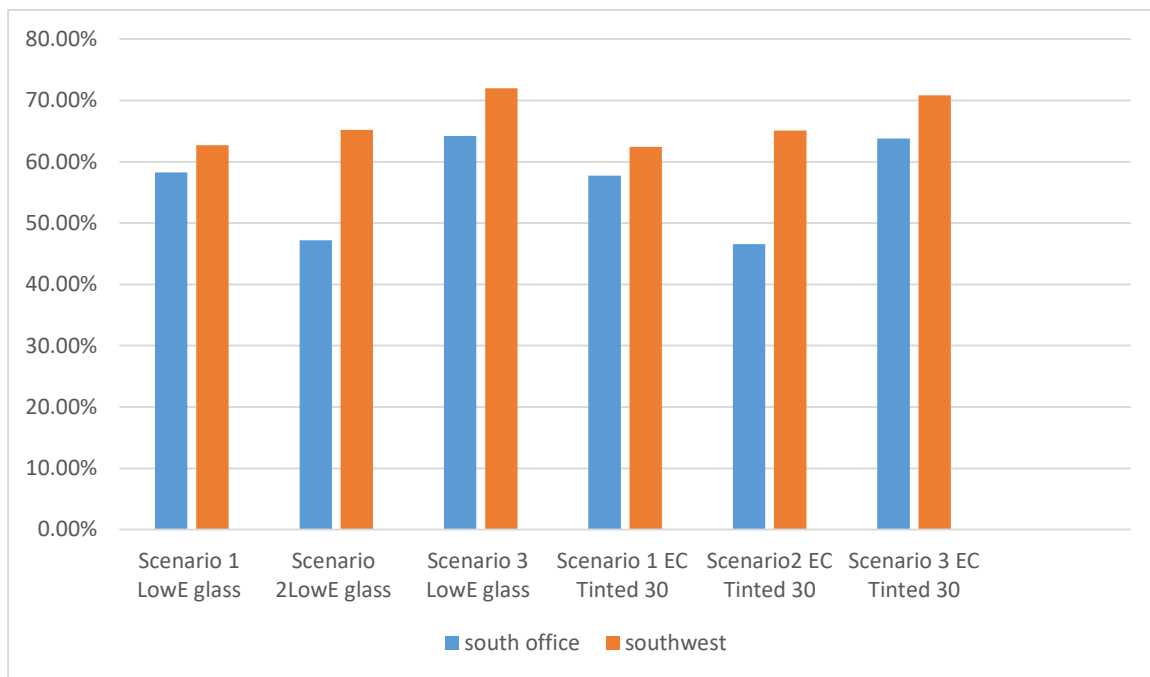


Figure 67: Three scenarios comparison of cooling load energy reduction (Author2022)

6.4 PV-Generated Energy

Compared to the third scenario in Figure 68 for energy generation, the highest values for the year were for the southern side of the office, where the highest value scenario for generation is the last.

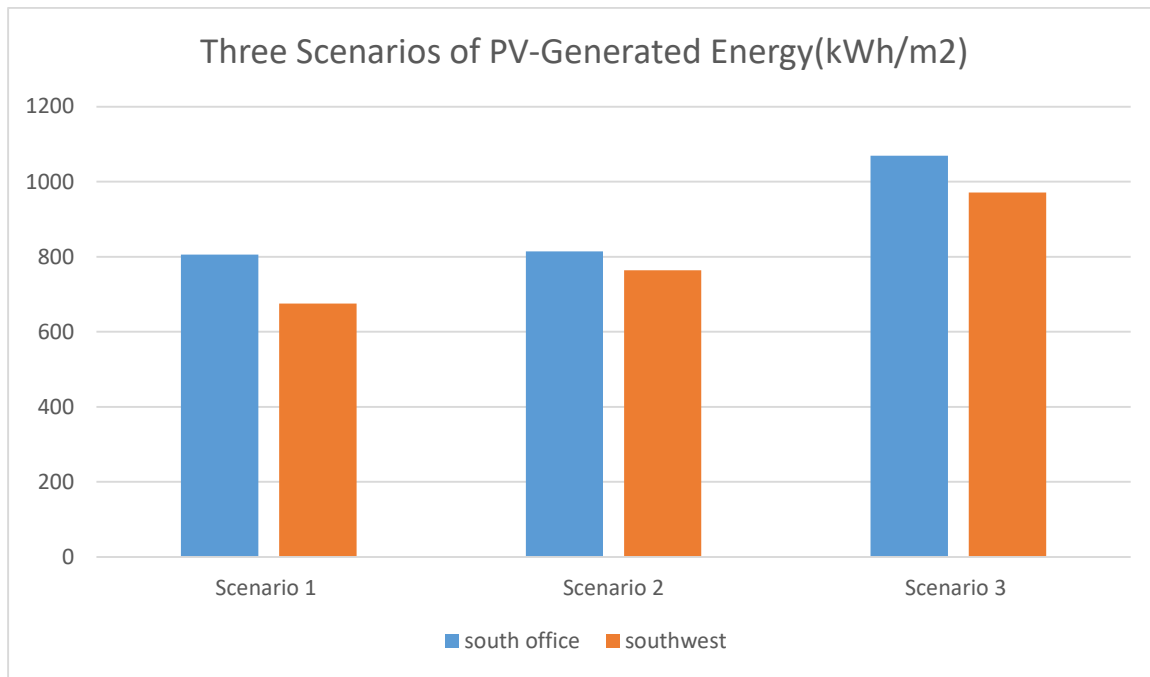


Figure 68:PV-generated energy for the three scenarios (Author2022)

6.5 Energy Consumption with PV-Generated Energy

The Figure 69 below shows a comparison of the scenarios and their reduction percentage with the Base Case. The energy consumption includes the total of cooling load, lights and electrical equipment for the whole building. The third scenario achieved the highest rate of reduction, as it exceeded 35% during the year along with EC Tinted glass.

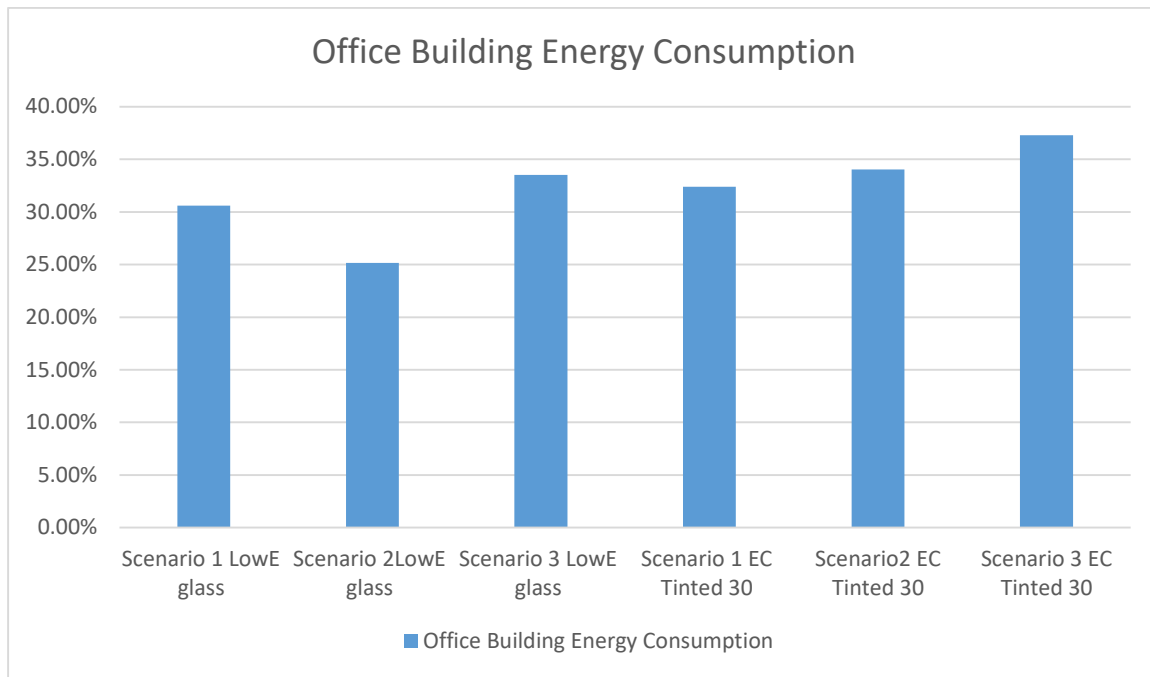


Figure 69: The total energy consumption of the office building (Author2022)

The final investigation from verifying the performance of the solar panels that the best performance in terms of all types of energy and visual comfort is the third scenario. The highest energy was generated from PVs panels during the third scenario, as the total electrical energy during the year was 2041.0kWh/m². The table and the drawing indicate the extent to which the chosen scenario was reduced in addition to energy generation, as the percentage of reduction was approximately 43%, along with the actual bills for the building's electricity energy.

Table 39:Energy Consumption of Scenario3 with PV generated energy (Author2022)

Energy Consumption of Scenario3					
Months	Actual bills energy consumption(kWh)	Base Case Energy Consumption(kWh)	EC Tinted 30 glass (kWh)	PVs Generated Energy	Total senario3 energy consumption
January	2095.04	2072.993	1213.171	188.49	1024.681
February	2119.68	2103.534	1244.753	197.14	1047.613
March	2266.19	2199.543	1303.058	180.08	1303.058
April	2248.35	2229.67	1483.040	165.59	1317.45
May	2474.32	2477.161	1728.28	146.75	1581.53
June	2287.29	2290.367	1574.770	134.26	1440.51
July	2638.43	2658.498	1945.804	128.78	1817.024
August	2743.77	2752.611	1979.958	155.25	1824.708
September	2684.40	2709.752	1804.597	182.23	1622.367
October	2741.01	2734.965	1730.291	183.25	1547.041
November	2466.86	2454.959	1438.684	187.16	1251.524
December	1997.31	1990.125	856.514	192.03	664.484
Total	28762.65	29187.664	18302.930	2041.01	16441.99
% Reduction over actual bills			43.4617%		

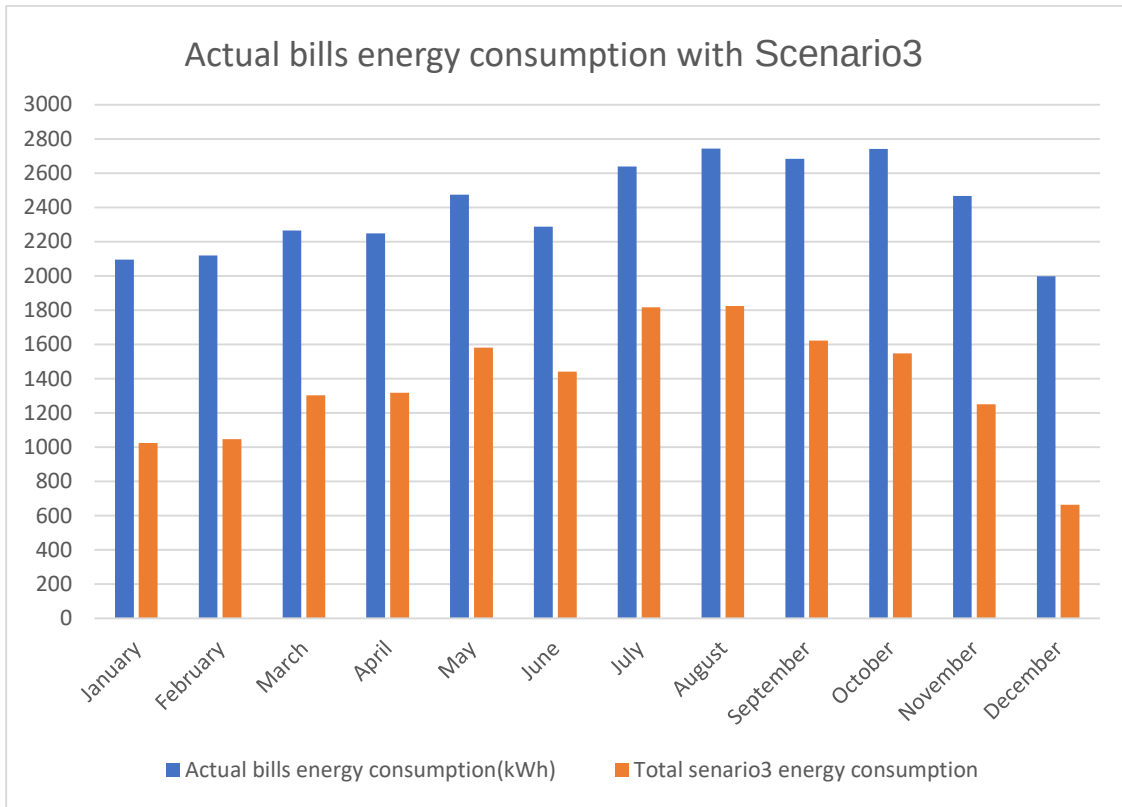


Figure 70:Actual bills energy consumption with scenario3(Author2022)

CHAPTER 7 : CONCLUSION

Smart facades are one of the most important elements in modern architecture and their impact on energy consumption in the construction sector is widespread. Studies have shown that the effect of facades on energy consumption is inevitable, as the glazing of windows for buildings has spread widely, which has led to pressure in terms of energy consumption, especially in cities in hot regions.

This study was carried out to verify the dynamic performance of smart facades to solve the problem of buildings with high-glazing windows and the task of the early design of smart facades to reduce energy consumption and benefit from direct sunlight to generate energy.

Through the literary review of previous research, there is little or no research in terms of dynamic solar panels for architectural facades, where most of the focus was on fixed ones during the year with one angle. Especially in the Arabian Gulf, specifically the UAE. Most countries in the world are used direct glazing panels constantly to generate thermal energy for buildings. This research focuses on the efficiency of solar panels, not only in terms of power generation, but also in shading performance, energy consumption, and visual comfort.

The proposed scenarios were adopted according to the movement of the sun, meaning that the plates take angles that follow the sun's azimuth for each month during the year. Unquestionably, every month has different angles during the year, and therefore the results differed despite the use of the same angle in most of the scenarios that carry fixed angles. The scenarios included different glazing materials and were selected according to the recent uses of smart glazing to reduce energy consumption. Note that the office in which the study was conducted had a high percentage of glazing in terms of office space, as the level of glare was exceeding the acceptable glare for visual comfort and was reduced after the scenarios by more than 50%. The glare values were higher in the south office compared to the southwest, where after using the scenario1 the glare values average for low glass exceeding 1000cd/m^2 . for scenarios 2 and 3 the values not exceeding 600cd/m^2 for two glasses, however, tinted glass was controlling stable values during the year for both offices (south, southwest).

The number of all angles during the year for the three scenarios was 314 angles. That Simulations were done monthly for each scenario. The panels were distributed on the two windows of the building. The study indicated that the offices accompanied by the window consumed more than 30% of the total energy for the entire building, where, after applying the scenarios, the lowest percentage of reduction was 68% for the southwest office.

The highest scenario in lighting energy reduction was scenario 3 of the southwest office, where recorded 81% in lowE glass and tinted type. also, cooling load height reduction was 72% in scenario 3 southwest with lowE glass and 70.8% of reduction for type tinted glass for the same scenario.

As for cooling energy, more than 40% of consumption has been reduced for offices exposed to glazing. In terms of energy consumption for the whole building, the highest percentage of energy reduction other than the generated energy amounted to 37.29% when applying the third scenario. It was concluded that it is not possible to adopt one angle for a specific month or a specific place, when the panels move individually. as the energy generation for each panel differs based on various factors, including the angles of the sun and the shades of the panels themselves, as the panels are affected when they move next to each other, which affects the efficiency of energy production. Where the angle may be repeated for the same month, but the electricity production differs. The highest energy values recorded in south office panels for scenario 3.

7.1 Further work and Recommendation

The simulation stage is important when installing solar panels, especially dynamic ones. It is also possible to reach more than one absolute angle to generate the highest amount of energy during the year. The angle varies for several factors, including the shadows, the location, the height of the building, and also the efficiency of the panels. It is not possible to adopt an angle for a specific place for another place, but it is possible to change angles and factors to reach fixed angles during the year for the highest relative generation of energy. The facades of the buildings still lack in-depth studies in terms of the types of solar panels, especially in hot regions.

The research focused on the performance of the panels in terms of energy, lighting, and different angles during the year. Thus, one of the limits of the study is to discuss the economic analysis of using the panels in addition to the mechanical system. Thus, an extension of this research in

the future may be the technique of fixing the panels from the mechanical and financial side. Especially for existing buildings, as installing panels from the early stage during design and planning may avoid countless difficulties in terms of installation and space.

In addition to the aesthetic aspect of the facades, recently dealing with solar panels has become more flexible through the increase in the number of factories manufacturing panels in different shapes, sizes, and technologies competing globally in the current situation. There are still limitations also in terms of using solar panel technologies for software simulation as well as dynamics.

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