

**ASSESSMENT OF THE IMPACTS OF VARIOUS SMART
WINDOW GLAZING SYSTEMS ON ENERGY AND DAYLIGHT
PERFORMANCE IN OFFICE BUILDING**

BY

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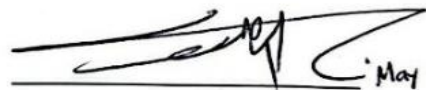
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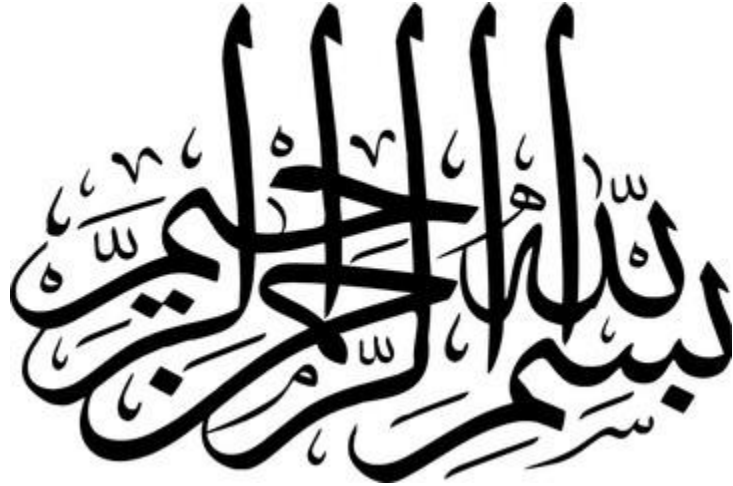
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DEDICATION



This work is Dedicated to my parents:

**Late Alqady Haruna Sa'eed Dukku &
Aishah Idris Pindiga.**

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ABSTRACT

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This study evaluated the impacts of smart windows on building energy consumption and daylight performance. The study identified and focused on six smart windows which are available in market, these are Electrochromic (EC), Gasochromic (GC), Polymer dispersed liquid crystal (PDLC), Photochromic (PC), Suspended particle device (SPD) and Thermochromic (TC) windows. The identification was carried out through extensive reviews of literature and related industrial reports. Relevant properties of the six smart windows were obtained from manufacturers databases and some published research work. These properties were used in *DesignBuilder* V7.3 to model and simulate energy consumption and daylight performance in a typical office building with each of the identified smart windows and under three different climate zones: hot-humid (Jeddah), hot-dry (Riyadh) and moderate (Taif) climates across Saudi Arabia. The study further evaluated the building energy consumption with different window-to-wall ratios (WWR) and identified the optimal WWR for each window under each climate. Moreover, the study evaluated daylight performance of the windows using sDA and UDI as performance metrics. The results of the study indicated that optimum WWR for smart windows in all three climates ranges between 50%-70%. In Jeddah, energy savings of up to 15.6%, 13%, 18%, 15.5%, 14% and 8.6% is achieved with EC, GC, PC, PDLC, SPD and TC windows respectively. In Taif, 11%, 18%, 24%, 23%, 21% and 9.7% of energy can be saved with EC, GC, PC, PDLC, SPD and TC windows respectively. In Riyadh, up to 13.7, 16.7, 25, 23, 19 and 11% energy can be saved with the EC, GC, PC, PDLC, SPD and TC windows respectively. Smart windows save energy mainly in summer months and are less effective in winter due to blockage of solar radiation which is required in the winters. Moreover, smart windows offer significant reduction in cooling peak load: highest peak load reduction is achieved with PC

windows which saves 27%, 25% and 14% peak load in Jeddah, Taif and Riyadh respectively, whereas lowest reduction in peak is seen with TC window which reduces 5%, 3% and 9% peak load in Jeddah, Taif and Riyadh respectively. These will enable a reduction in HVAC system size thereby reducing total initial installation cost. Daylight metrics show acceptable performance under all climates: sDA show 65-75% in all scenarios whereas UDI ranges between 60-80% in all scenarios, which show very good performance based on t ratings of LEED v4.1. Further economic and environmental assessments show significant reduction in annual energy cost and associated carbon emission. However, analysis of cost-benefits revealed that PDLC and GC windows have longer payback periods than their service lives and should therefore be used in private rooms and not facades, whereas EC, PC, TC and PDLC offer greater benefits than their investment costs and can therefore be applied for energy efficiency purposes. |

ملخص الرسالة

الاسم الكامل: عمر هارون

عنوان الرسالة: تقييم تأثير أنظمة التزجيج الذكية المختلفة على أداء الطاقة والإضاءة الطبيعية في المباني المكتبية

التخصص: الهندسة المعمارية

تاريخ الدرجة العلمية: مايو 2025 :

قيمت هذه الدراسة تأثير النوافذ الذكية على استهلاك الطاقة في المباني وأداء الإضاءة الطبيعية. وقد حددت الدراسة وركزت على ستة أنواع من النوافذ الذكية المتوفرة في السوق، وهي: النوافذ الإلكترومترونية (Electrochromic - EC)، النوافذ الغازومترونية (Gasochromic - GC)، النوافذ البلورية السائلة المشتتة في البوليمر (Polymer Dispersed Liquid Crystal - PDLC)، النوافذ الضوئية (Photochromic - PC)، النوافذ ذات الجسيمات المعلقة (Suspended Particle Device - SPD)، والنوافذ الحرارية (Thermochromic - TC).

تم تحديد هذه الأنواع من خلال مراجعة موسعة للأدبيات العلمية والتقارير الصناعية ذات الصلة. وتم جمع الخصائص الفنية المتعلقة بهذه النوافذ الستة من قواعد بيانات الشركات المصنعة وبعض الدراسات البحثية المنشورة. تم استخدام هذه الخصائص في برنامج DesignBuilder V7.3 لنمذجة ومحاكاة استهلاك الطاقة وأداء الإضاءة الطبيعية في مبنى مكتبي نموذجي باستخدام كل نوع من النوافذ الذكية المذكورة، وذلك تحت ثلاث مناطق مناخية مختلفة في المملكة العربية السعودية: المناخ الحار الرطب (جدة)، الحار الجاف (الرياض)، والمعتدل (الطائف).

علاوة على ذلك، قامت الدراسة بتقييم استهلاك الطاقة في المبنى مع نسب مختلفة من مساحة النوافذ إلى الجدار (WWR)، وتم تحديد النسبة المثلى لكل نافذة ضمن كل مناخ. كما تم تقييم أداء الإضاءة الطبيعية باستخدام مؤشر sDA (معدل التوفر النهاري) و UDI (مؤشر التوزيع المفيد للضوء الطبيعي) كمقاييس للأداء.

أظهرت نتائج الدراسة أن النسبة المثلى لمساحة النوافذ إلى الجدار في جميع المناخات الثلاثة تتراوح بين 50% إلى 70%. وفي جدة، تم تحقيق توفير في الطاقة بنسبة تصل إلى 15.6%، 13%، 18%، 15.5%، 14% و 8.6% باستخدام نوافذ EC، GC، PC، PDLC، SPD و TC على التوالي.

أما في الطائف، فقد أمكن توفير 11%، 18%، 24%، 23%، 21% و 9.7% من الطاقة على التوالي لنفس أنواع النوافذ. وفي الرياض، وصلت نسبة التوفير إلى 13.7%، 16.7%، 25%، 23%، 19% و 11% على التوالي.

توفر النوافذ الذكية في استهلاك الطاقة بشكل رئيسي خلال أشهر الصيف، لكنها أقل فعالية في الشتاء بسبب حجبها للإشعاع الشمسي الضروري خلال هذا الفصل. كما توفر هذه النوافذ تقليصًا ملحوظًا في حمل التبريد الأقصى، حيث سجلت نوافذ PC أعلى نسبة في تقليل حمل الذروة بنسبة 27% في جدة، 25% في الطائف، و 14% في الرياض. في المقابل، أظهرت نوافذ TC أدنى نسبة تقليل حمل الذروة بنسبة 5%، 3% و 9% في المدن الثلاث على التوالي. هذا من شأنه تقليل حجم نظام التكييف (HVAC) وبالتالي خفض تكلفة التركيب الأولية الإجمالية.

أظهرت مؤشرات الإضاءة الطبيعية أداءً مقبولاً في جميع المناخات، حيث تراوحت قيم sDA بين 65%-75%، بينما تراوحت قيم UDI بين 60%-80%، وهو أداء ممتاز حسب تقييمات معيار LEED v4.1.

كما أظهرت التقييمات الاقتصادية والبيئية انخفاضًا كبيرًا في تكلفة الطاقة السنوية والانبعاثات الكربونية المرتبطة بها. ومع ذلك، كشفت تحليلات التكلفة والمنفعة أن نوافذ PDLC و GC تمتلك فترات استرداد أطول من عمرها الافتراضي، ولذلك يُوصى باستخدامها في الغرف الخاصة وليس في الواجهات. أما نوافذ EC و PC و TC و PDLC، فإن فوائدها تتجاوز تكاليف الاستثمار فيها، وبالتالي يمكن استخدامها لأغراض تحقيق كفاءة الطاقة.

CHAPTER 1: INTRODUCTION

1.1 Background

One of the fundamentals of realizing a nation's socioeconomic development is the construction sector particularly the infrastructure and buildings (Alfalah et al., 2023). In Saudi Arabia, the consumption of electricity accounts for one-third of daily nations oil production out of which 80% goes to building energy consumption (Felimba, et., 2019). Buildings are known to imply significant costs throughout their life cycle; from cradle-to-grave. However, an important element in reducing initial and operation cost of building is the building envelope performance (Alshamrani et al., 2017). The building envelope plays a significant role in controlling the energy consumed in the building and regulates the indoor environmental quality in the buildings (Khalifa et al., 2023a).

However, the main deficiencies of traditional building envelopes lie in the rivalry between their static behavior and the dynamic external environment, this triggered attention to the need for dynamic envelope systems such as smart windows which are usually made from materials that can easily switch between transparent state to an opaque, translucent, and reflective state (Carlucci, 2021). Depending on the presence or absence of an external stimulus, the smart materials have different characteristics and performance and can combine the dual function of a sensor which can sense the changes in external stimulus and actuator which can change the material properties (Sommese et al., 2023).

With the understanding that traditional building material doesn't adjust their property with change in the environmental condition, smart materials have become a trending topic of

research in the field of sustainable architecture and facade technology(Elaheh Najafi & Mohsen Faizi, 2017)

Under the traditional practice, the building envelope selection can be influenced by cost constraint, local availability and technical input, which affects their overall performance (Alfalah et al., 2023).

In hot climate, the external climatic characteristic (temperature and daylight) can be utilized in controlling the dynamic behavior of certain smart glazing such as those that respond to heat and light (Imbert et al., 2019a). Range of smart glazing exists as covered in many studies, these include thermochromic, electrochromic, photochromic, mechanochromic, humidity chromic, liquid crystal windows and so on (S. Wu et al., 2023). Several studies evaluated the energy performance of using EC smart glazing in buildings, while studies on other smart glazing materials were mainly introduction to performance improvement strategies.

Subsequent studies including those studies by: (Wu et al., 2023; Khalifa et al., 2023b); (Budaiwi & Abdul Fasi, 2023); (Budaiwi & Abdul Fasi, 2023) and (Mustafa et al., 2023a) have evaluated energy performance of different smart glazing. Interestingly, most of them were limited to EC windows & few on TC windows but none of them considered including other recent smart glazing such as the liquid crystal (LC) and suspended particle devices (SPD). In addition, the previous studies did not provide for evaluating their performance based on different WWR.

However, it is important to look at these windows particularly on energy & daylighting to form a basis of comparison with each other and with other non-smart windows with a view to understanding their optimum usage and effects on daylighting.

1.2 Problem Statement

The increasing demand for energy efficient building has brought more attention and growing concern to the advancements in building envelopes, particularly smart glazing systems. These systems such as electrochromic, thermochromic, and photovoltaic glazing offer the potential to dynamically manage solar heat gain and natural light, significantly improving energy efficiency and indoor comfort (Karakaya & Özgünler, 2022). Despite their potentials, there is a notable lack of in-depth research that examines the effects of different WWR on the energy consumption and daylighting levels, especially as it relates to different climatic regions like those found in the Kingdom of Saudi Arabia.

In hot climates, office buildings, especially those with high proportion of window-to-wall experience intense exposure to sun, which leads to substantial energy demands (Mumme et al., n.d.). Conventional glazing systems often fail to adequately reduce solar heat gain, resulting in increased energy consumption and higher operational costs. Smart glazing technologies, with their capability to adjust their physical properties in response to external conditions could offer a promising solution to this problem (Rezaei et al., 2017). However, the adoption of these technologies has been slow, largely due to concerns about their initial costs, uncertainties about long-term financial benefits and probably inadequate guideline towards the integration of these systems (Moghaddam et al., 2023); Harmathy, n.d.). Determining the energy saving potential and evaluating the effects of different window to wall ratio (WWR) is crucial in evaluating the performance of smart window glazing system in office building (Nunes et al., 2019).

Most of the existing studies focused on the energy performance of individual smart glazing technologies without comparing them with other smart windows, with no specification on

optimum WWR and with little economic evaluation over the building's lifespan. Other parts of the existing studies focus on improving the thermal properties of smart materials, light transmittance or control strategy of smart glazing whereas as some studies are merely on material development and not their applicability to real buildings. The previous studies were limited to either electrochromic or thermochromic smart windows and could not evaluate their performances at different WWR & across different climates.

This research intends to bridge the gap by assessing the impacts on energy & daylighting, with a view to evaluating the best WWR of various smart glazing systems (particularly those that are commercially available), in office building across different climates.

Table 1 Summary of previous studies and research gap.

	Reference	Budaiwi & Fasi	Lontonio & Krarti	Arnesano et al.	Khalifah et al.	Carlucci (SLR)	Harmathy	Mustafa et al (SLR)	Wu et al. (SLR)	Elmilgy at al.	Cabral & Blanchet	Imbert et al.	Lin et al.	ALJalal et al	Tao et al.	Liang et al	Haruna et al (Proposed)
	Year	2023	2022	2021	2023	2021	2016	2023	2023	2024	2023	2019	2016	2023	2022	2021	2025
	Location	KSA	USA	Italy	Egypt	-	Multiple	Jordan	China	Egypt	Denmark	Danish	Taiwan	KSA	China	China	KSA
	Building Type	Office	Office	Office	Office	---	Comm.	---	Multi.	Office			Office	Resid.	-----	Office	Office
	Envelope	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Energy Analysis	•	•	•	•		•			•	•	•	•		•		•
	Daylight Assessment																•
	WWR Evaluation									•				•			•
	Design Optimization		•			•	•			•				•		•	
Targeted windows	EC	•				•				•							•
	LC																•
	SPD																•
	GC					•										•	•
	TC			•		•		•	•		•	•			•	•	•
	PC					•		•									•

1.3 Aim and Objectives

This study aims to assess the performance of various smart window glazing systems in office buildings to evaluate their performance based on energy, and lighting with a view to revealing optimum WWR.

- i. To investigate the impact of applying different types of smart windows on energy consumption of office buildings.
- ii. To assess the effects of each type of smart windows on the acceptable daylighting levels in the office building.
- iii. To evaluate the effects of different window-to-wall ratio (WWR) on energy consumption and daylighting for each of the identified smart window systems.

1.4 Scope and Limitation

This study will be limited to office buildings in three different climates in Saudi Arabia: looking at various smart windows to assess their impacts on energy and daylighting, while evaluating the best WWR of each of the smart window glazing systems.

- The study will cover six different smart glazing identified based on market availability and applicability in office buildings.
- While studying different smart glazing, it will be investigated across three different cities in Saudi Arabia: Jeddah, Taif and Riyadh representing hot-humid, moderate and hot-dry climates respectively.

1.5 Significance

It is important to consider the fact that smart windows adjust to their environment to provide better indoor condition, the smart glazing application in buildings is still under

evaluation. Studying their potential should not only be limited to impacts on energy consumption but should consider their optimum WWR to use in integrating them. The significance of this study can be described in two ways:

- It will aid designers in early design decisions when integrating smart glazing as part of office building façade to minimize energy costs over their useful lives.
- It will aid policy makers in the development of guidelines and regulations on using smart windows in buildings (which are lacking in most national and international building codes of the present) and promote environmental conservation policies.

CHAPTER 2 LITERATURE REVIEW

2.1 Building Envelopes Systems

Building envelopes are all outer building elements that separate the interior space from the exterior environment. This encompassing roofs, exterior walls, ground-contact floors, and the outer surfaces of buildings, which play a critical role in interacting with the environment and facilitating energy exchange with the outdoors (Elaheh Najafi & Mohsen Faizi, 2017). Therefore, they are essential in maintaining comfortable conditions within buildings.

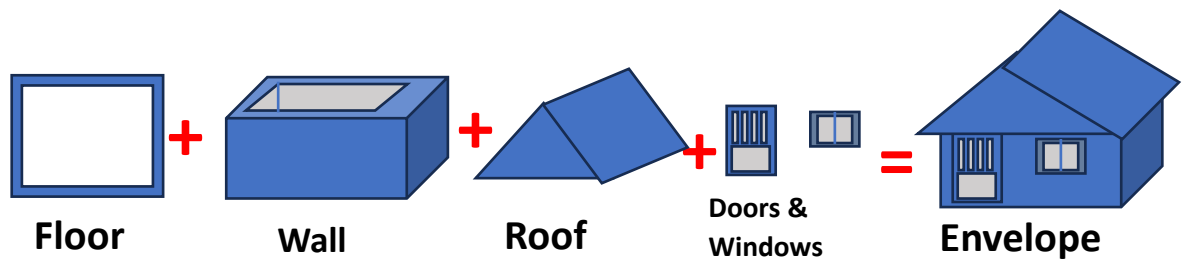


Figure 1: Elements of the building envelope. Source (Wang & Wei, 2021)

The primary functions of the building envelope are *thermal regulation* which helps in maintaining a stable indoor temperature by minimizing heat loss and heat, *moisture control* which protects the interior from rain, snow, and humidity, providing *privacy & security*, preventing moisture from penetrating & causing damage and to serve as *air barrier* which prevents unwanted air infiltration & exfiltration, enhancing the building's energy efficiency and indoor air quality (Ascione et al., 2019). Other functions of the building envelope include providing *structural support*, *providing sound insulation*, improving *aesthetical appearance*, and allowing for the integration of *natural light & ventilation* by incorporate windows and ventilation systems that allow natural light and air to enter, improving IAQ and reducing the need for artificial lighting (Ascione et al., 2019).

However, the issue of sustainability causes continuous transition from one envelope material to another over time. The material availability, cost implications and impacts on the environment are the key determinants of the sustainability of envelope materials (AlJalal et al., 2023).

2.2 Sustainability of Envelope Systems

In the light of green building design concept, sustainability of building envelope is a critical aspect known to impact energy efficiency, indoor environmental quality and overall performance of a building (Tao et al., 2022). Energy efficiency is impacted by thermal insulation, air tightness and solar heat gain control offered by the envelope (Singh et al., 2017a). The indoor environmental quality in a building is impacted by the moisture control offered by the envelope material as well as integration of natural light & ventilation through the envelope (Harmathy et al., 2016).

Building envelopes can however be designed to adapt or respond to specific climatic conditions such as high temperature, humidity or extreme weather events to ensure high sustainability and resilience (Mann et al., 2020a). The desire for responsiveness of building envelopes to their environment and the surrounding conditions triggered the evolvement of the smart glazing in the envelope systems.

Of all the building envelope systems, the window component is known to be the weakest element in terms of heat transfer which greatly contributes to heat gains and heat losses. According to (Hafnaoui et al., 2024), building fenestration comprises of three elements: the shading, the glazing and others (frames and spacers). Adding to this: the glass component of the fenestration is made of one of seven different glazing systems known as *low-e coatings, Photovoltaics, vacuum glazing, smart glazing, aerogels, double/ triple*

layers and self-cleaning glazing (Hafnaoui et al., 2024). The smart glazing system is continuously evolving systems consisting of both mature elements such as thermochromic and electrochromic, and others under research and development.

2.3 Smart Glazing Technologies.

Smart glasses are the advanced glazing systems that respond to their environment and automatically adjust their physical properties based on the environmental condition (Ruiz et al., n.d.; Akristiniy & Boriskina, 2018). Also known as dynamic glazing, chromogenic or intelligent glazing, have optical and thermal properties that can be regulated either actively or passively, thereby adjusting the daylight level and solar heat gain in a building (Michael et al., 2023).

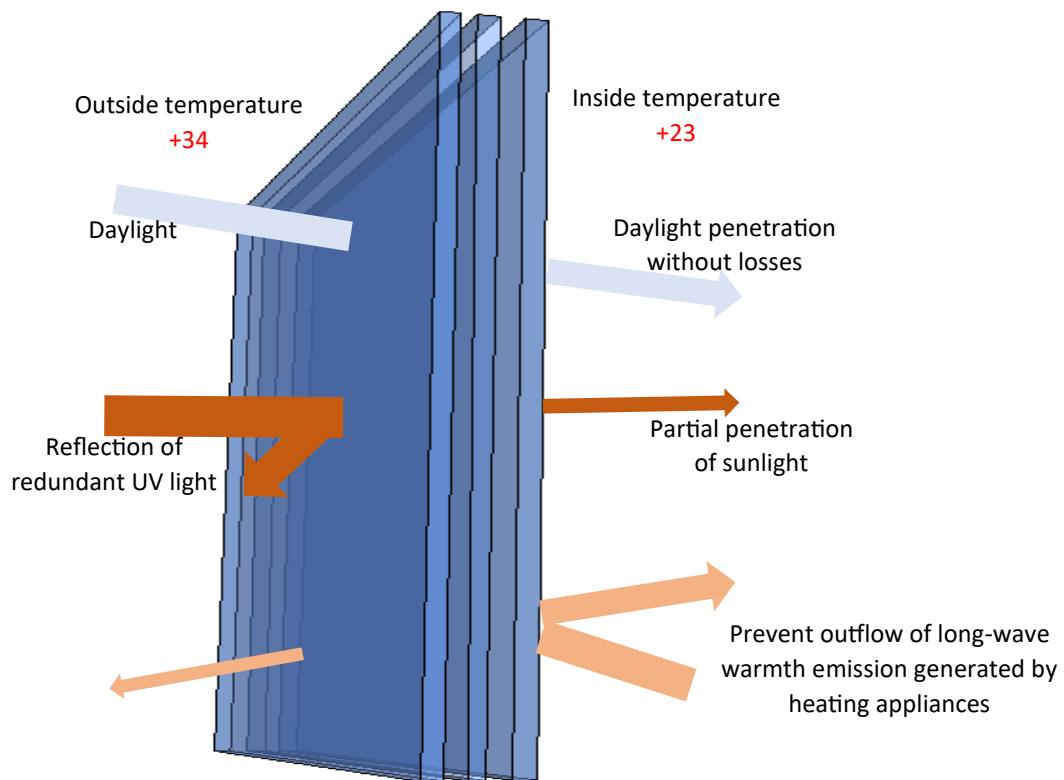


Figure 2: Smart glass schematic diagram.

Source: (Akristiniy & Boriskina, 2018)

Achieved through the introduction of different chromogenic material which is added into the pane layers during the manufacturing process, the smart glass is classified differently depending on their material composition, stimulating factor or response mechanism (Ghosh et al., 2024).

2.3.1 Classification of smart glazing

Smart glass can be categorized into two main types based on their operation: active command (controlled by user) and passive command (regulating itself). The following diagram summarizes the state of the art advanced (smart) glazing based on their operation mode and market availability (Zakirullin, 2020; Carlucci et al., 2021; Moghaddam et al., 2023; Michael et al., 2023; Lantonio & Krarti, 2022; Casini, 2018)

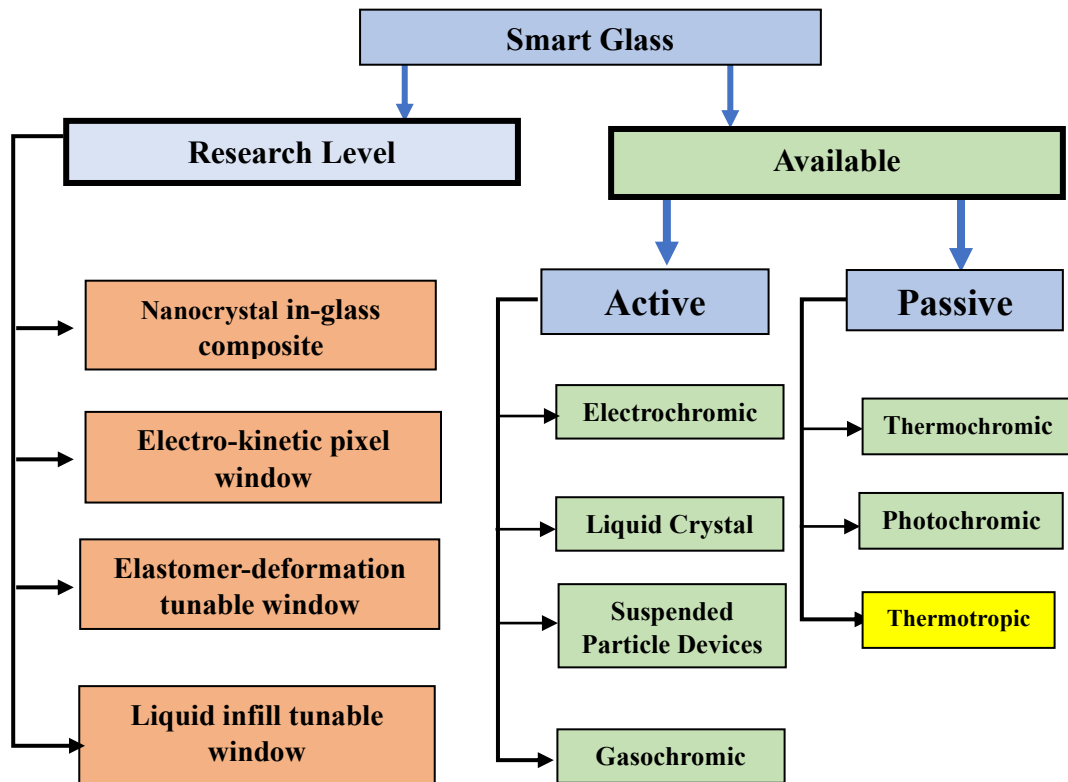


Figure 3. Classification of Smart Glazing

I. Active Dynamic Glazing

Active dynamic glazing systems can adjust based on external conditions (such as heat and sunlight) or internal conditions (such as artificial light levels, thermal loads, and user preferences). These adjustments can be made either manually or automatically via control systems (Rezaei et al., 2017). Technologies integrated with photovoltaic panels offer energy independence and can be controlled remotely via smartphones. This allows for individual adjustment of different sections within the glass panel and opens possibilities for touch-screen functionalities, transforming them into interactive visual displays.

1. Electrochromic (EC) smart glass

These are glasses that change their color in response to electric voltage applied. It's the only active chromic glass that works with direct current (DC). EC glass remains **transparent** until a low electric current is applied on it (**12 V DC**) making it **colored** (S. Wu et al., 2023).

Table 2: Characteristics of EC smart glass

(Budaiwi & Abdul Fasi, 2023) (Carlucci et al., 2021).

Stimuli:	Electrical voltage (12 V) DC
Response:	Tint
light transmittance:	75% at the clear state. 13% at the dark state.
Solar heat gain coefficient:	0.73 in a clear state. 0.11 at the dark state.
Power usage:	2.5 W/m ² per transition.
Switching speed:	5-12 minutes

Control	Switch, remote, movement sensor, light and temperature sensors, timer
Avg Cost	-
Durability	30 years (Avg)
Extra info	- Most used technology in buildings despite the relatively long switch time

2.0 Liquid crystal (LC) smart glasses.

Another active smart glass that uses liquid crystal to technology to regulate light transmission. It operates by scattering the fallen light in all directions giving it a frosted look when switched off and a transparent look when switched on. It involves a thin layer of liquid crystal between two conductive layers.

Table 3: Characteristics of LC smart glass

(Chidubem Iluyemi et al., 2022; Rezaei et al., 2017; Ruggiero et al., 2022)

Stimulus:	Electrical voltage (110 V) AC
Response:	Clarity
light transmittance:	75% at the clear state. 50% at the tint state.
heat gain coefficient:	0.69 at the clear state. 0.55 at an opaque state.
Power usage:	5-10 W/m² per transition.
Switching speed:	instantaneous (40 milli seconds)
Control	Switch, remote, movement sensor, light and temperature sensors, timer
Durability	Only 10 years

Extra info	- A solution for homes and offices getting privacy without sacrificing daylight. - Good Privacy, minimize glare. - Has only 2 states: either frosted or clear.
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3. Suspended particle device (SPD)

It is a form of polarized particle smart glass that operates with the application of alternating current (AC). Remain translucent or opaque when switched off and transparent when switched on. Microscopic particles are placed between two panes of glass or plastic. The table 4 below shows the characteristics of SPD smart glazing.

Table 4: Characteristics of SPD smart glass (Ghosh et al., 2015) (Ghosh et al., 2016)

Stimulus:	Electrical voltage (110 V) AC
Response:	Clarity
light transmittance:	65% at the clear state. 0.5% at the Opaque state.
heat gain coefficient:	0.57 at the clear state. 0.06 at the dark state.
Power usage:	5 W/m ² per transition.
Switching speed:	1-3 seconds
Control	Switch, remote, movement sensor, light and temperature sensors, timer
Durability	20 years
Extra info	-A solution for homes and offices getting privacy. - It allows any required degree of clearness.

4. Gasochromic smart glass

This smart glass operates based on the concentration of certain gas applied within its cavity. Gasochromic glazing tint by exposing a **sensible gas layer** to diluted hydrogen (H₂) or oxygen (O₂) pumped in the window cavity. (Morrey & Ghosh, 2024; Ghosh & Norton, 2018; Carlucci, 2021)

Table 5: Characteristics of GC smart glass

Stimulus:	Gases concentration
Response:	Clarity
light transmittance:	54% at the clear state. 15% at the dark state.
heat gain coefficient:	0.65 at the clear state. 0.28 at the dark state.
Power usage:	12.5 W/m² per transition.
Switching speed:	1 minute
Control	Switch, remote, movement sensor, light and temperature sensors, timer
Durability	Only 10 years
Extra info	- It is the second most Mature type of smart glass after the EC. - Has faster switching times compared to EC (at least 10 times quicker)
Sustainability	In an office building in Shanghai, it obtained a reduction of HVAC loads of 28,4% against single-pane clear glass.

II. Passive Dynamic Glazing

Passive dynamic glazing technologies do not require electrical input to operate. These systems autonomously respond to environmental factors such as light (photochromic windows) or temperature (thermochromic and thermotropic windows)(Liang et al., 2021) compared to active technologies, passive systems are easier to install and generally more reliable, though they lack user-controlled adjustability.

1. Thermochromic smart glass

This responds to the outdoor temperature on the glass surface. To operate, **a chemical reaction** is initiated by a **temperature-based** stimuli to switch between a **clear** state at **low** temperatures and a **darkened** state at **high** temperatures (Haratoka et al., 2022a).

Table 6: Characteristics of TC smart glass (Liang et al., 2021; Pérez et al., 2021)

Stimulus:	Heat
Response	Tint
Light transmittance:	60% - 26% at the clear state. 13% - 4% in the dark state.
Solar transmittance:	45% - 9% at the clear state. 35% - 2% in the dark state.
Switching speed:	20 – 30 minutes
Durability	20 years
Extra info	- Its clearest state is usually between 10-25 C and darkest state is 65 C. -TCW can contribute to improving the energy performance and user comfort of buildings - Transitioning states are on a continuous spectrum.

2. Photochromic smart window

This smart glass changes its color base on the external light intensity. It operates by a photo-induced transformation between two chemical isomers that have different absorption spectra causes the glass to be tinted when it receives high level of lighting.

Table 7: Characteristics of PC smart glass

Stimulus:	Light
Response	Tint
light transmittance:	78% - 13% at the clear state. 73% - 9%at the dark state.
Switching speed:	30 seconds
Durability	only 10 years
Extra info	Extra info: PCW can also contribute to improving user comfort Transitioning states are on a continuous spectrum

3. Thermotropic smart glass

Operates by exposing a **sensible gas layer** to diluted hydrogen (H₂) or oxygen (O₂) pumped in the window cavity.

Table 8: Characteristics of thermotropic smart glass

Stimulus:	Gases concentration
Response:	Clarity
light transmittance:	54% at the clear state. 15% in the dark state.
heat gain coefficient:	0.65 at the clear state. 0.28 in the dark state.

Power usage:	12.5 W/m² per transition.
Switching speed:	1 minute
Control	Switch, remote, movement sensor, light and temperature sensors, timer
Durability	200 cycles.
Extra info	- It is the second most Mature type of smart glass after the EC. - Has faster switching times compared to EC (at least 10 times quicker)
Sustainability	It can provide a reduction of HVAC loads of 28,4% against single-pane clear glass.

2.4 Smart Windows Structure and Working Mechanism

Smart windows generally work in response to an external stimulus. This is achieved by installing a layer of chromogenic material during the manufacturing process of the glass which adjusts its thermal characteristics and the light transmission properties. The working mechanisms of different smart windows is summarized as follows:

2.4.1 Electrochromic Structure

Usually made an insulated double-glazing unit (DGU) TiO₂ Indium Tin Oxide (ITO)/ Titanium dioxide (TiO₂) are the common based chromogenic material (Jiang et al., 2024a). The smart layer usually is installed in the exterior pane; the system is connected to power source which is controlled by a sensor which detects solar radiation. When it reaches 250 w/m², the smart property is automatically activated (Zakirullin, 2020). The figure 4 below

shows electrochromic window. Although there are many ways in which the products are made, the DGU is the most common product except for customizable purposes.

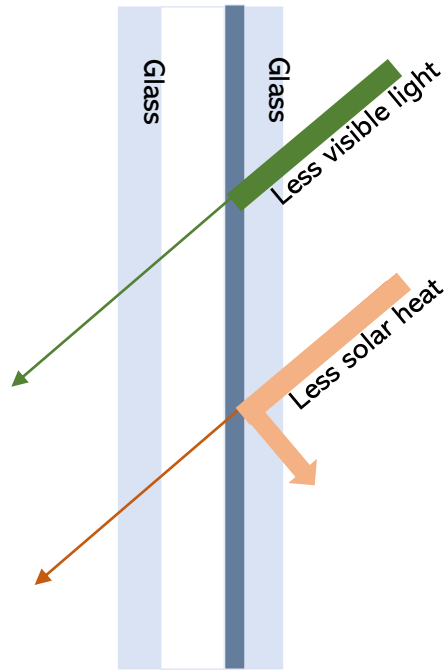


Figure 4: Electrochromic window. Source: (Zakirullin, 2020)

2.4.2 Gasochromic Structure

Primarily developed to address the limitations of EC glazing which requires constant power at tint state and are only applicable to certain substrates (Morrey & Ghosh, 2024). Its normally achieved by applying 1 mm layer of gasochromic material (WO_3 or HWO_3). When Oxygen gas is intended, WO_3 is used as the gasochromic layer is made of whereas HWO_3 serves as the Gasochromic layer when hydrogen gas is used.

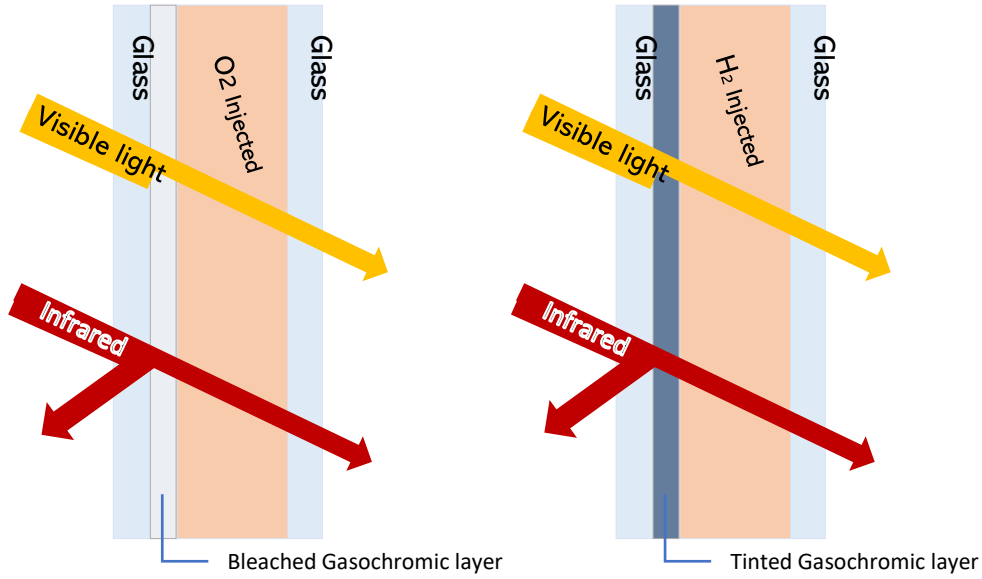


Figure 5a: Gasochromic Window. Source: (Morrey & Ghosh, 2024)

2.4.3 Thermochromic Structure

Usually, the external pane of a double or triple pane window is divided with a mid-layer of the chromogenic material usually Vanadium dioxide (VO_2) (Ghosh & Norton, 2018; K. Lin et al., 2021). Different studies conducted in laboratory as well as industrial reports discussed the behaviors of VO_2 under different temperatures. Figure 6 shows the structure and working mechanism of thermochromic windows.

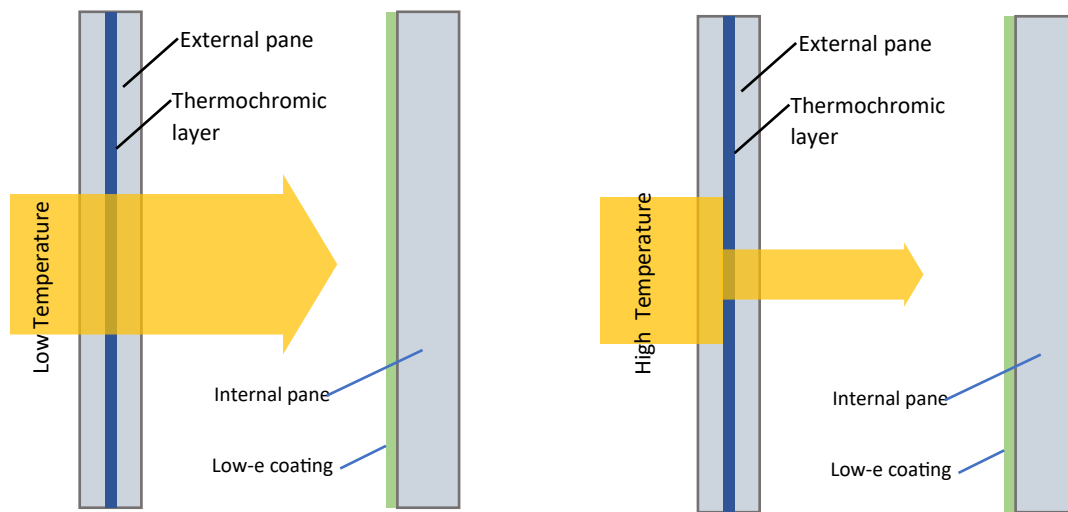


Figure 6: Thermochromic Window. Source: (Jiang et al., 2024a)

2.4.4 Photochromic

Usually achieved by applying a layer of Silver Halides (AgCl, AgBr) in the interior pane of double or triple glazed window, which responds to Sunlight (Jiang et al., 2024b). Although not desirable in four seasoned countries as even in winter, the colored state will block the sunlight., PC smart window is made by embedding active materials into transparent host matrices followed by coating on a transparent substrate(Ke et al., 2019) .

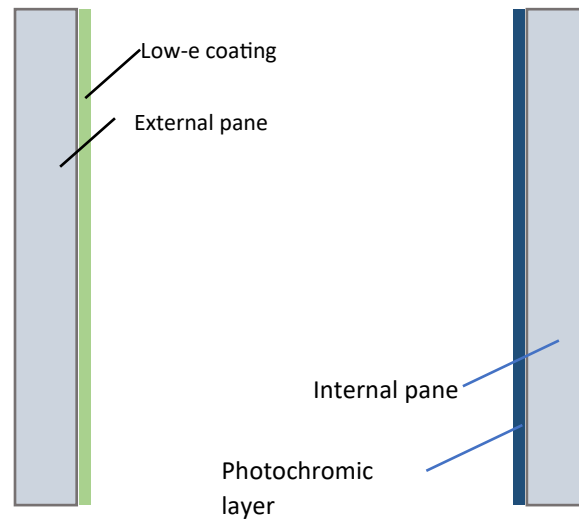


Figure 7: Photochromic Window. Source (Ke et al., 2019)

2.4.5 SPD in Hot Desert (Mesloub et al., 2022)

A switchable SPD smart windows (in the OFF and automated states) can achieve a promising reduction of net energy by up to 58% against DG low-e. Conversely, the opaque (OFF state) had a counterproductive impact on lighting energy consumption and visual comfort. Acceptable daylight autonomy (DA300lux) and Useful daylight illuminance (100lux-2000lux) could result from SPD smart window in the ON and automated controlled states; moreover, owing to its significant reduction in daylight glare probability (DGP), SPD glazing can be a good alternative to standard glazing in a hot desert climate.

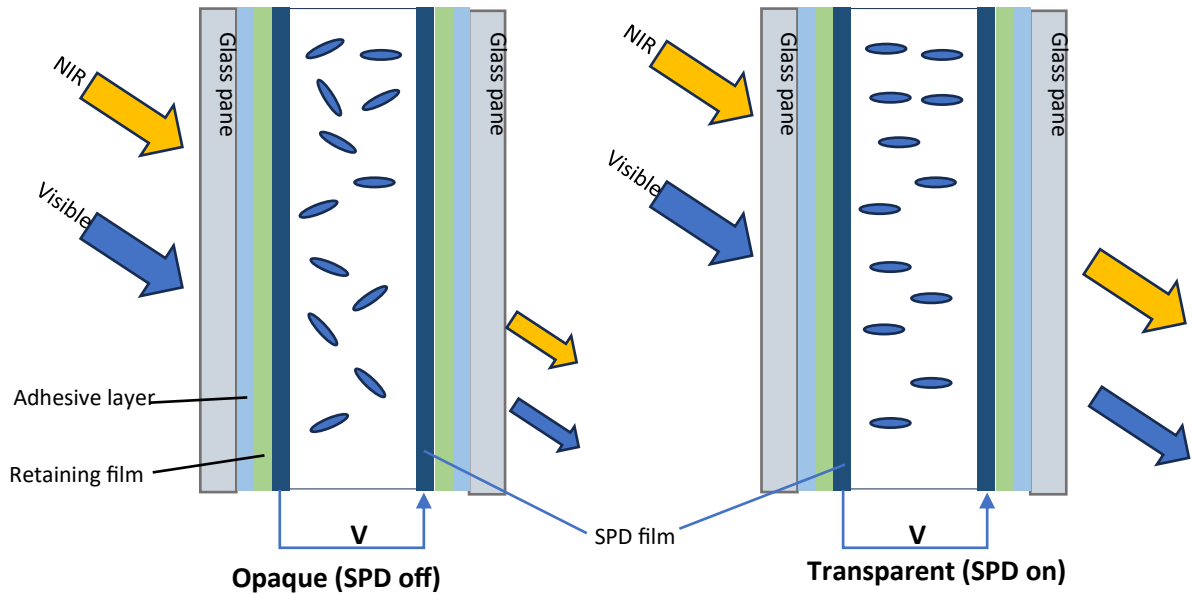


Figure 8: SPD glazing in opaque & transparent state.

Source: (Mesloub, Ghosh, Touahmia, et al., 2022)

2.4.6 PDLC (Polymer dispersed liquid crystal)

Smart PDLC Film is an interlayer film in the middle of Switchable PDLC Glass. When their Power is off, the LC Molecules inside are scattered irregularly, so the incident light will disperse and cannot pass through, and the PDLC film Opaque (Milky White). When there is the Power on, the LC Molecules are arranged in an orderly manner, so the incident light passes through freely, and the PDLC film appears Transparent (Clear state).

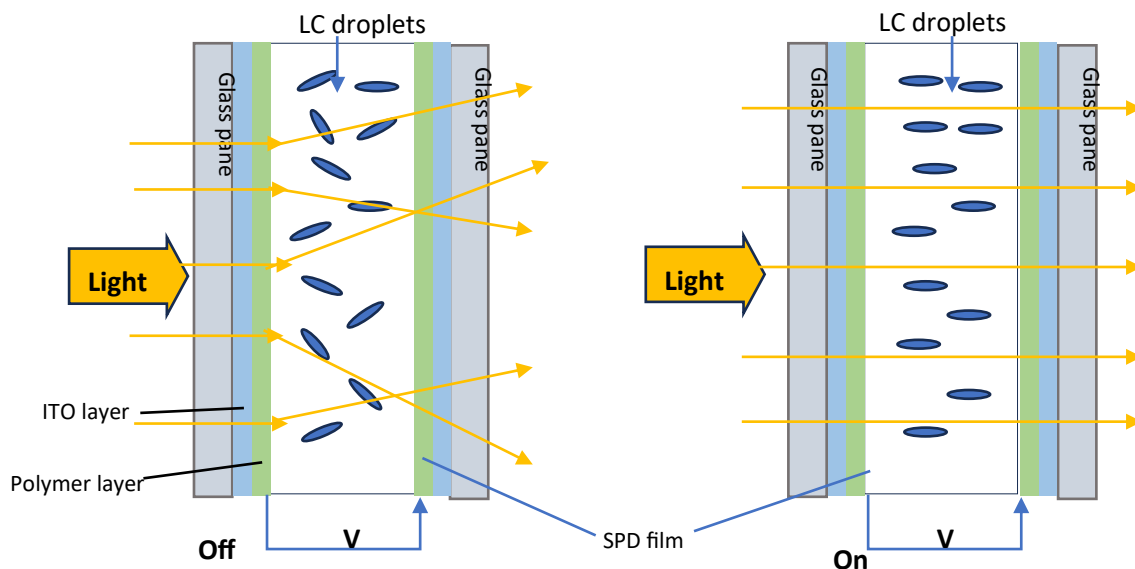


Figure 9a: PDLC Smart Window Source: Hemaida et al. (2020)

Indium Tin Oxide (ITO) is a transparent conducting oxide composed primarily of indium oxide (In_2O_3) and tin oxide (SnO_2), typically in a ratio of about 90% indium oxide to 10% tin oxide. ITO is renowned for its excellent electrical conductivity combined with high optical transparency, especially in the visible spectrum

Table 9: Summary of the Smart windows characteristics

Window	Type	Stimulus	Response	Switching Time	Power Use (W/m ²)	Dura. (Years)
EC	Active	(12 V) DC	Tint/ Clar	5-12 mins.	2.5	30
LC		(110 V) AC	Clarity	Instant	5-10	10
SPD		(110 V) AC	Clarity	1-3 sec.	5	20
GC		Gas conc..	Clarity	1 min.	12.5	10
TC	Passive	Heat	Tint	20-30 sec.	-	20
PC		Light	Tint	30 sec.	-	10

2.5 Energy performance simulation.

Simulation is basically a technique of creating a virtual model of a system or process and running experiment on this model to observe outcome. Simulation models a real-world system and studies its behavior under different conditions (Chidubem Iluyemi et al., 2022). The primary purpose of simulation is to understand the behavior of the system under certain scenarios and to predict future performances (Haratoka et al., 2022b). Energy performance is one of the key criteria in the selection of advanced building envelopes and smart glazing (Khalaf et al., n.d.). In a simulation study aimed at evaluating the energy performance of

smart glazing in office building envelopes, it's crucial to consider several key parameters. The following are the key parameters used in conducting the simulation:

a. Thermal Properties(Carlucci et al., 2021 ; Harmathy et al., 2016):

U-value (heat transfer coefficient): This measures how well the glazing insulates the building. Lower U-values indicate better insulation performance.

Solar Heat Gain Coefficient (SHGC): This determines the amount of solar radiation that passes through the glazing. Lower SHGC values mean less solar heat enters the building, thus reducing cooling demands.

b. Optical Properties (Singh et al., 2017b) (Chidubem Iluyemi et al., 2022):

Visible Transmittance (VT): This measures the amount of light that is visible which can pass through the glazing. Higher VT is beneficial for natural lighting.

Tinting Capabilities: For dynamic smart glazing like electrochromic types, this assesses how the range of tinting affects daylight and glare control.

c. Energy Performance (Haratoka et al., 2022 ;Arnesano et al., 2021):

Heating and Cooling Loads: Simulating the annual impact of smart glazing on heating and cooling energy demands.

Lighting Loads: Evaluating how changes in natural daylight availability influence the use of electric lighting.

d. Control Strategies:

Dynamic Control: Implement various control algorithms for dynamic glazing, such as adjusting based on external temperature, solar radiation, and occupancy levels.

Manual vs. Automated Control: Compare the energy performance between manually operated and automated smart glazing systems.

e. *Climate Data:*

Location-specific Weather Data: Utilizing detailed climatic data for the specific location, including temperature, solar radiation, and humidity, to ensure accurate simulation results.

2.6 Daylighting

Daylighting is the practice of using natural light to illuminate indoor spaces. The goal is to reduce reliance on artificial lighting during the day, which can save energy and enhance the overall quality of the indoor environment. Useful daylight illuminance (UDI) is used to estimate the daylight factor (Talaie & Sangin, 2024). As one of the important aspects of indoor environmental quality, the strategic design of windows, skylights, and reflective surfaces can harness sunlight to brighten spaces, create pleasant atmospheres, and even improve occupants' well-being.

Spatial Daylight Autonomy (sDA) and *Useful Daylight Illuminance (UDI)* are metrics used to measure how effectively daylight is used within space. It considers the amount of natural light that falls onto an area and how well it meets the lighting needs of that space. UDI helps in evaluating whether a room receives sufficient daylight and ensures that it is neither too bright (which can cause glare) nor too dim (Mesloub et al., 2023). The goal is to achieve a balance where daylight contributes positively to the lighting conditions without causing discomfort or compromising visibility.

2.7 Saudi Arabia Climates

Saudi Arabia generally experience a hot desert climate which has been categorized in different ways. According to the Saudi Building Code (SBC), the climates are categorized into three broad zones: hot-dry, mild and hot-humid climates as in (Ghazanfar, 2024) . However, these zones have been further broken down into six sub-zones by different

researchers. These include subtropical, hot-dry with desert, hot-dry with maritime desert, cold-dry with desert and empty quarter as can be seen in figure 9 by (Indraganti & Boussaa, 2017). In another classification by (Alayed et al., 2022), the Saudi Arabian climates are hot-arid, hot semi-arid, humid coastal and moderate. However, for the purpose of energy research, it is imperative to consider climate classification based on temperature difference, thus the SBC three broad classifications will be more suitable (Al-Hashim et al., 2024). These are hot-humid, mild and hot-dry climates and can be represented by the cities of Jeddah, Taif & Riyadh respectively.

2.8 Criteria for selection of envelopes in building.

Selection of external wall enveloping system is determined by various criteria which form the basis for any design decision. Although literature highlighted many criteria, these criteria are classified by (Hamida & Alshibani, 2020) in to “three main categories: technical, economic and socio-environmental criteria”

Technical criteria: Thermal performance, fire resistance, material weight, acoustic performance, water & air tightness and wind resistance among others

Economic criteria: Ease of design, ease of construction, initial cost, construction time, maintenance cost, and durability.

Socio-environmental criteria: Aesthetic, light control, maintainability, material availability, material consumption, energy consumption, waste generation, and recyclability.

2.9 Criteria for selecting smart glazing systems.

The selection of smart windows for a building involves evaluating several key criteria to ensure they effectively meet the building's needs and enhance performance. Some of the

factors to consider in selecting smart windows are similar to the general criteria for the selection of building envelopes. In addition, *light control*, *climate adaptability*, *integration with building systems* and *user control* are specific factors peculiar to smart window selection (Ruggiero et al., 2022; Lantonio & Krarti, 2022; Gutai & Kheybari, 2021).

- i. *Light Control*: Effective light management is crucial. Smart windows should allow for adjustable tinting to control glare and optimize daylight entry, balancing natural light with indoor comfort.
- ii. *Climate Adaptability*: The technology should be suitable for the weather conditions of the region, providing benefits like reduced heat buildup in hot climates or improved insulation in colder areas.
- iii. *Integration with Building Systems*: Compatibility with existing building management systems is essential. This will promote coordinated control with heating, cooling, and lighting systems, enhancing overall building performance (Suzuki et al., 2022).
- iv. *User Control and Automation*: Smart windows, especially the active ones offer user-friendly controls logics. This includes the ability to adjust settings manually or program them to respond to environmental changes automatically.

2.10 WWR Assessment.

Window-to-wall ratio (WWR) is the term used to describe the surface area covered by windows from the overall external wall surface, usually expressed in percentage. Assessing WWR involves evaluating how the size and placement of windows relative to the wall area can impact a building's energy use (Kishore et al., 2022). The assessment of WWR

involves climate consideration, and effects on both lighting and heating/ cooling loads (Nazari et al., 2023). Optimum window to wall ration varies from one region to another however, as a general rule of thumb, WWR should not go below 30% as this may result in to increased lighting energy demand, while the maximum should be between 70-80%, above which there will be elevated heating and cooling energy demand with climates (De Masi et al., 2023; (Khalil et al., 2023).

2.11 Previous Related Works

An overview preliminary survey of research database (Scopus) shows that publication on the “smart window technology in buildings” began in the 1980s, started to grow after 2010 showing exponential growth from 2016. While China & US lead the trend, other European countries like Italy & UK also show growing interest in this area. The fig 10 below shows the growing research trends in smart windows and glazing.

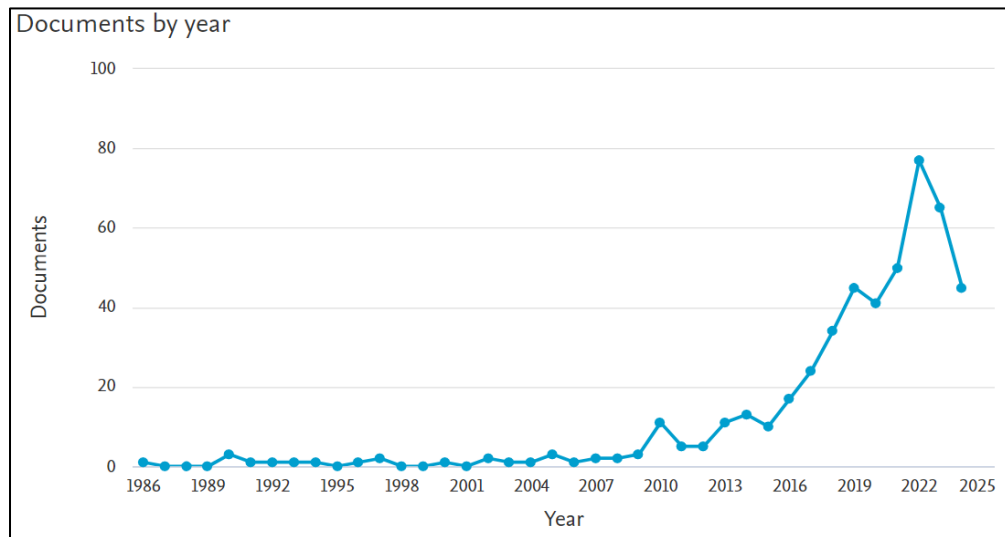


Figure 10: Documents published by year. Source: Scopus Database (2024)

Although many of the publications investigated the technology and working principles of smart glazing, there are also several studies that evaluated the energy performance of using EC smart glazing in buildings, while studies on other smart glazing materials were mainly

introduction to performance improvement strategies. These studies include but are not limited to the following:

A study by (Budaiwi & Abdul Fasi, 2023) uses simulation approach to investigate the energy saving potential and visual comfort of using thermochromic smart windows in office building in Dhahran, Saudi Arabia. The study revealed that thermochromic windows have potential of 23% reduction in cooling energy demand, but shortfall visual comfort.

Another study by (Lantonio & Krarti, 2022) uses simulation approach to conduct simultaneous design and control optimization of smart glazed window based on control strategy under the cold & dry climate of Colorado, USA, the results show potential cost savings of 17.3 % for both temperature-based controls, and between 11 % - 14% cost saving for Solar radiation-based controls.

In London, (Arnesano et al., 2021) used experiment & dynamic simulation to conduct design optimization of thermochromic glass design under two different climates (Italy & Poland), the result shows that TCW layer optimized in VIG glazing system can yield up to 22% net energy saving.

Another study by (Khalifa et al., 2023c) in Egypt uses simulation approach to study impacts of electrochromic windows on energy consumption in office building. The result revealed that buildings with electrochromic windows use 14% less energy overall than the conventional reference window with low-e window glass.

(Carlucci et al., 2021) conducted a review of the technology and classification of smart and responsive buildings over multiple climate conditions, the outcome concludes that each smart & responsive system can be less or more effective depending on their nature and location.

In Jordan, (Mustafa et al., 2023a) investigated the potentials of state-of-the-art smart window technology on net-zero buildings through simulation, they arrived at a conclusion that incorporating smart materials promote thermal comfort, energy performance and green building practices.

A study by (S. Wu et al., 2023) in China conducted a 5-year studies review on the TC & EC materials development and their application in buildings, the outcome proved that TCW performance depends largely on external environmental while control strategy is fundamental for the performance of ECW. Another simulation study under the cold and arid climate in Egypt by (Elmiligy et al., 2024a) investigated the impact of using smart material technologies in managing LCC of admin. buildings' Façade. The finding shows that EC with smart PV material can offer up to 35% energy saving based on LCA.

In the mild climate of Denmark, (Cabral & Blanchet, 2023a) studied performance of thermochromic in the climate of Danish from the perspectives of visual comfort using simulation approach, The study showed that thermochromic glasses are not suitable for mild climate because: for a major part of the year, the effect has not been activated.

Another study by (Imbert et al., 2019b) investigated the response of various commercial products to the peculiar Danish climate by running numerical simulations of a single room building with the Energy Plus (Design Builder) software. The study also uncovers that the thermochromic effect is not activated for a major part of the year. Regarding indoor illuminance comfort, it showed variable performance on annual bases, depending on the tested thermochromic glazing.

In 2016, authors (Harmathy et al., 2016) uses BIM tools to conduct a multicriteria optimization of building envelopes in the function of indoor illumination quality, the study

provided that optimum window to wall ratio (WWR) and window geometry (WG) is achievable under varying building orientation depending on desired energy saving. Thus, optimization is flexible and can be applied for different climatic conditions. Another study by (Liang et al., 2021) uses a combination experimental and survey approach to investigate the effects of thermochromic windows on visual performance and sustained attention, the findings show that the occupant visual perception and concentration are Both significant issues to be considered for a space lit by daylight Filtered through TC windows.

(AlJalal et al., 2023) uses a combination of survey and simulation approach to develop an integrated decision support framework for selecting envelope and AC systems for residential buildings in hot-humid climate. The finding highlighted that the best combination of envelope and AC systems varied according to the desired objective.

In Taiwan, a study by (Y. H. Lin et al., 2016) conducted design optimization of office building envelope configuration for energy conservation. The findings show that the optimized enveloped design realizes nearly 41% budget savings, thus demonstrating the feasibility of the proposed. A different study in China on the heat transfer characteristics of thermochromic smart window by (Tao et al., 2022) uses computational fluid dynamics (CFD) analysis of the environmental impacts. The results proved that: a) absorbed solar heat flux determines the difference between the TC glazing temperature and the ambient temperature. b) environmental condition range (outdoor temperature 5-35°C and solar intensity 200-1000W/m²).The table below summarizes the focus and methods used in the mentioned studies on smart glazing and envelopes in buildings

Table 10: Recent studies on smart windows and envelopes in buildings.

Author	Study	Location/ Climate	Methods	Parameters
(Budaiwi & Abdul Fasi, 2023)	Thermochromic Smart windows.	Dhahran, KSA (Hot & Humid)	Energy simulation	Energy saving. Visual comfort
(Lantonio & Krarti, 2022)	Smart window control strategy	Colorado, USA (Cold & Dry)	Simulation based optimization	Temperature Solar radiation
(Arnesano et al., 2021)	Thermochromic glass design.	Italy & Poland.	Experiment & dynamic simulation	VIG layers. VO ₂ layer
(Khalifa et al., 2023b)	Electrochromic windows in office building.	Egypt (Hot & Dry)	Energy simulation	Lighting HVAC load
(Carlucci, 2021)	Review and classification of smart windows	Multiple	Systematic review	Impacts on energy. Climate.
(Harmathy et al., 2016)	Building envelope optimization	Multiple	Simulation with BIM	WWR WG Building orientation
(Mustafa et al., 2023a)	Net-zero buildings via smart window technology	Jordan	Simulation	Carbon emission

(S. Wu et al., 2023)	5 years studies review on the TC & EC	China	Systematic review	Materials development Building application
(Elmiligy et al., 2024b)	EC with PV smart material	Egypt	Managing LCC	LCC
(Cabral & Blanchet, 2023b)	TC glass performance	Denmark (mild humid)	Simulation	Visual comfort
(Imbert et al., 2019a)	Thermochromic glass performance	Danish	Simulation	Thermal resistance Visual comfort
(Y. H. Lin et al., 2016)	Envelope Design Optimization	Taiwan	Simulation	Configuration Energy conservation
(AlJalal et al., 2023)	Framework for selecting envelope and AC systems in hot-humid climate	Saudi Arabia	Survey + Simulation	AHP MAUT
(Tao et al., 2022)	Thermochromic smart window	China	CFD Analysis	U-value SHGC
(Liang et al., 2021)	Thermochromic visual performance	China	Experimental & Survey	Light transmittance Glare

It can be summarized that these studies focused on improving either thermal performance, light transmittance or control strategy of smart glazing and configuration of envelope

design, while ignoring the effects of window sizes. Most of the studies also did not make comparisons of different smart window performance. Other parts of the studies assessed how smart glazing affects energy consumption in the building only in single climate zones. There are however numerous studies on WWR in buildings, although not with smart windows, less on daylight effect and not across Saudi Arabian climate zones. Table 11 below summarized previous studies related to window to wall ratio in building.

Table 11: WWR Envelope Evaluation Based Studies

Author	Study Method	Envelope Type	Location/ Climate	WWR (%)	Impacts on Energy
(Bano & Dervishi, 2021)	“Thermal performance in high-rise building”	Glazed office building with vertical greenery	Mediterranean	50 70 100	Cooling energy consumption increases by 17.9 kWh/m ² /y when WWR rises from 50% to 100%
(Ruggiero et al., 2022)	“Energy Saving through building automation”: - Energy saving - Control Logics	LCD smart glass	Athens, Cairo & London	18% Real case 100% assumed office building.	100% WWR demands off milky state. 9 to 35 % energy saving depends on season. 18% WWR control logic depends on the exposure. mxm of 11% saving.
(Méndez Echenagucia et al., 2023)	Simulation; “Impacts of WWR on Carbon emissions: Embodied & operation energy”	Simulation.	Mild: Los Angeles	0, 20%, 40%, 60% & 80%	Low WWR reduces both embodied and operational carbon, Low WWR reduces cool energy demand, but increases lighting energy demand 40% of WWR has better overall performance.

(Sakiyama et al., 2021)	“Building optimization through parametric design”: -Simulation -Sensitivity analysis		Temperate	20% - 80%	Bigger WWR leads to Higher natural ventilation effectiveness (NVE) Higher total cooling load (TCL) Lower total heating load (THL)
(Pereira Suzane Silva & Flora Calili, 2021)	“Impact of window-integrated organic photovoltaic cells on energy demand” -Simulation -Sensitivity analysis		Brazil	50 – 95%	The optimum WWR for buildings with window-integrated organic PV is 95%
(Pang et al., 2023)	“Effects of complex spatial geometric parameter on energy consumption”: Spatial atrium.	CMU with cladding + double LoE glass window.	China Cold climate	50 - 90%	WWR has negligible impact on energy consumption in buildings with spatial complex geometric atrium.
(Phillips et al., 2020)	“Sustainability assessment of WWR in US office buildings”		3 US climate -Boston -Miami -S Francisco	20% 40% 60%	Improving building performance by Changing WWR is not a universal principle: Regions with pronounced heating season as Boston shows pronounced change in energy use with different WWR.

					Increasing the WWR will rise SHG due to lower solar altitude.
(Qiu et al., 2021)	“Determinants of passive solar design in office building envelope”.		Guangzhou, China: Hot & humid	15-90%	Optimal WWR is found to be 30%. Increase in energy demand as WWR rises from 30 - 90%.
(De Masi et al., 2023)	“Role of windows on energy performance under current & future weather conditions”.		Europe: Almeria Copenhagen Helsinki Oslo Split	20% (BC) 40% 60% 80% 100%	Increase in WWR from 20-40% in all cities results in higher cooling demand energy. At the same 40% WWR, E_C in Benevento increased by 15%, and by up to 90% in Almeria.
(Alkhatbeh et al., 2023)	Exploring Optimal classroom design		US climate zones.		Optimal WWR is between 35-40% for mixed-humid, cold, hot-dry, & hot-humid climate zones.
(de Gastines & Pattin i, 2020)	“Windows Energy Efficiency: Determining factors and energy savings strategies”.	CMU + plaster +Polystyrene insulation CMU Brick +plaster -Low-e double glazed window	Argentina: Mild winter High solar irradiation	20–100%	WWR & orientation produces more energy saving than window technology. -With efficient solar control devices, high WWR is beneficial in summer. -No numeric values provided regarding impacts of WWR.
(Gupta & Deb, 2023)	“Envelope design for low-energy buildings in the tropics: A review”	Review Paper	Tropic	20% 30% 40% 50%	-For tropics like China & Malaysia, optimum WWR is 40%. - Optimum WWR of 35-40% can reduce cooling loads by 17.5% in India &

					39% in hot and humid regions of the US - For Dubai hot climate, at least 50% of window should be in the north.
(Khalil et al., 2023)	“Optimization of an office building form using a lattice incubate boxes method”		- Cairo: Arid -London: cold - Chicago: Temperate	30% 60%	-Optimal WWR is 30% for North and 60% for E, W & S. -The optimal WWR provides EUI reduction of 16.8%, 16.86% % 12.9% for Cairo, London & Chicago respectively.
(Pourghorb an & Asoodeh, 2022)	“The impacts of advanced glazing units on annual performance of the Trombe wall systems in cold climates”	Trombe wall system- Double CMU + double & triple Low-e glass	Cold Climates	99% 75% 50%	50% proves to be the optimum WWR: -10-25% E_c reduction -8% increase in E_h -6% reduction in overheating - 13 - 30% overall reduction in energy demand.
(Feehan et al., 2021)	“Building energy simulation and LCA framework for the optimization of facades & fenestration in building envelopes”	Insulated masonry cavity wall+ double/ triple pane Low-e glass window	Dublin Ireland (<i>Temperate maritime</i>)	10% 20% 30% 40% 50%	- 20% WWR proves to be the optimum (39.9 kWh/m ² /yr). -The same WWR with variable window layout can further reduce up to 5% energy.
(Nasrollahzadeh, 2021)	“Comprehensive building envelope optimization:	Double/ triple pane clear and low-e glass window	Mediterranean : <i>Humid subtropical climate</i>	10, 20, 30, 40, 50, 60,	-40% WWR proves lowest overall energy demand (EUI of 137.69 kWh/m ² /yr), optimal UDI,

	Improving energy, daylight, and T.C performance of the dwelling unit”			70, 80 & 90%	and least PPD in thermal comfort.
(H. Wu & Zhan g, 2022)	“Multi-objective optimization of energy, visual, and thermal performance for building envelopes”	Brick wall + double pane low-e glass filled with Argon (5-12Ar-5)	China: hot summer and cold winter climate zone	10- 90%	- Optimal WWRs is between 60% - Optimal WWRn is 16% (Operable windows) _ improve daylight, energy consumption & T.C
(Tala ei & Sangi n, 2024)	“Energy performance of envelope-integrated algae-based bio shading and static shading systems through multi-objective optimization”	Adiabatic wall+ glass window (integrated with novel algae-based bio shading systems)	Iran: Dezful & Shiraz ; Hot (BSh) and cold semi-arid (BSk) climates.	10-90 (Increme nt 5%)	In Dezful, optimum WWR is 35% for north & 20% for south. In Shiraz, optimum WWR is 40% for the north & 25% for south.
(Kobe yev et al., 2021)	“Design and energy performance analysis of a hotel building in a hot and dry climate: <i>A case study</i> ”	Concrete walls are insulated with gypsum + electrochromic windows. - PV panels installed and PCM already	Hot & Dry	5-70 (Increme nt of 5%)	- 15% proves to be the optimal WWR, although slightly affected by change in orientation. - PV, PCM and EC technology have already reduced 34% energy consumption compared to conventional systems.

		integrated into the envelopes			
(Wefki et al., 2024)	“Estimating the energy consumption for residential buildings in semiarid and arid desert climate using AI”.	Simulation	Semi-Arid and Arid desert climate	0- 80%	Optimum WWR for all orientations is between 30-40% with potential annual energy saving up to 20%
(Lahmar et al., 2019)	“Investigating the impact of EC glazing on energy performance in hot arid climate using parametric design”	Plastered Hollow brick wall + EC glazing.	Biskra, Algeria: <i>Hot dry climate.</i>	10- 90%: increment of 10%	EC windows allow for up to 20% WWR increase without negative effects on energy: - 8.5% laminated glass equals 20% EC. - 60% laminated glazing & 70% double glazing equals 90% WWR in EC glazing.
(Nazar i et al., 2023)	“Optimization of <i>commercial buildings</i> envelope to reduce energy consumption and improve IEQ using NSGA-II algorithm”	Metal sliding with interior gypsum board layer + Double glazed window	Tehran, Iran: Seme-arid continental climate.	30- 80%, increment of 10%	-WWR highly affects cooling load but less on heating load: -Optimal WWR depends on size for commercial building: Retail store 1000m ² - 40% 2000 m ² - 60% 3000 m ² - 50% Supermarket 1000m ² - 40% 2000 m ² - 50% 3000 m ² - 80%
(Cesari et al., 2020)	“The energy saving potential of wide windows	Double glazed widow using 9 different diverse glasses	Italy: -Milan -Bologna -Rome	25% (common)	With improved glazing properties, up to 17% reduction in total primary energy demand (PED) can

	in hospital patient rooms, optimizing the type of glazing & lighting control strategy under different climatic conditions”		-Naples	- 77%: (floor to ceiling)	be reduced with 77% (floor to ceiling) WWR. - Daylight responsive dimming control -Glass U-value of 0.7W/m ² K for Milan & Bologna. -Glass U-value of 0.57W/m ² K for Rome & Naples.
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CHAPTER 3: METHODOLOGY

The study provides assessment of the impacts of various smart window glazing systems in office building across different climate in Saudi Arabia. Overall, the study adopted a simulation approach. Different smart windows were identified based on market availability and applicability to buildings envelopes. The study assesses their impact on energy consumption and daylighting; it further describes how different WWR affects energy and daylighting. Fig 12 summarized the methodological framework for the study

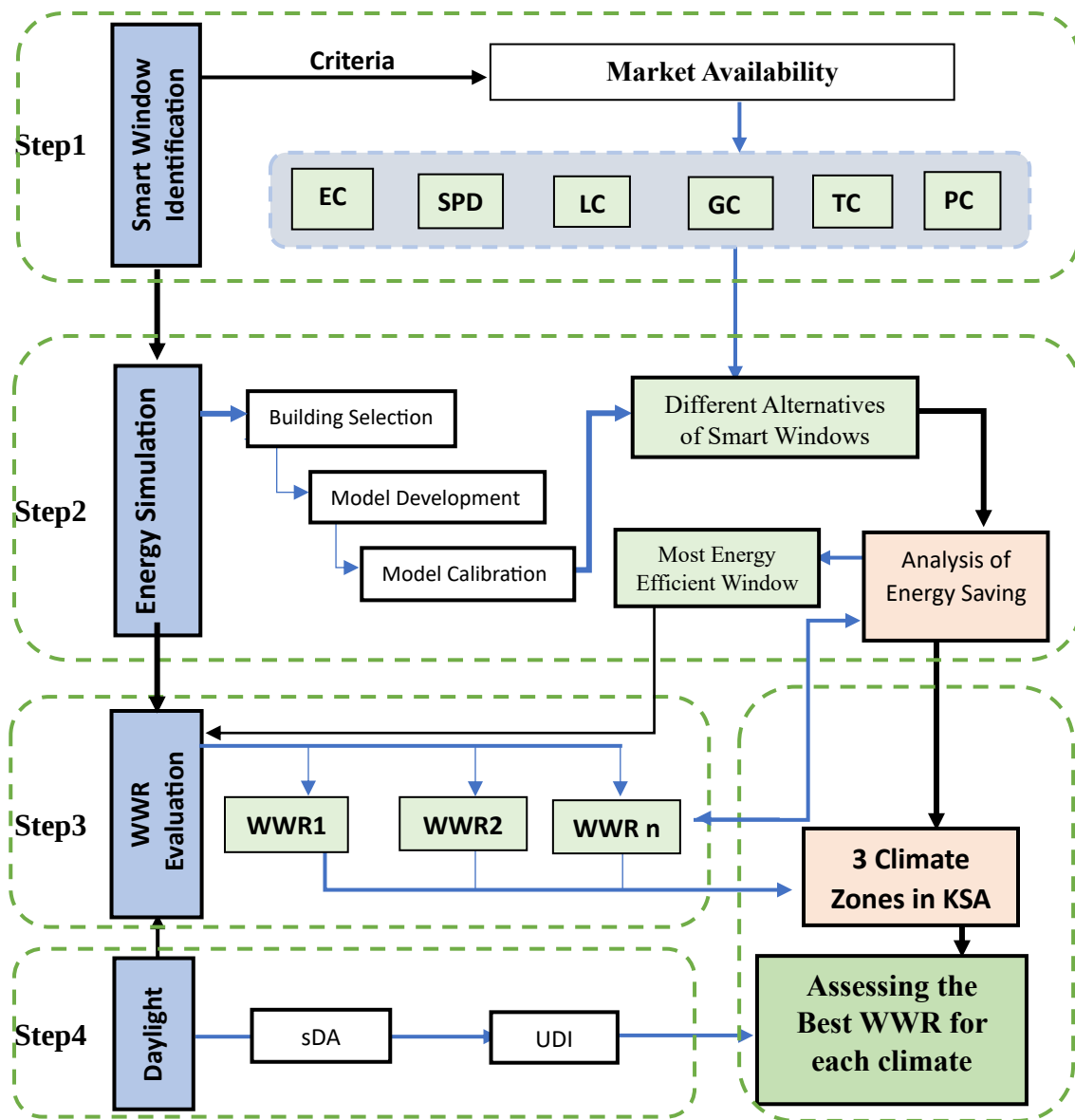


Figure 11: Framework for the general research design

The framework for the research procedure can be summarized as input (comprising the envelope material and system characteristics, process (which involves the simulation and analysis) and output which is the optimized selection of the most favorable alternative based on the assessment.

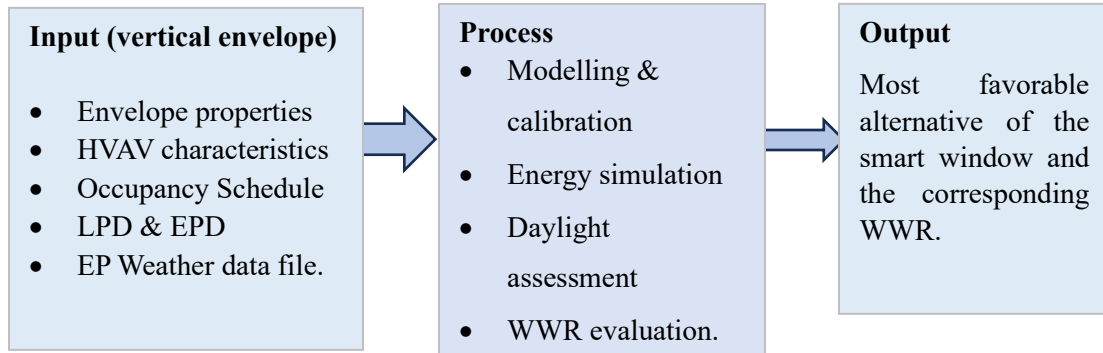


Figure 12: Methodology framework for smart window assessment in office building

3.1 Data Collection

3.1.1 Literature Review:

To establish theoretical foundation for this study, a comprehensive review of relevant literature is carried out, which will involve different envelope characteristics, smart glazing technologies, benefits of smart glazing, previous studies on office building envelopes both in Saudi Arabia & other regions, energy performance simulation tools, daylighting & WWR. The outcome of the literature review identified seven commercially available smart glazing that could be suitable for office building application. Fig 3 showed the identified smart glazing alternatives based on market availability.

3.1.2 Energy Performance Simulation:

The study will utilize energy simulation tools, such as EnergyPlus to simulate the energy performance of different alternatives of smart glazing as recommended by (Cabral & Blanchet, 2023). Input parameters can include climate data, building geometry, occupancy

schedule, lighting power density (LPD), equipment power density (EPD), HVAC system, and glazing properties (Haratoka et al., 2022a).

The simulations will help assess the effects of each alternative on energy usage in the building. This will reveal the saving potential of using smart glazing. However, value engineering demands that cost savings should consider the implication through the building life, therefore a life cycle assessment of the best alternative will be conducted.

Another important source of information is the industry report and brochure which describe the products' characteristics both thermal and optical. Manufacturers' information is therefore used. Where the manufacturer couldn't provide all required information, literature data is used from studies that conducted laboratory experiments on the targeted windows.

3.1.3 Daylight Assessment

This utilizes the Design Builder simulation tool to assess the daylighting levels. Glazing properties required include visible light transmittance (VLT), response time, window position, control mechanism & interior surface reflectance to assess the windows effect on useful daylight illuminance (Yao et al., 2022).

3.1.4 WWR Evaluation

Under the builder, optimization engine can be utilized in assessing the effects of WWR adjustment on different parameters, in this case energy consumption and daylighting levels. This will generate a basis of comparison among different windows and in relation to the climate characteristics.

3.2 Data Analysis

3.2.1 Analysis of Energy Savings

Result of the study of different smart glazing such as the (EC, TC, LC, SPD, GC & PC) will yield different energy saving potentials in envelope systems. Analysis of energy saving will be made relative to the base case model and relative to other smart window systems. However, the simulated WWR may not be the best configuration for the region. Thus, there is need to further evaluate the WWR to understand their effects across the different climates.

3.2.2 Analysis of daylighting

Daylight is often evaluated based on indoor illuminance level and useful daylight illuminance. However, for reliability of performance, this can be made in comparison to standard guidelines on indoor environmental quality, standards and national building codes. This includes but is not limited to ASHRAE guideline 14.

3.2.3 Analyzing the effects of WWR.

It is important to note that the typical office building selected and used as the base case may not offer the optimum WWR that offers the best energy saving and useful daylight intensity. Thus, evaluating the effects of the smart window from an energy point of view, there is need to further analyze how the WWR affects the performance under different climates. This will provide a basis for the development of guidelines on how to use the smart windows in each of the climates under study.

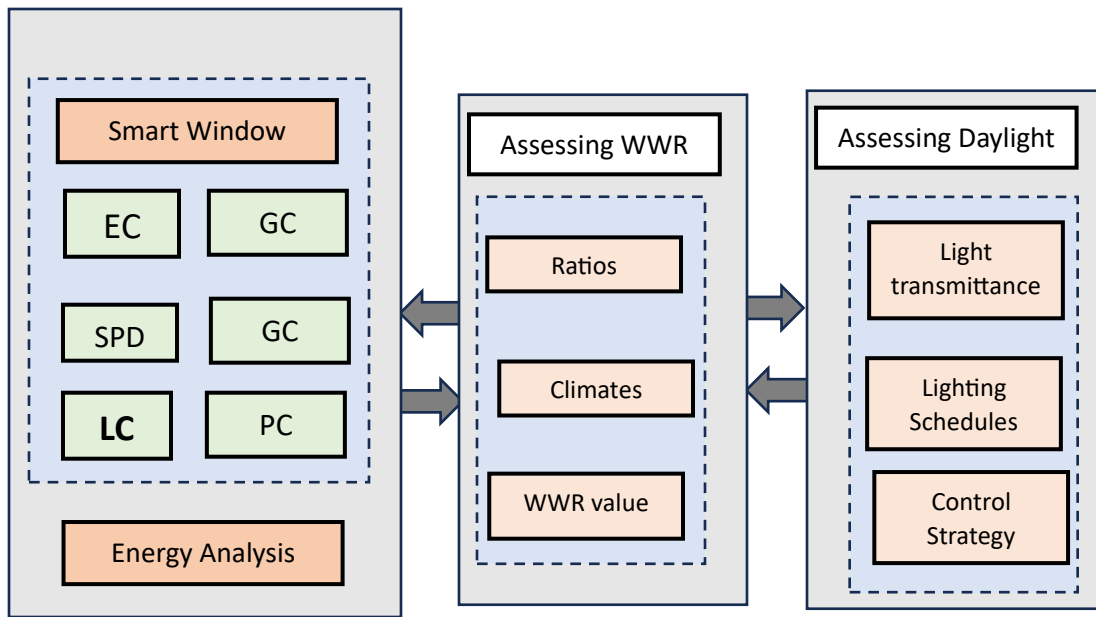


Figure 13: Smart Windows Assessment Framework

3.3 Model Validation

For simulation results to be considered valid, there should be a means of validation

However, the accuracy of simulation results depends on the accuracy of the representative model and the validity of the input data. This mainly consists of weather data, internal loads, building geometry, systems & components, LPD, EPD, operation strategies and specific simulation parameters (Alamin *et al.*, 2023). Thus, there is need to calibrate the model of the case study building to depict the characteristics of the real case.

Calibration process

The model to be used for simulation studies will be calibrated using the annual energy consumption in the real building case study obtainable from the utility bills of the building, compared with the energy consumption of the base case model. Less than 15% deviation based on coefficient of root mean square error (RMSE) and less than 5% normalized mean bias error (NMBE) show reliability of the model (ASHRAE Guideline 14-2014)

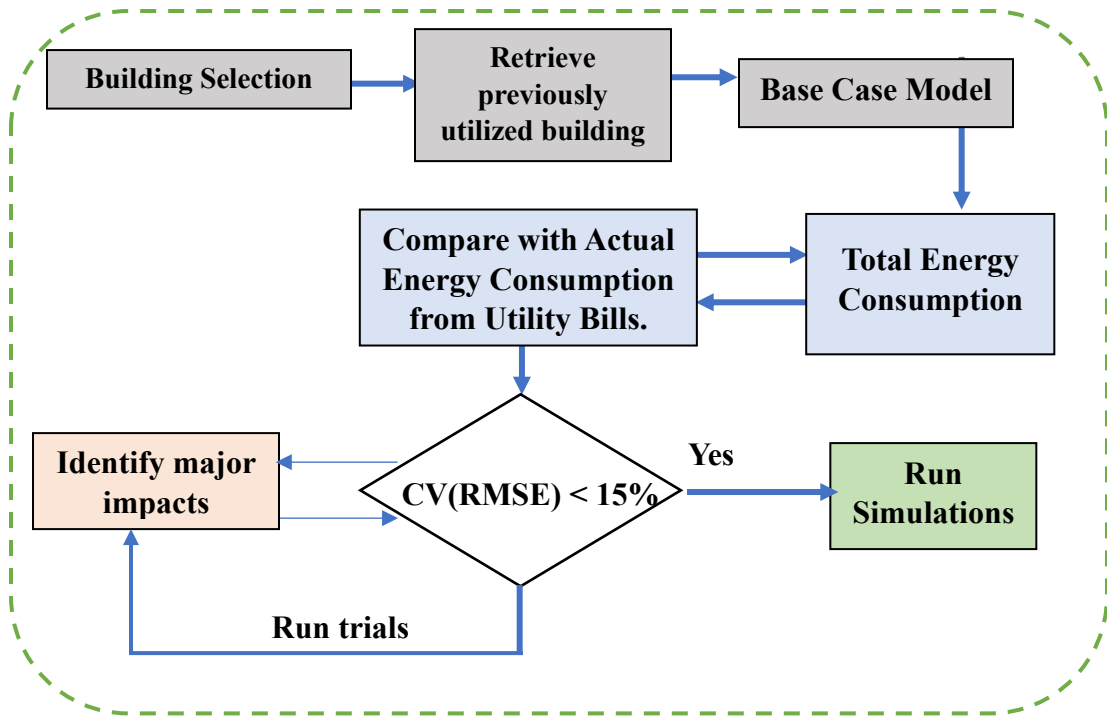


Figure 14: Model Calibration Framework

CHAPTER 4: FORMULATION OF BASE CASE MODEL

4.1 Model Development

The simulation requires a base case study building for validation. For this purpose, 11 floor office building said to be in Khobar neighborhood (Saudi Arabia in the eastern province) is adopted from previous study. This forms a base case for the entire study upon which all other analyses will be built. The building is selected because of the availability of data required for calibration provided and used previously by (Budaiwi & Abdul Fasi, 2023).

The model is built with Design builder v6.1.8.021. This is because the software provides the plugin for EnergyPlus simulation engine which is required for the study. However, after building the model is built and all the calibration processes are completed, the version does not provide flexibility in modelling and simulating smart window templates. When all trials to simulate the new window templates failed, Design Builder help center was contacted for assistance on how to model and smart windows. A response is received with guides on procedures to model smart, adding to suggestions of upgrading to higher version for more simulation flexibility. Design builder was updated to the latest version (v7.3.0.43) at that time. This provided flexible more options to model and simulate smart windows.

However, the accuracy of simulation results depends on the accuracy of the representative model and the validity of the input data, which mainly consist of weather data, internal loads, building geometry, systems & components, LPD, EPD, equipment operation strategies, occupancy schedule and specific simulation parameter (Alamin *et al.*, 2023). Thus, there is need to calibrate the developed model of case study building to depict the characteristics of the reference case. Figure 16a and 16b shows the 3D and 9 thermal zones in each floor of the building base case model.

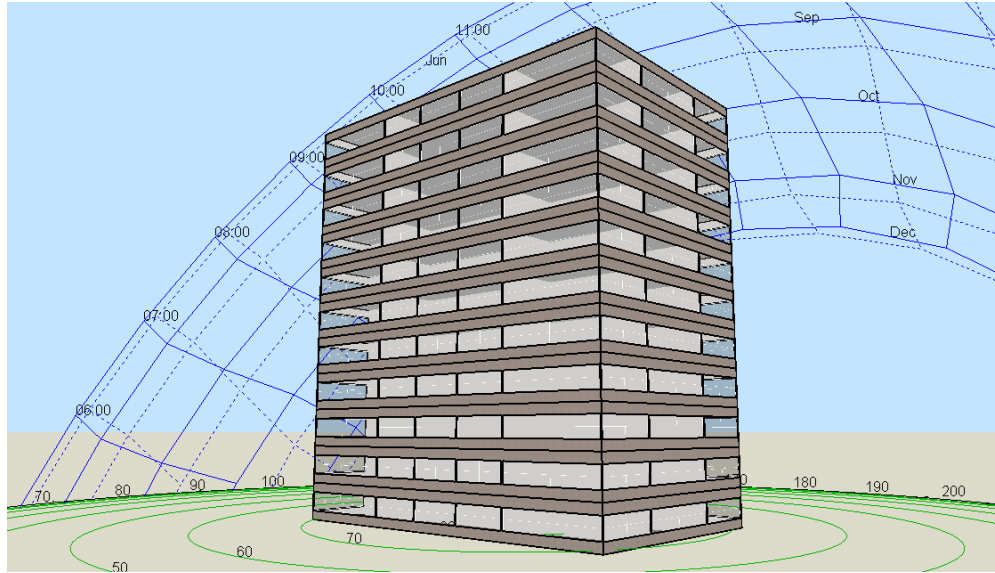


Figure 15: The Study Base Case Building (3D)

The 11 floors of the building are identical. The floor plan of the building is rectangular in shape, having 22x36m which is further subdivided into 9 thermal zones. Eight of the nine zones fall around the building perimeter and represent the office work spaces, while one zone at the center represents the core zone comprising staircase, corridors and other vertical transportation systems. All the eight perimeter zones have the same cooling and lighting requirements which vary from that of the core zone.

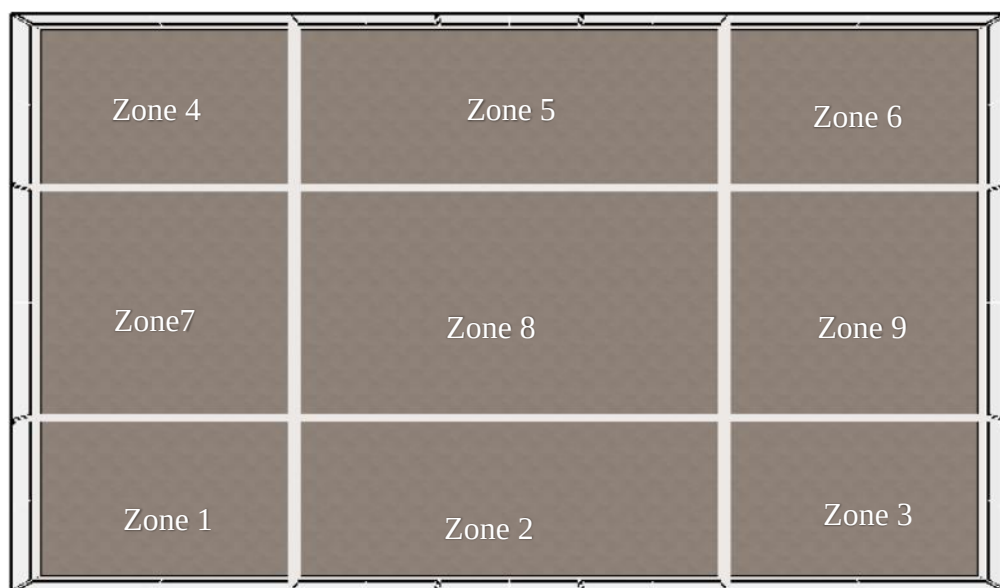


Fig 16b: The Plan showing 9 thermal zones

4.2 Building Characteristics

The area of the base case is considered based on the previous survey results conducted by researchers in the hot-humid region. Based on the review of design drawings, it is found that the average floor area that is commonly found in office buildings in Dhahran region ranges from 300 m² to 800 m² (Budaiwi & Abdul Fasi, 2023) and the common geometry of the office building plan is rectangular. For the base case model, the total floor dimension is 792 m², approximately of dimensions 22m x 36 m in length, and the larger dimension is assumed to be facing the North orientation.

The modelled building has eleven floors including the ground floor and roof floor, with the same office function throughout the floors. The height of each block (floor) is given as 3.7m which equals 8712 total floor area for all the 11 floors. Each floor in the model is divided into 9 thermal zones, having 8 zones around the perimeter and a typical core zone which houses mainly corridors and elevators.

4.2.1 The building envelope

Table 12 provides the details and thermal characteristics of the building envelope systems.

Table 12: Cross Section and Physical Properties of the Envelope

Construction Assembly	Elements from outside to inside	Thickness (m)	Thermal cond. (W/m-K)	Thermal Resist. (m ² -K/W)	U-value (W/m ² - K)
Wall Cross section	Stone cladding	0.02	2.9	0.007	0.740
	Air gap	0.025	0.3	0.083	
	EPS	0.025	0.04	0.625	
	Lightweight concrete	0.1	0.17	0.588	

	Plaster board	0.013	0.25	0.052	
Roof Cross section	Built-up roofing	0.0095	0.16	0.060	0.303
	Fiber board sheathing	0.012	0.06	0.2	
	R-15, Insulation board	0.075	0.035	1.85	
	Lightweight concrete	0.203	0.17	1.19	
Floor Cross section	Flooring	0.03	0.14	0.214	0.509
	Floor screeding	0.07	0.41	0.17	
	Cast concrete	0.1	1.13	0.09	
	Foam	0.06	0.04	1.5	

In the reference building, doubled pane tint glass window (6mm/13mm/6mm) is used as a representative of an office building and it is one of the commonly used window systems in hot-humid region (Al-Ashwal & Budaiwi, 2011). The window-to-wall ratio (WWR) is 50% in all the orientations. Based on the common practice, the windowsill is defined as 0.9m as reported in (Budaiwi & Abdul Fasi, 2023). This glazing is potentially used in the construction of most office buildings across the region. The air cavities minimize heat gain, by acting as an insulation while the entire window acts as barrier between the outdoor and indoor environment and reduces the cooling load inside the building. The building envelope details are summarized in Table 13.

Table 13: Building Envelope Details for the Base Case Model

Characteristics	Description
Plan shape	Rectangle
Clear floor height (m)	3.7
Number of floors	11
Gross floor area (m2)	8712
Gross wall area (m2)	4464
Glazing area (m2)	2232
Overall WWR (%)	50
Type of glazing (mm)	Double Glazed-Tint 6/13/6

4.2.2 HVAC system characteristics

The main purpose of a heating, ventilation, and air-conditioning (HVAC) system is to provide thermal comfort and to help maintain good indoor air quality. It is also needed to control the temperature, humidity, air movement, and air cleanliness. It is an essential system and has a major role in building energy performance. HVAC systems can be generally divided into three categories:

- All-air systems
- All-water systems
- Air-water systems

All-air systems transfer conditioned air from a central air handling unit (AHU) via ducting, distributing air to the spaces being served. In all-water systems, water from a chiller or a boiler is transferred by means of pipes, to a fan-coil unit in the space being served. An Air-Water system is a hybrid of all-air and all-water system, where both air and water are distributed to room terminals to perform cooling or heating function. In this study, an All-Air system is adopted due to the following reasons as mentioned in the referenced study:

- All-water systems are not capable of providing ventilation air to the zones being served, and hence, could not provide the required thermal comfort conditions in the zone.
- Operation and control are complicated for all air-water systems, due to the need for handling and controlling both primary air and secondary water. Also, the initial cost is on the highest side, making it uneconomical.

Variable Air volume (VAV) HVAC system has been used for cooling the zones in the perimeter area, whereas constant air volume (CAV) is used for the core zone, as they are found to in the base case building and are assumed to be effective in hot climate.

The reason for the selection of VAV system is because it has been found that VAV system in office buildings can save substantial amount of electricity in Hot-humid region (Chang et al., 2023) VAV systems can significantly lower power consumption, especially in perimeter zones where variations in solar load and outside temperature allows for reduced air flow rates. A VAV system changes the quantity of supply air in space in response to changes in loads. Central AHU supplies air through a common duct network to all spaces conditioned by the unit. Each zone is provided with a VAV box (terminal control box) that adjusts air supply volume in response to the zone thermostat. The temperature of supply

air to each zone remains constant, whereas its flow rate varies depending on the load on that zone. The temperature of air supplied by the AHU may be varied occasionally to adapt to building-wide changes in loads, although instant control of individual zones is achieved through regulation of supply airflow rate. The VAV is achieved by VAV boxes having a modulating damper that throttles in response to the thermostat setting. When the indoor temperature conditions vary from the set point, the VAV box damper responds by regulating the air volume supplied to space. The supply temperature at the diffuser is set as 14 °C (based on ASHRAE standard). Electricity from the grid is considered the sole power source for cooling. Mechanical ventilation is set based on energy standards, which depends on the number of people and area to be ventilated for each zone. Figure 16 shows the layout of a typical VAV unit.

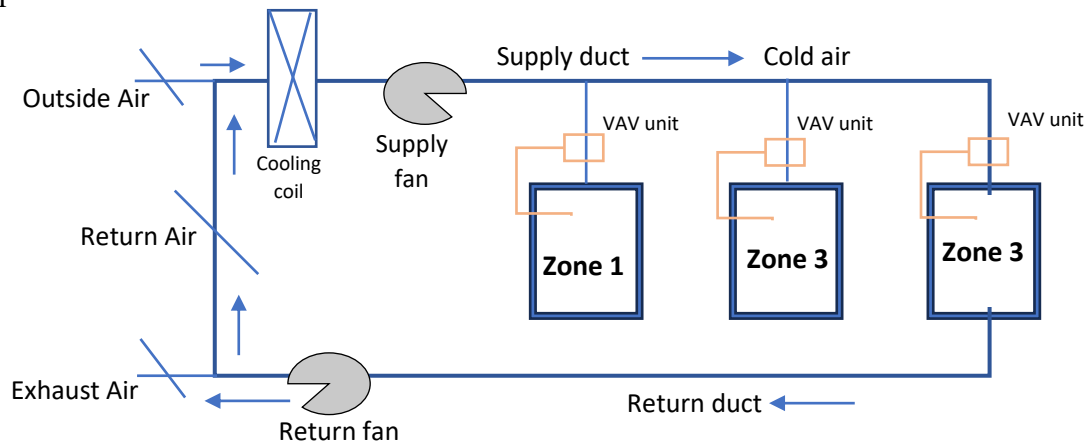


Figure 16: VAV Model Layout in the Software Tool

Table 14: The characteristics and parameters of HVAC for the base case model.

Characteristics	Description
System Type	VAV system for the perimeter zones, CAV system for the core zone
Indoor Cooling Design Temperature (°C)	24
Ventilation (m ³ /sec/person)	0.008 (ASHRAE 90.1-2010)

4.2.3 Lighting System Characteristics

Generally, the focus of lighting is to provide and maintain good, high-quality lighting for areas and tasks. Areas such as staircases and mechanical rooms require lower light levels. Finding ways to provide occupants with comfortable light levels, instead of providing the same light level throughout the building, is the key to improving energy efficiency and maintaining comfort and safety. This practice can reduce a building's lighting loads and cooling load substantially by reducing lighting heat build-up. It increases occupant comfort and reduces overall complaints regarding lighting levels (Budaiwi & Abdul Fasi, 2023).

In the base case model, the illumination level for the office area (perimeter zones) is set to 500 Lux based on IESNA whereas for the core zone which contains staircase and mechanical room, the illumination level is set to 300 Lux because that zone which requires lower light level as per the lighting standards (10th Edition Handbook, 2011). Due to their efficiency and long life (up to 10 times the lamp life of standard incandescent lamps), *Triphosphor Fluorescent* lamps were used for fulfilling the required illumination level in the base case model. The Luminaire is recessed into the ceiling and the display lighting power density (LPD) for the fluorescent lamp is set to 2.4 W/m² -100 Lux based on ASHRAE 90.1-2022.

Table 15: Base Case Office Building Lighting Characteristics

Light Characteristics	Perimeter zone	Core zone
Illumination level	500 Lux based on IESNA (10th Edition Handbook, 2011)	300 lux
LPD	2.4 W/m ² -100 Lux based on ASHRAE 90.1-2010	Triphosphor Fluorescent lamps
Luminaire Type	Triphosphor Fluorescent lamps	Triphosphor Fluorescent lamps

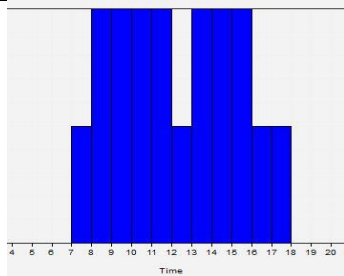
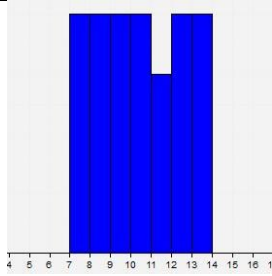
4.2.4 Operational Characteristics

Building occupancy follows the same pattern during both summer and winter seasons. Same lighting operation pattern is assumed throughout the year, while HVAC systems operations vary for summer (April to September) and winter (December to March), whereas as October and November were regarded transition from summer to winter and thus, system operations slightly differ from those of the winter months, all to meet cooling demand in all zones throughout the year.

Building occupancy schedule is set based on logical judgment and common practice. Building occupancy was assumed to start at 7:00 AM in the morning and go on until 6:00 PM in the evening, with a break of one hour for lunch, from 12:00 noon to 13.00 from Saturdays to Wednesdays whereas, occupancy is between 8:00am to 14:00 every Thursday.

Table 15 shows the occupancy profiles for the building users and schedules for the different building systems. Lighting is turned on 100% during occupied hours and only 10% during night and unoccupied hours. It is assumed that the lighting system and HVAC system in the building will be turned off on Fridays.

Table 16: Base Case Office Building Operation Schedules

SCHEDULE TYPE	SUNDAY TO WEDNESDAY	THURSDAY	SCHEDULE DESCRIPTION
Occupancy Pattern			100% during occupied periods, 50% first hour before and during break. 80% on Thursdays.

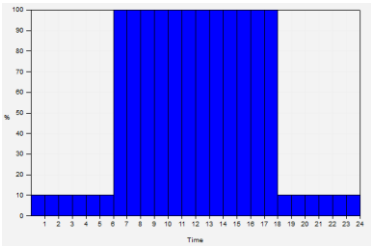
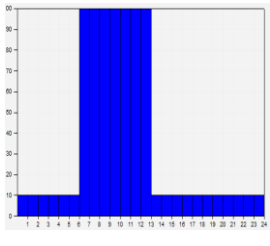
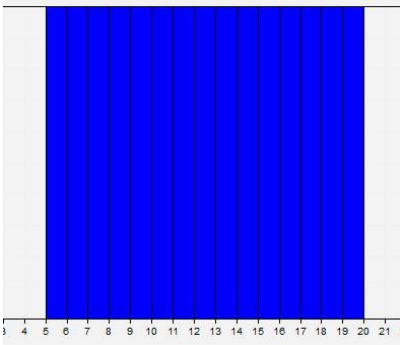
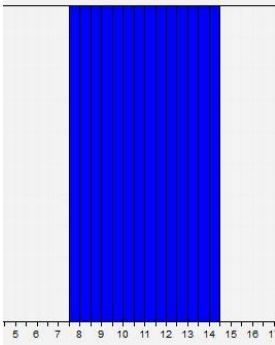
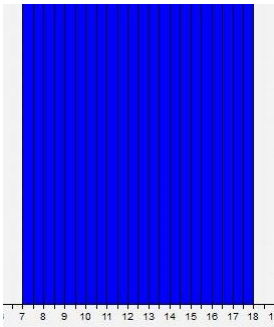
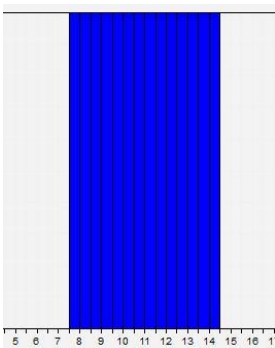
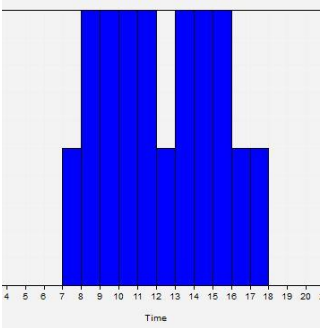
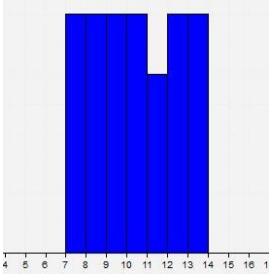
Lighting Schedule			100% during occupied periods, 10% during unoccupied periods
Cooling Schedule (Summer)			5:00 to 20:00 from Sunday to Wednesday, 7:30 to 14:30 on Thursday
Cooling Schedule (Winter)			7:00 to 18:00 from Sunday to Wednesday, 7:30 to 14:30 on Thursday
Equipment Schedule			100% during occupied periods, 50% first hour before and during break. 80% on Thursdays.

Table 17: General Characteristics of Base Case Model (Al-Ashwal & Budaiwi, 2011)

CHARACTERISTIC	DESCRIPTION
Type of building	Office
Weather Data file	Dhahran Weather file_Abdulaziz.AB.404160_TMYx
Plan Shape	Rectangle
Number of floors	11
Clear Floor Height (m)	3.7
Floor Dimension (m)	22 x 36
Gross Floor Area (m2)	8712
Gross wall area (m2)	4500
Window area (m2)	2250
Overall WWR (%)	50
Type of glazing (mm)	Double clear/Tinted/Low E
Building orientation	NORTH
Occupancy Density	9 m2 /person (ASHRAE 90.1-2010)
Perimeter Depth (m)	7
Solar Absorbance	0.5 for external walls and 0.5 for the roof
Lighting (LPD)	11 W/m2 (ASHRAE 2010)
Equipment (EPD)	5 W/m2 (ASHRAE 2010)
Computers	7 W/m2 (ASHRAE 2010)
Infiltration	0.5 ACH (Average tightness constructed building)
Target Illuminance	Perimeter Zone: 500 Lux, Core Zone: 200 Lux
HVAC Type	Perimeter Zone: VAV, Core Zone: CAV

Lamps	T8 (25mm diameter) Fluorescent –triphosphor- with stepped dimming daylighting control
Luminaire type	Recessed
Outside air definition	Minimum fresh air (sum per person + per area)
Fuel for cooling	Electricity from grid
Supply air temperature	14 °C

4.3 Model Validation

The developed model is validated according to the threshold prescribed by ASHRAE guide 14; 2023 found in (*ASHRAE-D-86890*, n.d.) which states that simulated building energy model should be validated with measured energy from real building utility bills using normalized mean bias error (NMBE) and coefficient of variation of root mean square error (CV(RMSE)), stating that for monthly measured data, results should not exceed 15% and 5% for CV(RMSE) and (NMBE) respectively. Figure 17a and 17b show the energy profile from the building model compared to actual utility bill.

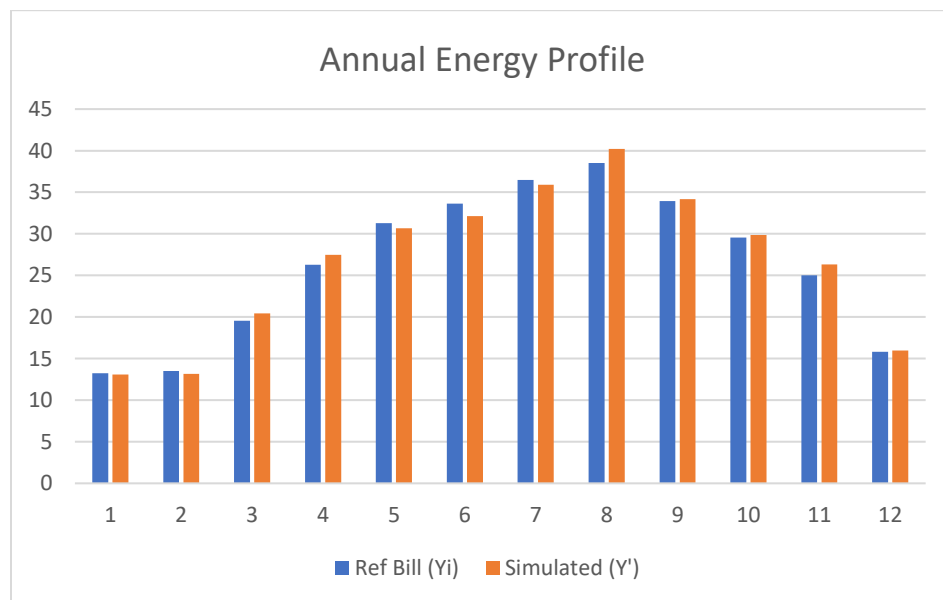


Figure 17a: Comparison between energy bills and simulated EUI

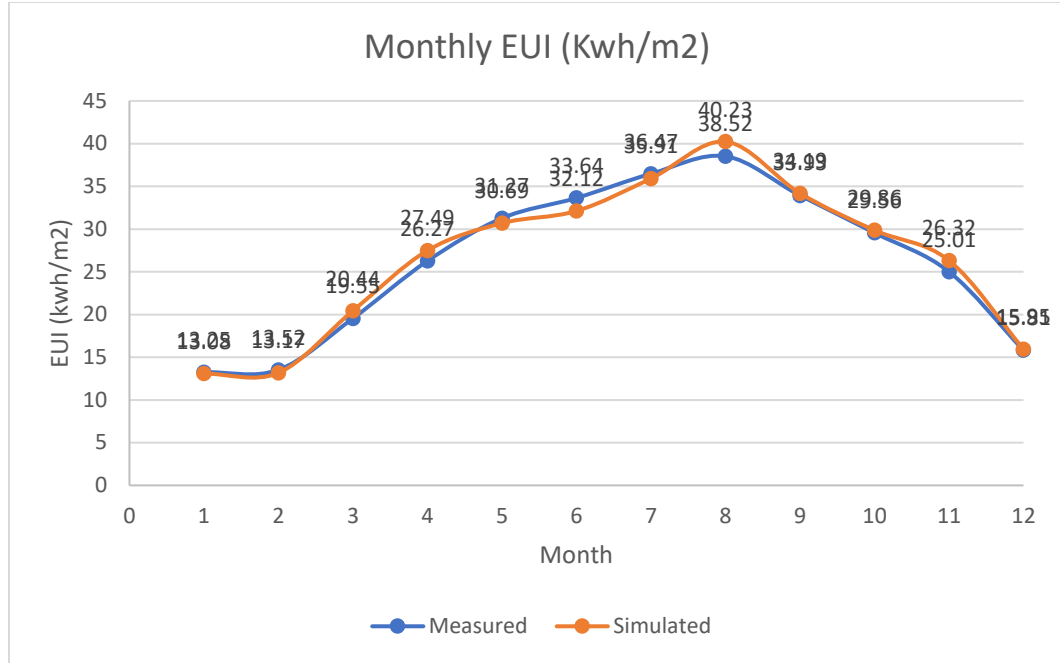


Fig 18b: Comparison between energy bills and simulated EUI

The following equations were used as prescribed in the ASHRAE guide 14.

$$NMBE = \left(\frac{\sum_{i=1}^n (Y'_i - Y_i)}{n \times \bar{Y}} \right) \times 100 \quad \dots\dots\dots (1)$$

$$CV(RMSE) = \left(\frac{RMSE}{\bar{Y}} \right) \times 100\% \quad \dots\dots\dots (2)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (Y_{sim,i} - Y_{meas,i})^2} \quad \dots\dots\dots (3)$$

Table 18: Comparing Measured energy (utility bill) and simulated energy

Month	Ref Bill (Yi)	Simulated (Y')	Error (Y'-Yi)	MBE (%)	SQR Error	RMSE
Jan	13.25	13.08	-0.17	-1.3%	0.03	0.6%
Feb	13.52	13.17	-0.35	-2.6%	0.12	1.3%
Mar	19.55	20.44	0.89	4.5%	0.79	3.4%
Apr	26.27	27.49	1.22	4.7%	1.50	4.6%

May	31.27	30.69	-0.58	-1.9%	0.34	2.2%
Jun	33.64	32.12	-1.52	-4.5%	2.32	5.8%
Jul	36.47	35.91	-0.56	-1.5%	0.31	2.1%
Aug	38.52	40.23	1.71	4.4%	2.92	6.5%
Sep	33.93	34.19	0.26	0.75%	0.07	1.0%
Oct	29.56	29.86	0.30	1.0%	0.09	1.1%
Nov	25.01	26.32	1.31	5.2%	1.71	5.0%
Dec	15.81	15.95	0.14	0.9%	0.02	0.5%
SUM	316.8	319.44	2.64			
AVG	26.40	26.62				

Calculating the Normalized Mean Bias Error (NMBE)

$$MBE = \sum(\text{Errors}) = \sum(Y' - Y_i) = 2.64 \quad \dots\dots\dots (\text{Table 14})$$

$$NMBE = \sum(\text{Errors}) / \sum(Y_i) * 100\% = 2.64 / 316.8 = \underline{\underline{0.83\%}}$$

Calculating the Coefficient of Variation of Root Mean Square Error (CV(RMSE))

From equation 3:

$$RMSE = \sqrt{\sum(Y' - Y_i)^2 / n}$$

$$RMSE = \sqrt{10.22 / 12} = \sqrt{0.852} = 0.923$$

$$\text{Mean of the reference bills (Y)} = 26.4 \quad \dots\dots\dots (\text{Table 14})$$

$$\begin{aligned} CV(RMSE) &= RMSE / Y * 100\% \\ &= 0.923 / 26.64 = \underline{\underline{3.46\%}} \end{aligned}$$

Conclusion:

The NMBE is **0.83%** and CV(RMSE) is approximately **3.46%**, which indicates the percentage variations between the simulated and actual reference bills. This satisfied the ASHRAE guide requirement which states that NMBE should be $\leq 5\%$ while CV(RMSE) should be $\leq 15\%$.

4.4 Modelling the Smart Windows

Smart windows are dynamic windows that change their level of transparency from clear to tint state in response to an external stimulus. The smart property is achieved by applying a layer of chromogenic material within the pane assembly during the manufacturing process. The chromogenic material used determines the stimulus and control logic. For the six smart windows under study: Electrochromic, Photochromic, Gasochromic and Thermochromic, Liquid crystal window and Suspended particle devices SPD, table 19 below summarized the chromogenic materials layer used to achieve the different smart windows properties.

Table 19: Smart window systems and their chromogenic materials.

	Smart Window System	Chromogenic Material	Source
1	Electrochromic	Indium Tin Oxide (ITO)/ Titanium dioxide (TiO ₂)	(Jiang et al., 2024a) https://www.sageglass.com/smart-windows
2	Photochromic	Silver Halides (AgCl, AgBr)	(Ke et al., 2019) https://smartglassme.com/self-tinting-photochromic-film/
3	Gasochromic	WO ₃ or HWO ₃ .	(Morrey & Ghosh, 2024; Ghosh & Norton, 2018; Carlucci, 2021)
4	Thermochromic	Vanadium dioxide (VO ₂)	(Ghosh & Norton, 2018; Lin et al., 2021)
5	Liquid Crystal/ PDLC	Indium oxide (In ₂ O ₃) and tin oxide (SnO ₂)	(Hemaida et al., 2020) www.gauzy.com www.pdlcglass.com
6	Suspended Particle Devices (SPD)	<i>Nanoparticles</i> (SnO ₂) or <i>LC</i> in a polymer film	(Mesloub et al., 2022; Ghosh & Norton, 2018)

Different windows can be simulated with *designbuilder* to evaluate their effect on heat gain and daylight into the building. *Designbuilder* provide options for creating new window templates and defining their properties.

Using EnergyPlus simulation engine in design builder, window properties can be defined in two ways: Simple and detailed (by material layer). A simple way is to define the overall properties of the assembly in terms of three parameters:

- i. Total solar transmission (SHGC)
- ii. Visible transmittance
- iii. U-value ($\text{W/m}^2 \cdot \text{K}$)

Detailed defining (by material layer) is more efficient and requires detailed definition of thermal and optical properties of each individual layer and the cavity in every doubled or tripled pane window. Design builders do not support simple definition for smart windows, rather detailed is required which involve numeric values for the following parameters:

4.5 Simulation Parameters

4.5.1 Optical Properties

1. Solar Transmittance (T_{sol})
2. Outside Solar Reflectance (R_{sol})
3. Inside Solar Reflectance (R_{sol})
4. Visible Transmittance (T_{vis})
5. Outside Visible Reflectance (R_{vis})
6. Inside Visible Reflectance (R_{vis})

4.5.2 Thermal Properties

1. Thermal conductivity ($\text{W/m} \cdot \text{K}$)
2. Infrared Transmittance (T_{ir})
3. Outside Surface Emissivity (E_{mis})
4. Inside Surface Emissivity (E_{mis})

The following figure 19 shows definition window for the window simulation properties in design builder.

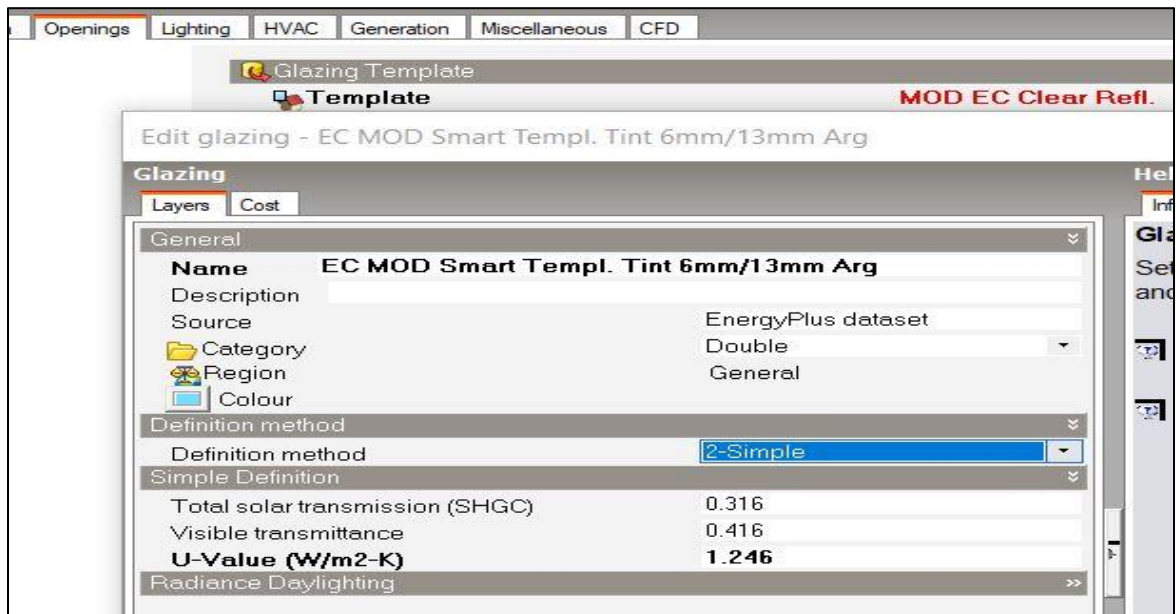


Figure 18: Simple window definition.

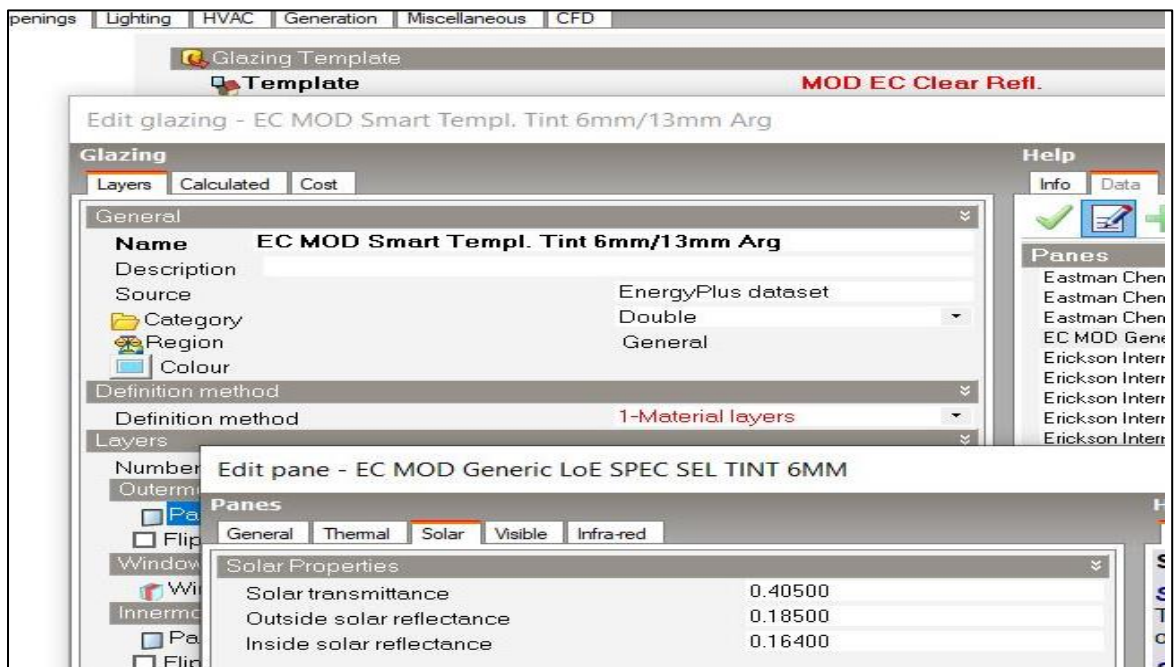


Fig 19b: Detailed window definition

4.6 Switchable Window Property Definition

Switchable glazing can change light transmittance, transparency, in response to an environmental signal such as sunlight, temperature or electrical control. EC, GC, LC and SPD windows change from transparent to tinted by applying an electrical current. Potential uses for smart window technology include daylighting control, glare control, solar heat control, and fading protection in windows.

Unlike ordinary windows, Smart windows have at least two states: the clear when the smart property is turned off and the tint state when the smart property is turned on. To define this dynamic property, design builder (v7.3.0.43) provided switchable options under window shading. This enables the definition of all thermal and optical properties when the smart characteristic is on, whereas the previous characteristics defined in fig 11 (above) are maintained as the window property when the smart property is off. Moreover, a control logic needs to be defined to specify the smart type of the windows. The control logic is the external condition that triggers the actuation of smart property. For the smart windows under study, the control logics include solar radiation, daylight, glare, outside air temperature and inside air temperature.

Depending on the control type, a setpoint is given. The window above means that the smart windows respond to the intensity of solar radiation and the tint property is activated once the intensity of the solar radiation reaches 300W/m^2 . Figure 20 below shows the switchable windows control logic definition window in design builder.

Shading

☒ Window shading

Type

MOD EC reflective 6mm

Position

4-Switchable

Control type

4-Solar

Solar setpoint (W/m²)

250

Operation

Schedule definition

1-Follow occupancy

☐ Local shading

Figure 19: Switchable shading and control logic definition window

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Smart Window Properties

This section provides the required detailed thermal and optical properties of the six smart windows under study. The information is obtained from industrial reports and brochures of manufacturers as well as supplementary data from studies that conducted laboratory experiments on the properties of various smart window glazing systems. Table 16 summarizes the detailed thermal and optical properties of

1. *Electrochromic (EC)*
2. *Gasochromic (GC)*
3. *Photochromic (PC)*
4. *Thermochromic (TC),*
5. *Liquid Crystal (LC) and*
6. *Suspended Particle Devices (SPD) Windows*

Table 20: Potential Manufacturers of Smart windows providing specifications

	Manufacturer	Smart Window	Website
1	 	Photochromic Thermochromic	https://smartglassme.com/self-tinting-photochromic-film/ https://www.smartglassworld.net/samples
2	 	Electrochromic Gasochromic	https://intelligentglass.net/products/ https://www.smartglasstech.us/priwa-tt-glass/
3		LC & SPD	www.gauzy.com
4		PDLC	https://www.pdlcglass.com/products/switchable-pdlc-glass/

5.1.1 Summary of the properties of the smart windows at clear and tinted state.

The numeric values for all the thermal and optical properties of the six smart windows under study are summarized in table 21 below, for both clear and tint states.

Table 21: Summary of smart windows thermal and optical properties.

	State	T_{sol}	R_{sol} (Out)	R_{sol} (In)	T_{vis}	R_{vis} (Out)	R_{vis} (In)	T_{ir}	Emis (Out)	Emis (In)	Cond. (W/mK)
Base Case		0.455	0.053	0.053	0.430	0.052	0.052	0.000	0.840	0.840	0.900
Electro-Chromic	Clear	0.405	0.173	0.114	0.636	0.183	0.122	0.000	0.840	0.138	0.788
	Tint	0.005	0.185	0.164	0.013	0.181	0.130	0.000	0.840	0.138	0.788
		(Morrey & Ghosh, 2024)									
Gasochromic	Clear	0.600	0.080	0.160	0.670	0.220	0.240	0.000	0.840	0.138	0.900
	Tint	0.170	0.180	0.190	0.170	0.070	0.150	0.000	0.840	0.138	0.900
		(Morrey & Ghosh, 2024)									
Photo-Chromic	Clear	0.450	0.150	0.080	0.750	0.220	0.240	0.050	0.840	0.138	0.750
	Tint	0.190	0.205	0.140	0.200	0.190	0.150	0.050	0.840	0.138	0.750
		https://smartglassme.com/self-tinting-photochromic-film/									
Thermo-Chromic	Clear	0.600	0.120	0.120	0.620	0.080	0.080	0.050	0.840	0.100	0.900
	Tint	0.230	0.150	0.150	0.180	0.120	0.120	0.050	0.840	0.100	0.900
		(Lantonio & Krarti, 2022) (Mustafa et al., 2023b)									
Liquid Crystal	Clear	0.629	0.177	0.177	0.715	0.245	0.245	0.00	0.840	0.138	0.800
	Tint	0.265	0.254	0.254	0.268	0.380	0.380	0.00	0.840	0.138	0.800
		(Mesloub, Ghosh, Kolsi, et al., 2022)									
SPD	Clear	0.460	0.180	0.180	0.650	0.120	0.120	0.00	0.840	0.138	0.850
	Tint	0.06	0.205	0.205	0.105	0.180	0.180	0.00	0.840	0.138	0.850

Source: (Morrey & Ghosh, 2024; Ghosh & Norton, 2018; Carlucci, 2021) (Li et al., 2024) (Gundogdu et al., 2024) (Mustafa et al., 2023a) (Lantonio & Krarti, 2022)

5.2 Simulation Results

The base case was formulated at 50% WWR, thus the first basis of comparison is at the same WWR for all windows. Followed by evaluation of different WWR for different windows to determine the optimum. Although total simulation output contains three electric loads: cooling, lighting and room electricity (appliances), room electricity remains constant at 30.84 kwh/m²/yr in all scenarios and therefore is not included in the analysis. Figure 20 shows the percentage distribution of energy consumption while Table 22 show heating and lighting energy consumption of EC, GC, PC, PDLC, SPD and TC windows relative to the base case (all at the same 50% WWR).

Table 22: Energy consumption of different windows at 50% WWR at Jeddah

		Window	Cooling Energy	Lighting Energy	Total EUI (kwh/m²/yr)	Energy Saving
		Base Case	76.25	284.11	360.4	-
	1	Electrochromic	87.5	233.9	321.4	10.8 %
	2	Gasochromic	74.90	245.2	320.11	11.2%
	3	Photochromic	66.1	232.2	298.3	17.2%
	4	Liquid Crystals	73.9	237.5	311.4	13.6%
	5	Thermochromic	79	256	335	7%
	6	SPD	82.9	240.4	323.3	10.3%

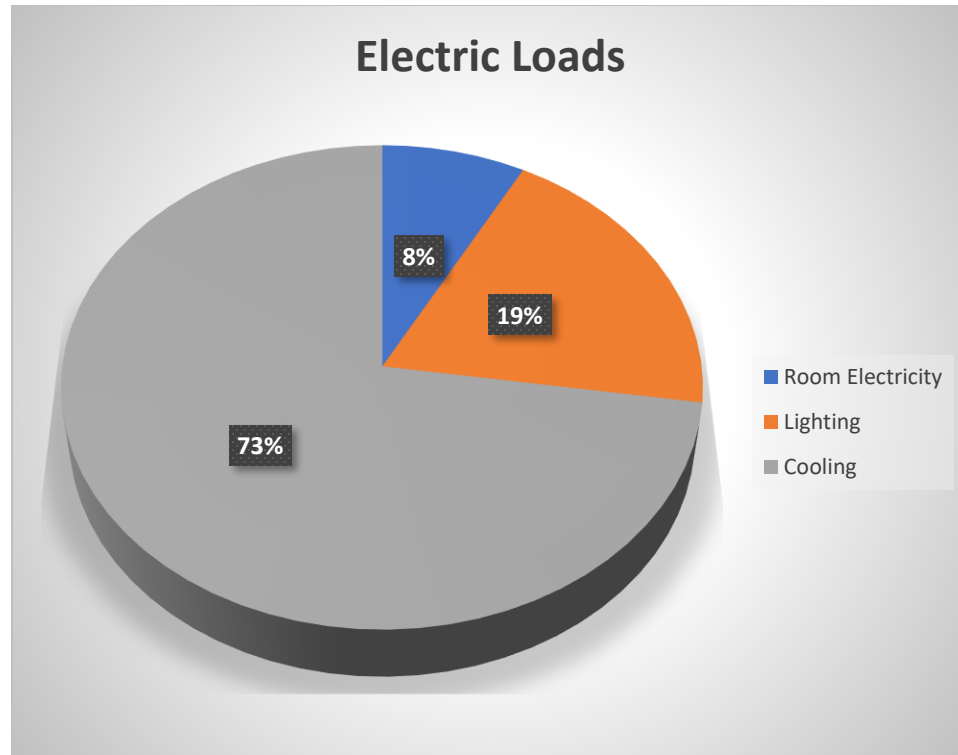


Figure 20: Percentage distribution of electric loads

Energy Profiles with Base Case Window at different locations

Although calibration of the base case model was done using Dhahran weather data file, the study scope is focused on three locations: Jeddah (representing coastal hot-humid climate), Taif (representing Mediterranean climate with mild winters and hot summers) and Riyadh (hot-dry climate) of Saudi Arabia Respectively. Thus, there is need to regenerate a base case for each of the three locations values for analysis purpose. This exercise yielded three different results, each representing a base case for one location. The figures 22 below show total cooling and lighting energy for the base case for the three locations: total EUI found to be 360.4 kw h/m²/yr for Jeddah, 245.5 kwh/m²/yr for Taif and 261.9 kwh/m²/yr for Riyadh

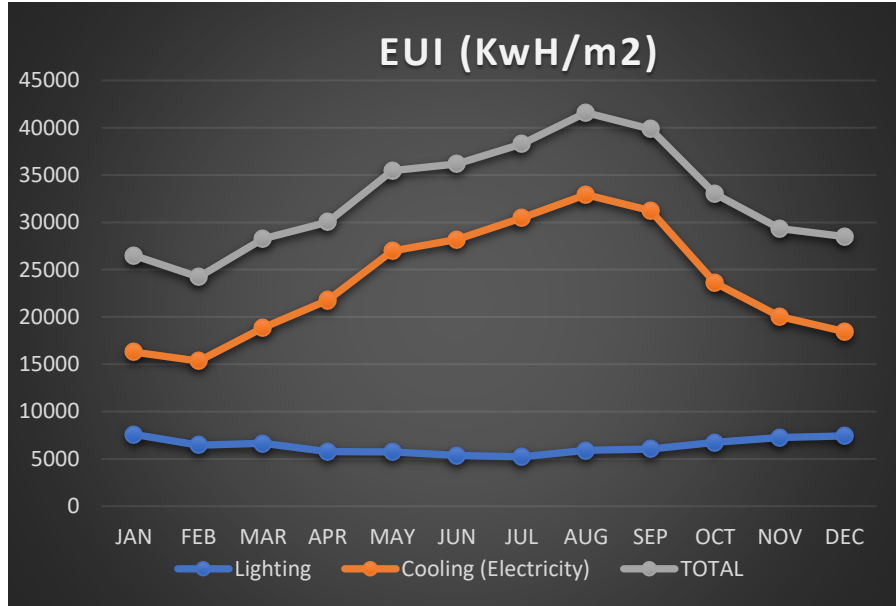


Figure 21a: Base Case Energy Profile for Jeddah (Coastal climate)

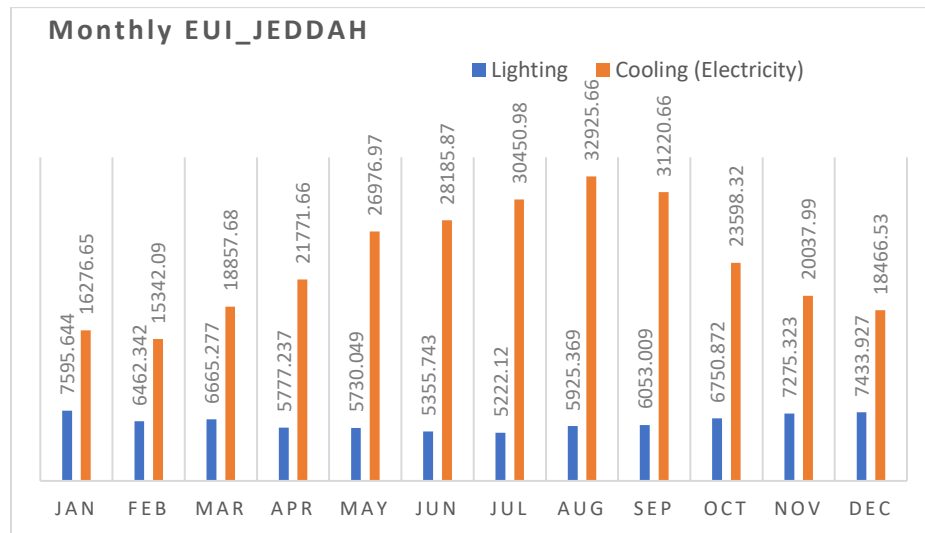


Fig 22b: Base Case Energy Profile in Jeddah

Taif represent another climate zone in Saudi Arabia, having features of Mediterranean climate with mild winters and hot summers according to (Alayed et al., 2022). Temperatures are relatively lower than coastal climate of Jeddah, this resulted in significant reduction in the annual energy consumption and the peak loads. Fig 22c shows the energy profiles in Taif.

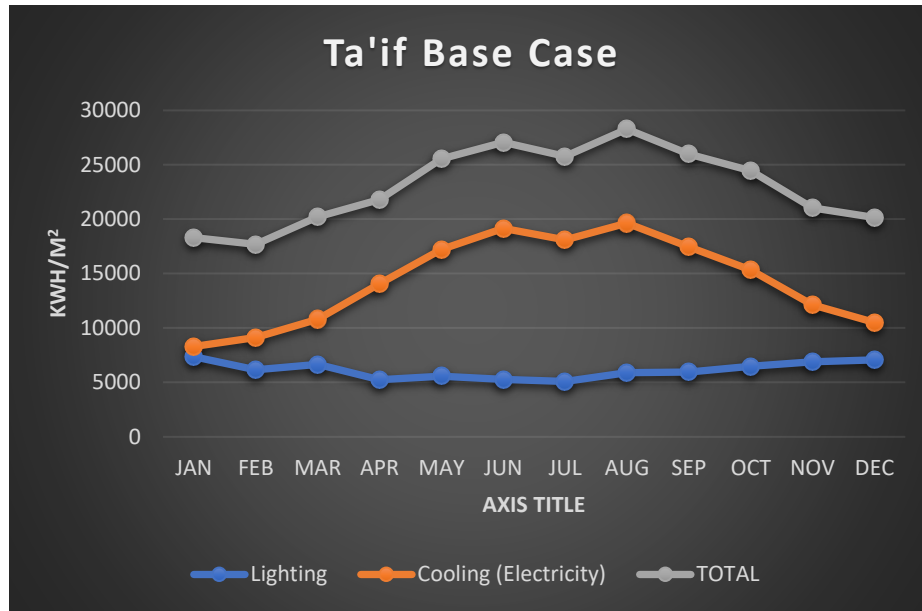


Fig 22c: Base Case Energy Profile for Ta'if (mild winters and hot summers climate)

Another climate zone (Semi-desert) is represented by the city of Riyadh. Although it has lower winter temperatures than Taif, the peak months have higher temperatures and thus higher builder energy profiles than the preceding zone (Taif). Fig 22d shows the base case energy profile for Riyadh.

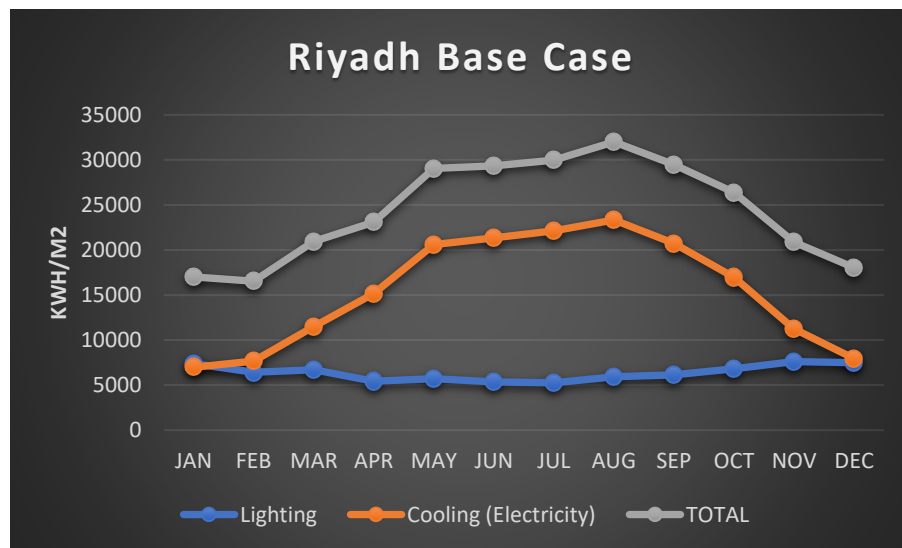


Fig 22d: Base Case Energy Profile for Riyadh (Hot-Dry climate)

5.2.1 Electrochromic Window (EC)

i. *Electrochromic Window in Coastal Climate (Jeddah)*

The following results show the energy profile with electrochromic windows under coastal hot-humid climate of Jeddah. Figure 23 show the total annual energy consumption at different WWR. Increased window size can lead to greater daylight which reduces the need for artificial lighting, this can be seen from the figure where electric consumption for lighting decreases as window size increases.

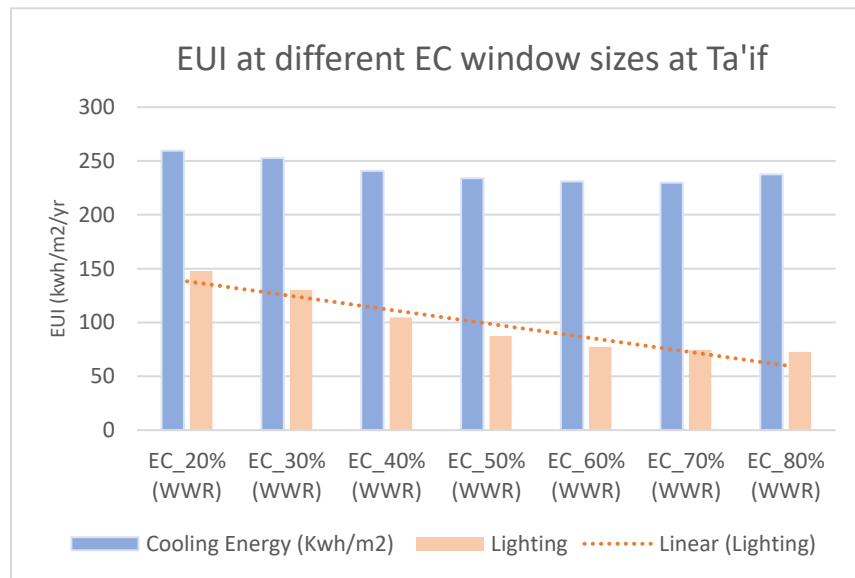


Figure 22: Electric consumption with EC window at different window sizes

Energy saving is seen from 40-80% with greatest saving of 15.56% achieved at 70% WWR which is therefore the optimum window size that offers greatest benefit in total annual EUI at the given location (Jeddah). Figure 24 shows the saving in the annual EUI at different window sizes and relative to the base case. At 20%, 30% and 40% WWR, the results show negative values which means there is no energy reduction, rather, an increase in energy consumption relative to the base case.

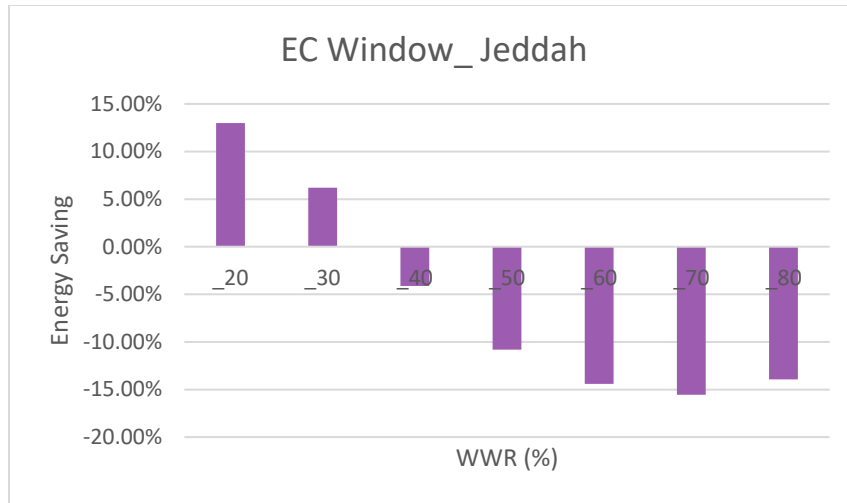


Figure 23: Percentages of energy rise/fall with EC window at different sizes

ii. *Electrochromic Window in Mediterranean climate (Ta'if)*

The figure 17 below shows the cooling and lighting energy profile for EC windows under the climate of Taif. Cooling energy demand increases with an increase in window size while lighting energy demand decreases as the window increases although not completely linear. The total annual energy consumption is lowest at 70% WWR making it the optimum EC window size in that location. Due to reduced temperatures of summer and peak times, Taif shows lower overall total annual energy consumption than the coastal climate of Jeddah

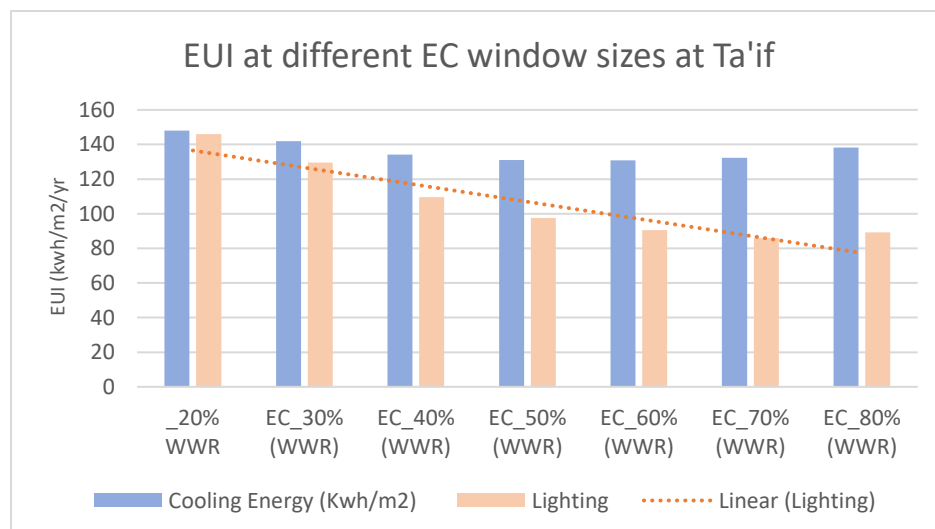


Figure 24: Electric consumption with EC window at different window sizes

EC windows in Taif shows only 4% reduction in cooling and lighting energy when the WWR is 50%, however, further reduction can be achieved with increased window size. 70% WWR appears to be the optimum with net savings of 11%, beyond this, the energy consumption tends to increase due to increased cooling load. At 30% WWR and below, EC windows result in increased building energy demand due to increased lighting energy profile. See fig 26 below.

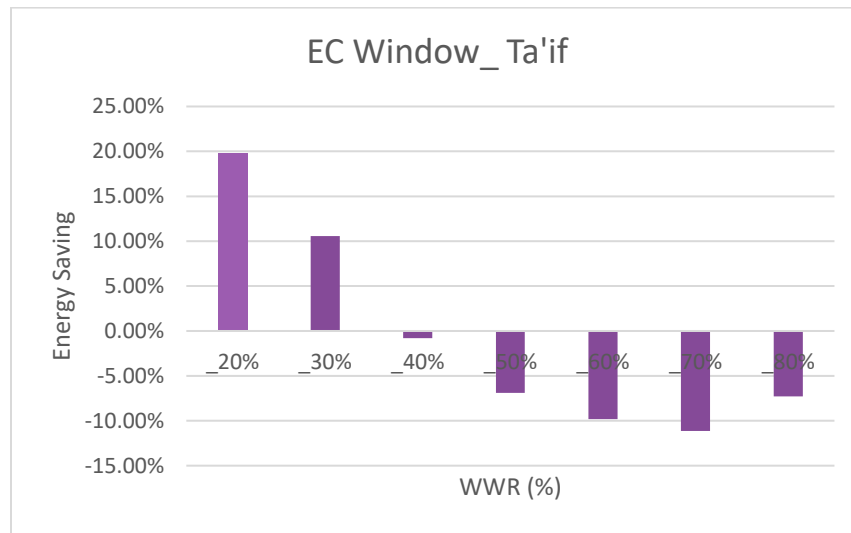


Figure 25: Percentages of energy rise/fall with EC window at different sizes

iii. Electrochromic Window in Hot-humid climate (Riyadh),

Like the trend in Taif, lighting energy reduces significantly in Riyadh with increased window size but little reduction in cooling energy occurs with change in window sizes. This is due to the moderate temperature found in the region leading to reduced cooling demand. At WWR of 30% and below, the lighting energy almost equals the cooling energy due to inadequate daylight which led to increased lighting energy. Overuse of electric light also may lead to increased cooling energy demand at some point due to increased internal heat gains that results from the artificial lightings as described by (Wefki et al., 2024).

Significant reduction in energy is seen when the WWR is between 60-70% as in fig 27

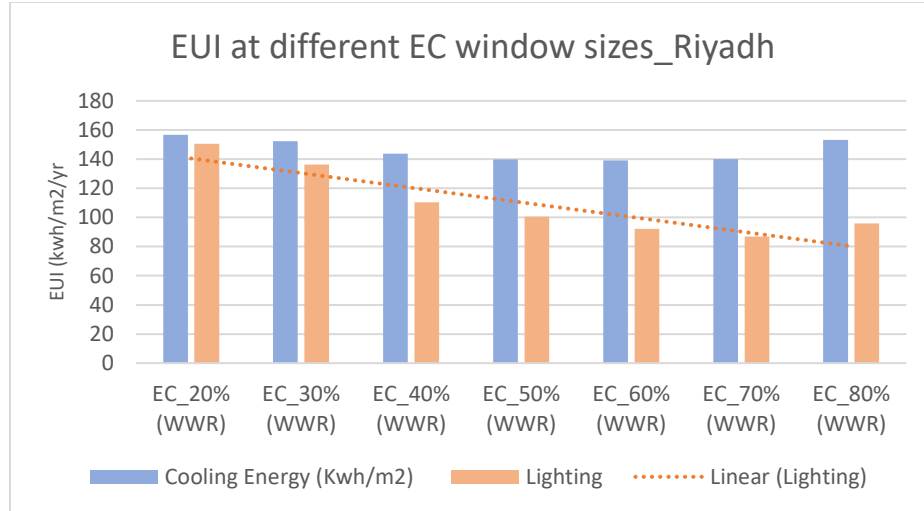


Figure 26: Electric consumption with EC window at different window sizes

Subsequently, energy saving is seen from 50-80% with greatest saving of 9.06% achieved at 70% WWR which is therefore the optimum window size that offers greatest benefit in total annual EUI at the given location (Riyadh). Figure 27 shows the saving in annual EUI at different window sizes and relative to the base case. At 20% and 30% WWR, the results show negative values which means there is an increase in energy consumption relative to the base case. Energy is saved from 40% WWR with a maximum saving is 13.7% achieved at 70% WWR in Riyadh. See fig 28 below.

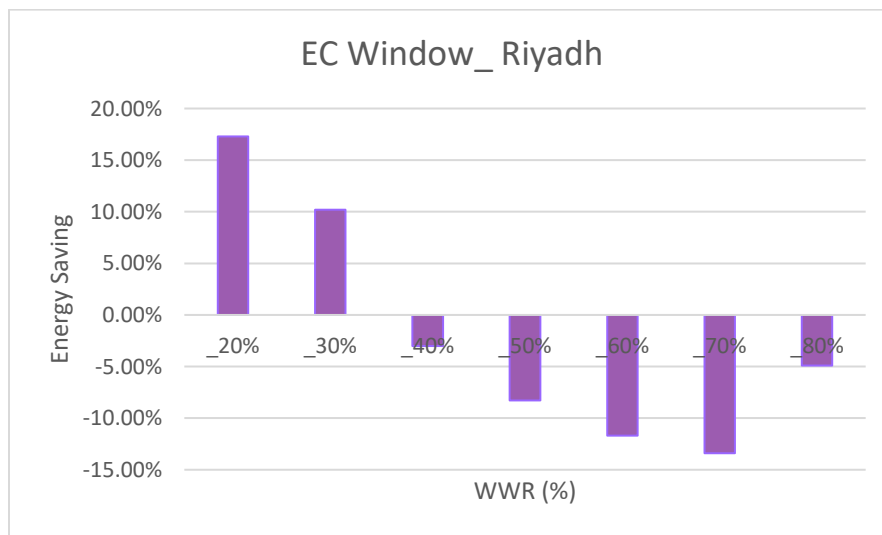


Figure 27: Percentages of energy rise/fall with different sizes of EC window at Riyadh.

5.2.2 Gasochromic Window (GC)

Gasochromic window also offers saving in terms of annual building energy consumption only when WWR is 40% or higher. 30% WWR and below tend to increase the building energy consumption due to increased lighting energy demand. As expected, the higher the WWR, the lower the energy required for lighting.

i. Gasochromic Window in Coastal Climate (Jeddah)

Figure 21 shows the cooling and lighting energy of the building with Gasochromic window of different sizes. Minimal reduction in cooling energy is seen with GC under this climate, while significant reduction in lighting energy is achieved at greater window sizes. A significant difference is seen between the cooling and lighting energy at all window sizes.

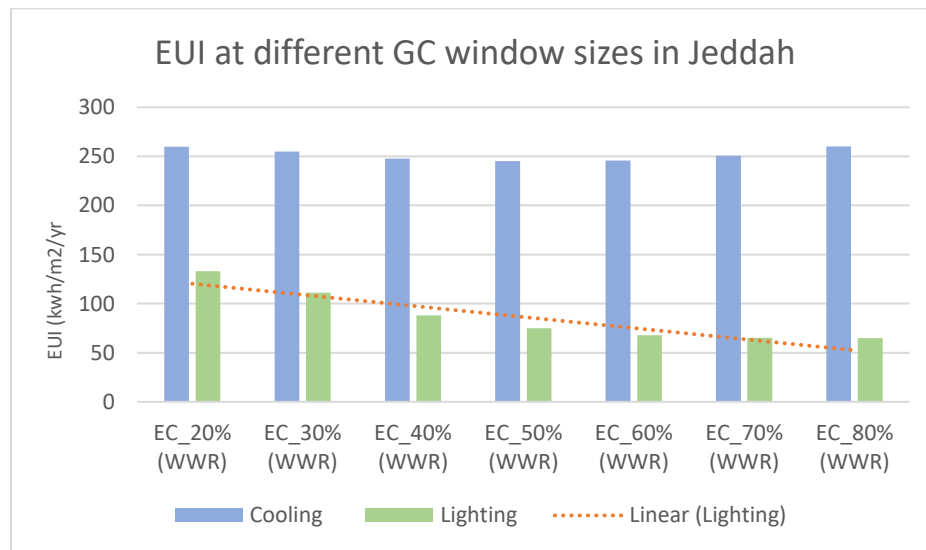


Figure 28: Electric consumption at different GC window sizes GC in Jeddah

Like EC, Gasochromic windows offers energy saving only at 40% or higher WWR while it tends to increase the energy consumption when the WWR is below 40%. Figure 30 shows the percentages of energy rise/fall with GC windows; maximum energy saving is achieved at 60% WWR.

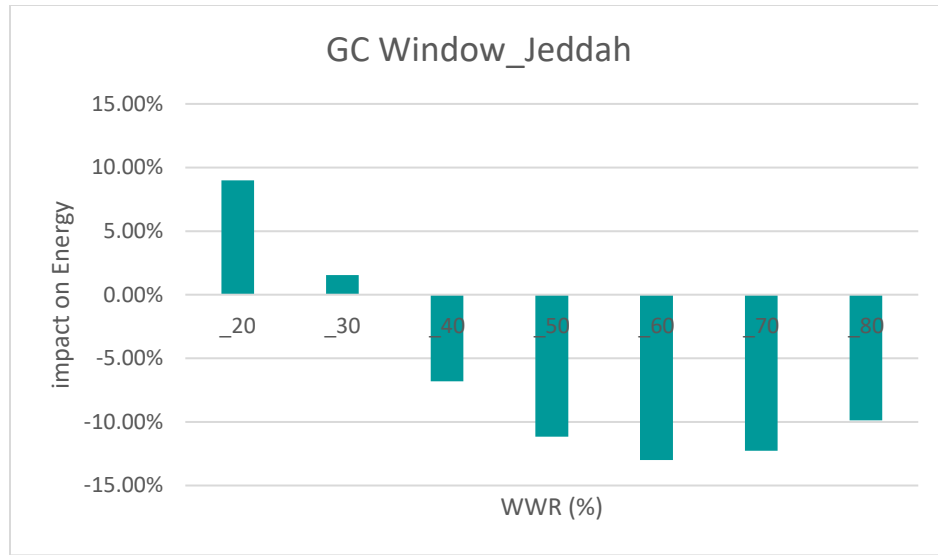


Figure 29: Percentages of energy rise/fall with GC window at different sizes

ii. Gasochromic Window in Mediterranean climate (Ta'if)

In this climate, cooling and lighting energy differs slightly at smaller window sizes but significantly at higher WWR. At 60-80% cooling energy is about twice that of lighting due to the significant increment in the daylight integration. Figure 31 shows the variations in the cooling and lighting energy at different GC window sizes.

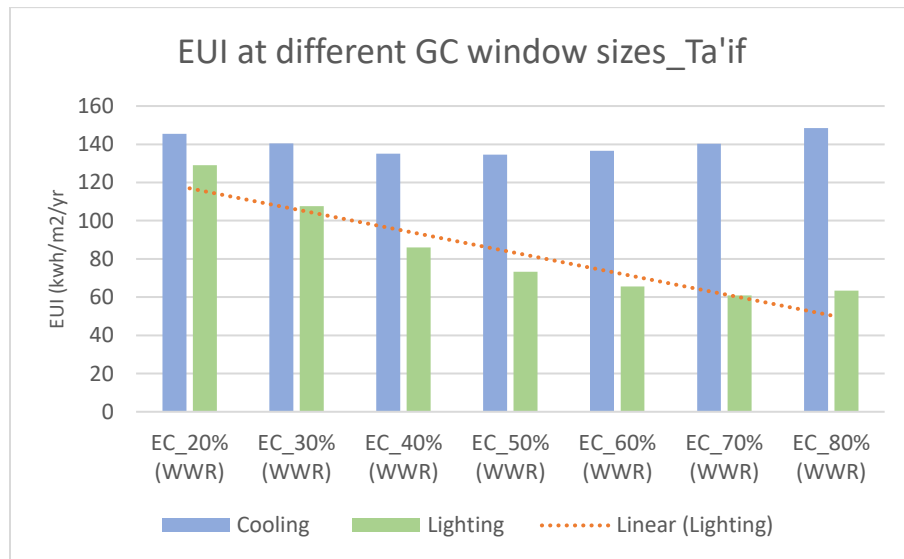


Figure 30: Electric consumption at different GC window sizes at Ta'if

GC windows show total saving in annual energy demand as the WWR reaches 40% with greatest saving of about 18% achieved at 70% WWR, making this the optimum window size for GC under the Ta'if climates. 30% and lower WWR result in increased energy demand due to the elevated lighting demand and thus, it's not a viable widow size.

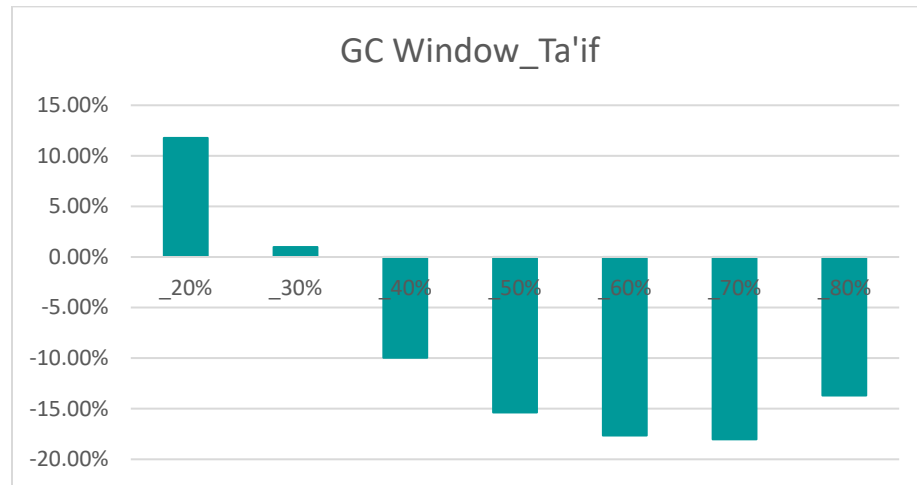


Figure 31: Percentages of energy rise/fall with GC window at different sizes in Taif

iii. Gasochromic Window in semi-desert climate (Riyadh),

GC widows in the semi-desert climate of Riyadh have shown little variation in cooling energy demand with change in window size but significant difference in lighting energy.

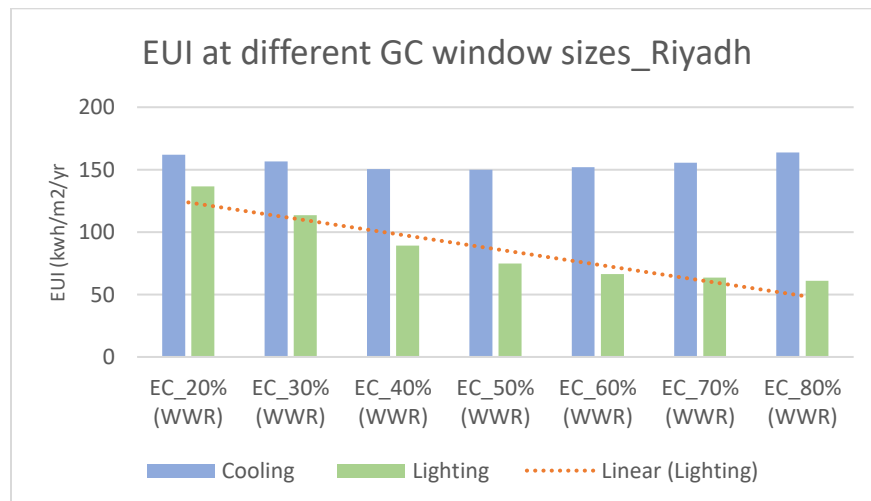


Figure 32: Electric consumption at different GC window sizes at Riyadh

Like the case in Taif, energy reduction is achieved at 40% WWR and above with greatest saving of 16.7% at 70% WWR and hence, the optimum.

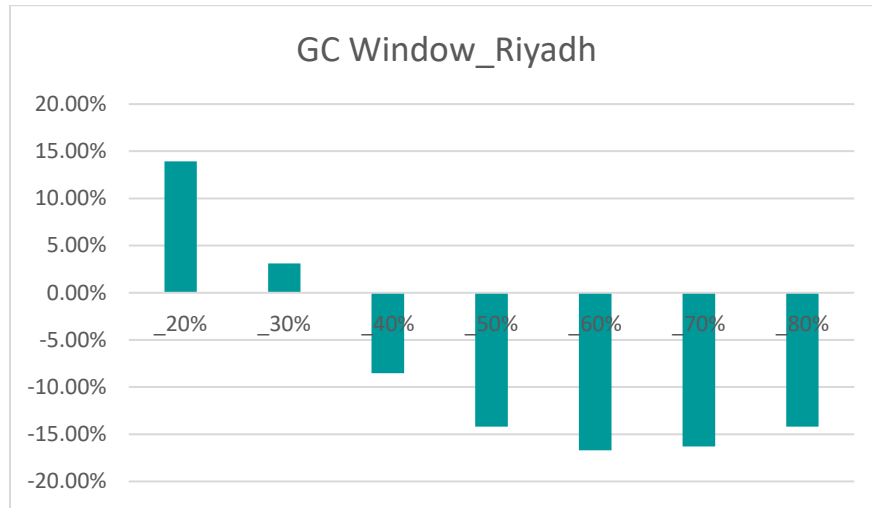


Figure 33: Percentages of energy rise/fall with GC window at different sizes in Riyadh

5.2.3 Photochromic Window (PC)

i. Photochromic Window in Coastal Climate (Jeddah)

Unlike the case in EC and GC, Photochromic windows show improved energy saving at all window-to-wall ratios. This implies that energy consumption even at 20% WWR is below the consumption at the base case window with 50% WWR.

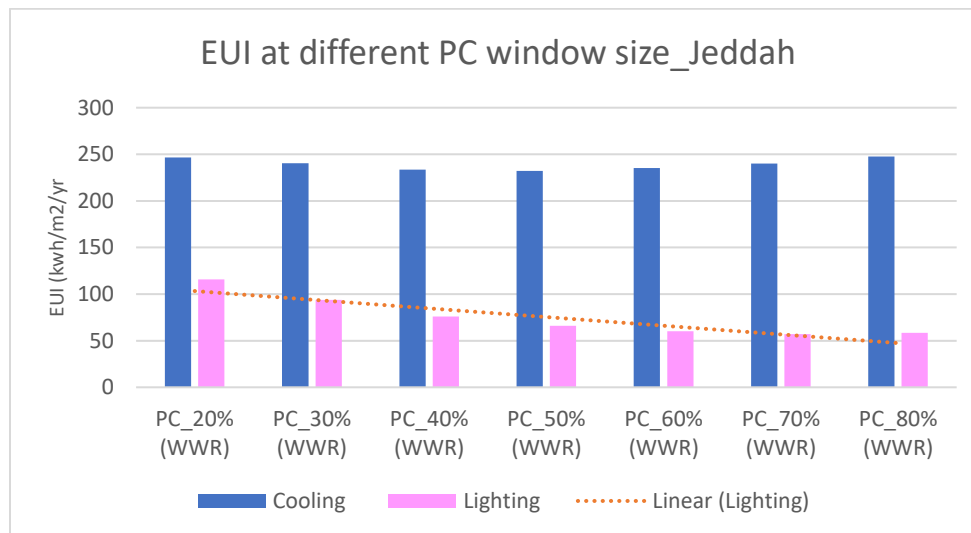


Figure 34: Electric consumption with PC windows at different sizes in Jeddah

As shown in the above figure, energy performance is enhanced incrementally from 20-60% WWR while the performance diminishes as the WWR goes above 60%, making 60% to be the optimum just like the case in GC windows.

However, lighting energy profiles follow the same pattern as the EC and GC windows with lower values at higher WWR. All window sizes offer significant energy saving while 60% offer the greatest saving making the optimal size for Photochromic window. This is possible because photochromic windows respond to exterior daylight levels rather than solar radiation, making it clearer that EC & GC at most of the time. This significantly reduces the need for artificial light, which in turn reduces internal heat gains and thus impacts the cooling load as well. Fig 36 shows the effects of the widow sizes on the energy performance of PC windows.

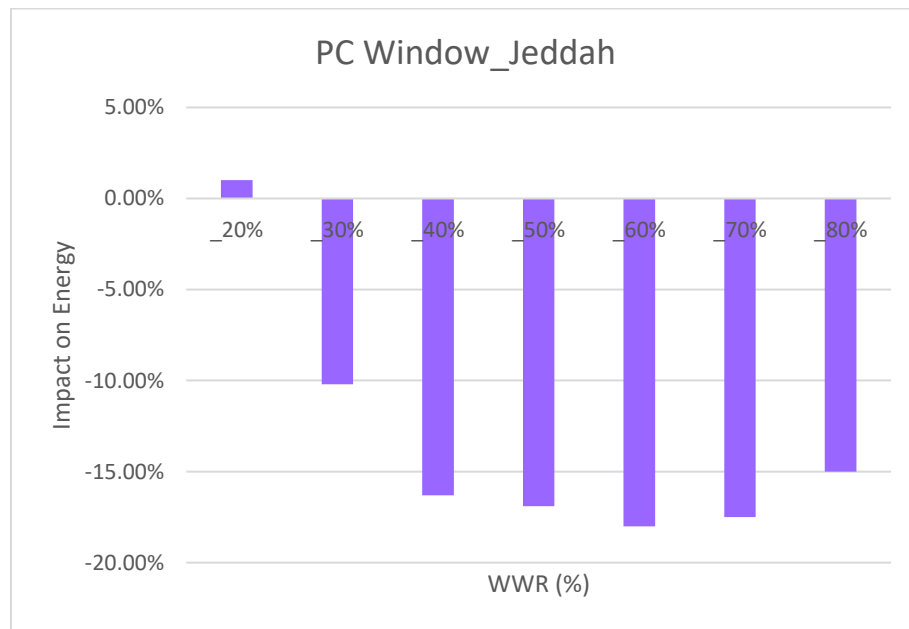


Figure 35: Percentages of energy rise/fall with PC window at different sizes in Jeddah

ii. Photochromic Window in Mediterranean Climate (Taif)

Taif shows slightly lower energy consumption than with photochromic windows than in Jeddah. Photochromic windows allow more daylight into the building and therefore showed reduced lighting energy demand than Electrochromic and Gasochromic windows. Due to the moderate climate conditions, the cooling energy demand is significantly lower than the case in Jeddah. Fig 37 shows the energy profile with PC at Taif.

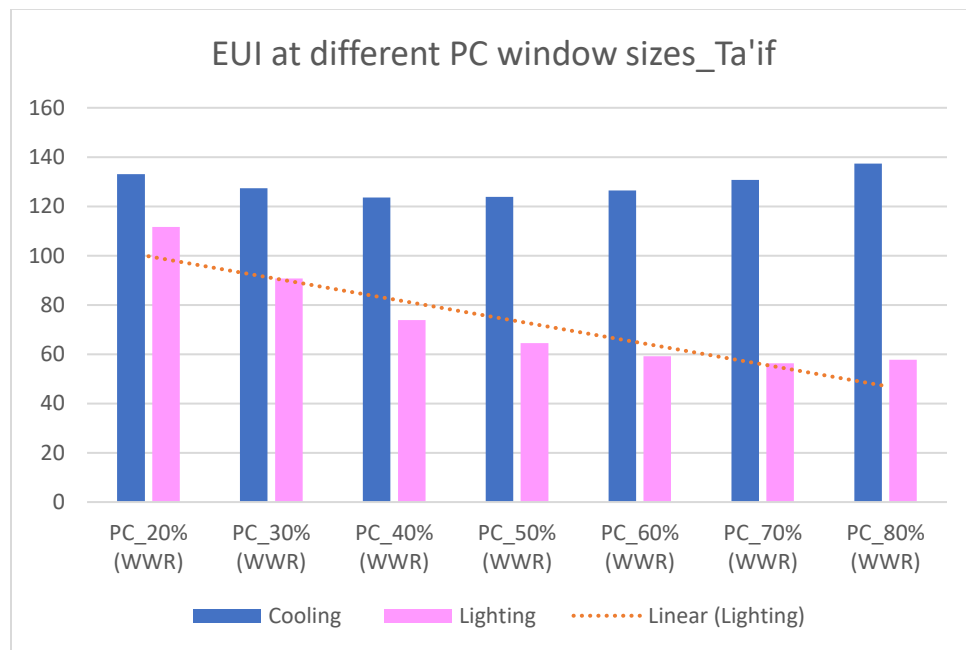


Figure 36: Electric consumption with PC windows at different sizes Taif

A significant reduction in total energy consumption is achieved at all window sizes. This implies that any WWR used with PC can bring reduction in energy demand, although the percentage varies as the window size increases. Optimum WWR is found to be between 50-60% where total energy is reduced by over 20%. Fig. 38 below shows the trend.

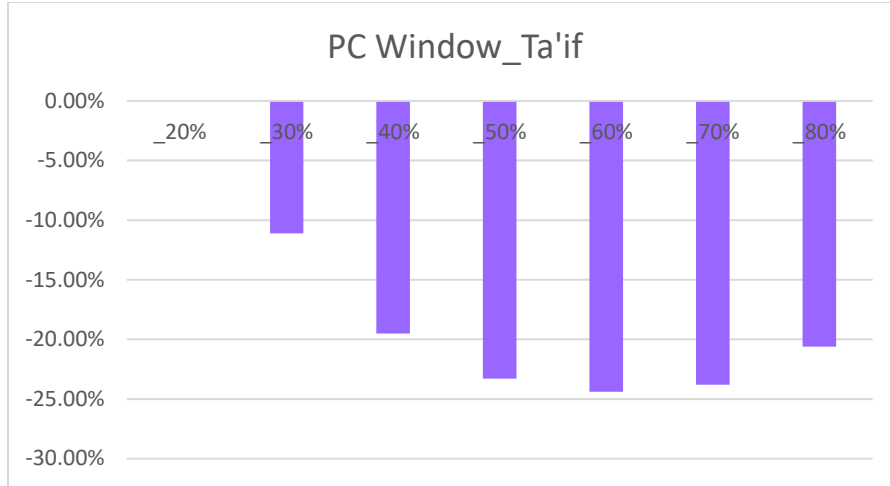


Figure 37: Percentages of energy rise/fall with PC window at different sizes in Ta'if

iii. Photochromic Window in Hot-dry Climate (Riyadh)

Like the trend in Ta'if, increment in WWR in Riyadh results in a slight increase in cooling energy and a significant decrease in lighting energy demand as can be seen in figure 39 below. Photochromic windows are therefore good for this climate as well.

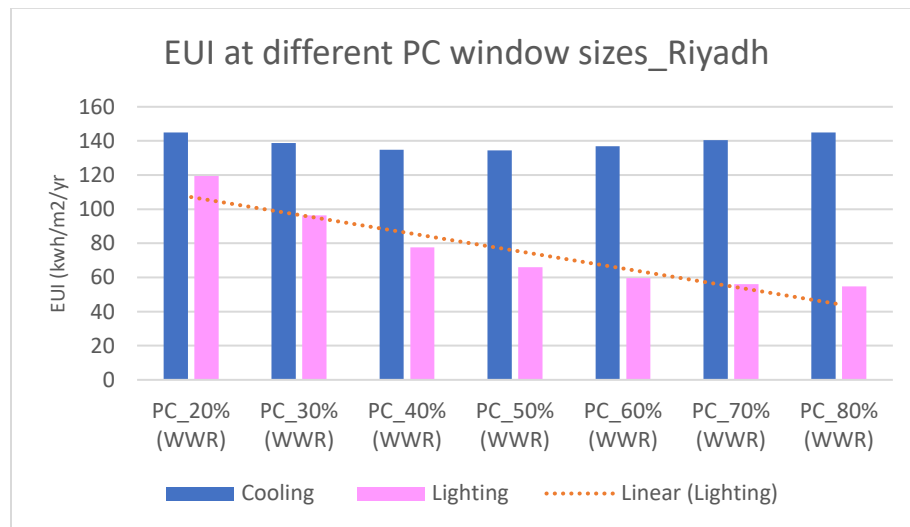


Figure 38: Electric consumption with PC windows at different sizes in Riyadh

Photochromic also offers the highest energy saving in this region than EC and GC windows. At all window sizes, there is a significant reduction in total energy demand relative to the base case window. Between 50-70%, energy savings exceed 20% with 60%

& 70% percent being the optimum that offers over 26% total annual energy reduction. See figure 40 below.

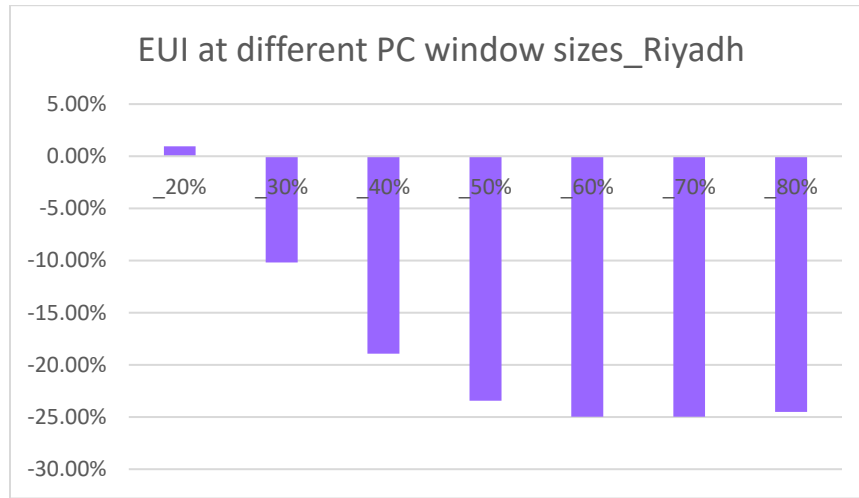


Figure 39: Percentages of energy rise/fall with PC window at different sizes in Riyadh

5.2.4 Polymer Dispersed Liquid Crystal (PDLC) Windows

i. PDLC in Coastal hot-humid climate (Jeddah)

The trend follows the same pattern as the previous windows where cooling energy increases with an increase in window size while lighting energy reduces as the window size increases. See fig. 41 below.

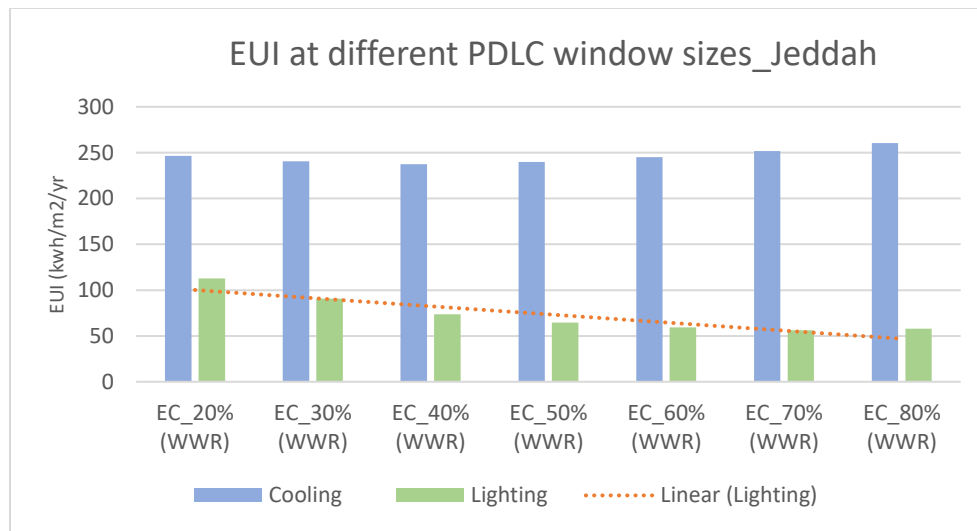


Figure 40: Electric consumption with PDLC window at different sizes in Jeddah

PDLC window offers energy saving from 30% WWR and greater. The maximum saving of 15.5% EUI is achieved at 50/60% WWR making these the optimum sizes.

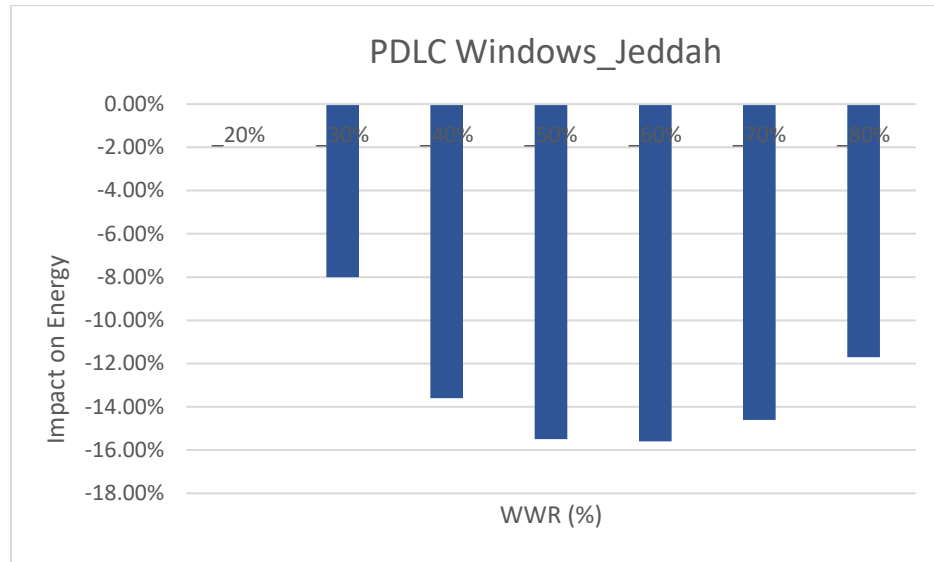


Figure 41: Percentages of energy rise/fall with PDLC window at different sizes in Jeddah

ii. PDLC in Mediterranean climate (Taif)

In Taif, significant reduction in lighting energy is seen as the PDLC window size is reduced.

The increment in cooling energy thought slightly, results from an increase in window size.

Fig. 43 explains the trend.

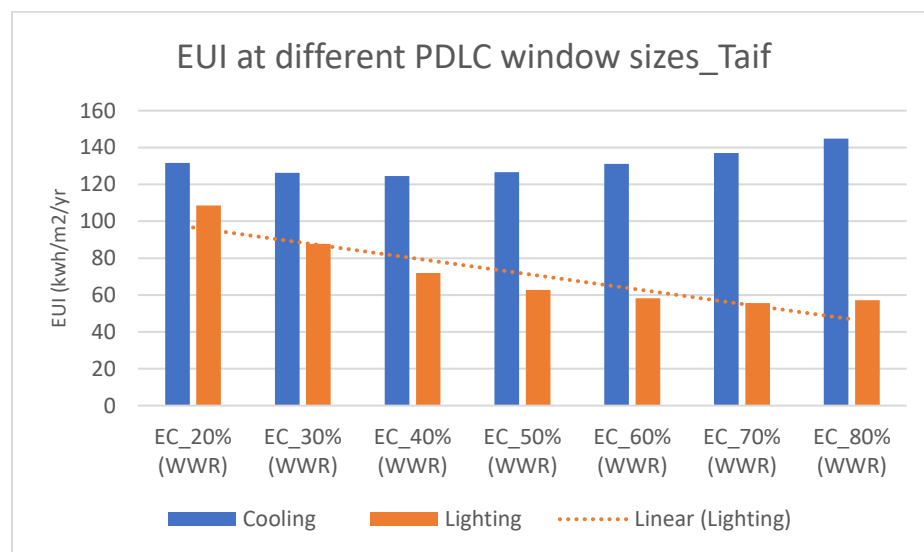


Figure 42: Electric consumption with PDLC windows at different sizes in Taif

Energy is saved at all simulated window sizes, but optimum saving of 23% EUI is achieved when the WWR is 50% as shown in figure 44. Improved performance of PDLC in Taif can be attributed to its mild climate characteristics.

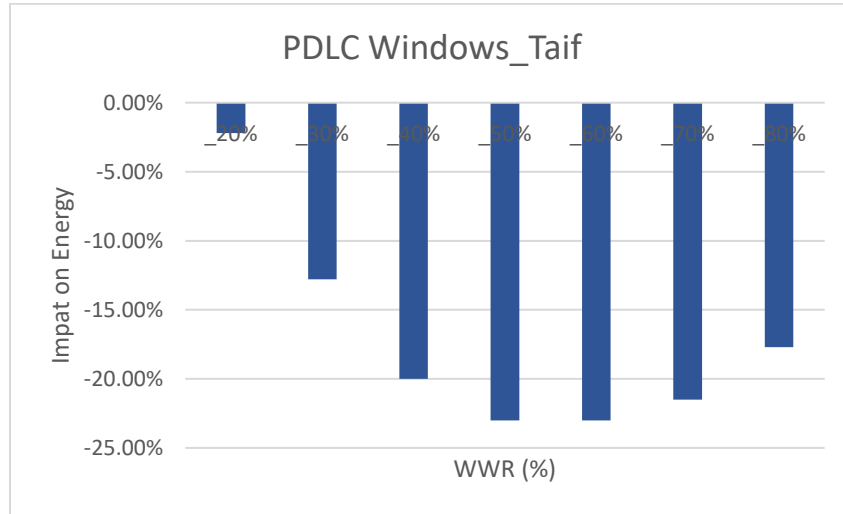


Figure 43: Percentages of energy fall with PDLC window at different sizes in Taif

iii. PDLC in hot-dry desert climate (Riyadh)

Significant reduction is seen in lighting energy as the window size increases and significant increase is seen in cooling energy as the window size increase. This is like the trend and the other smart windows. See figure 45 below.

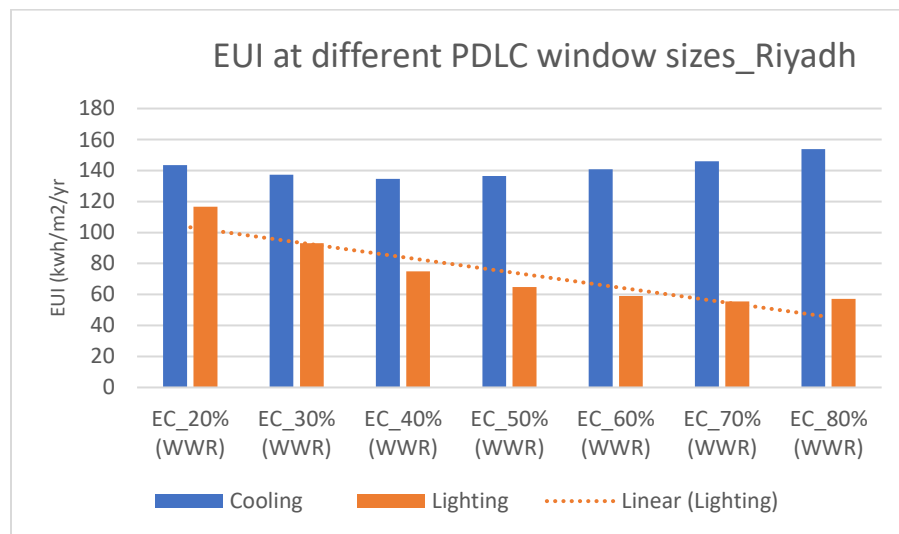


Figure 44: Electric consumption with PDLC window at different sizes in Riyadh

In Riyadh, PDLC windows offer energy saving from 30% WWR. The optimum WWR is 60% which offers about 24% energy saving. Figure 46 below shows the relative reduction in EUI at different widow sizes.

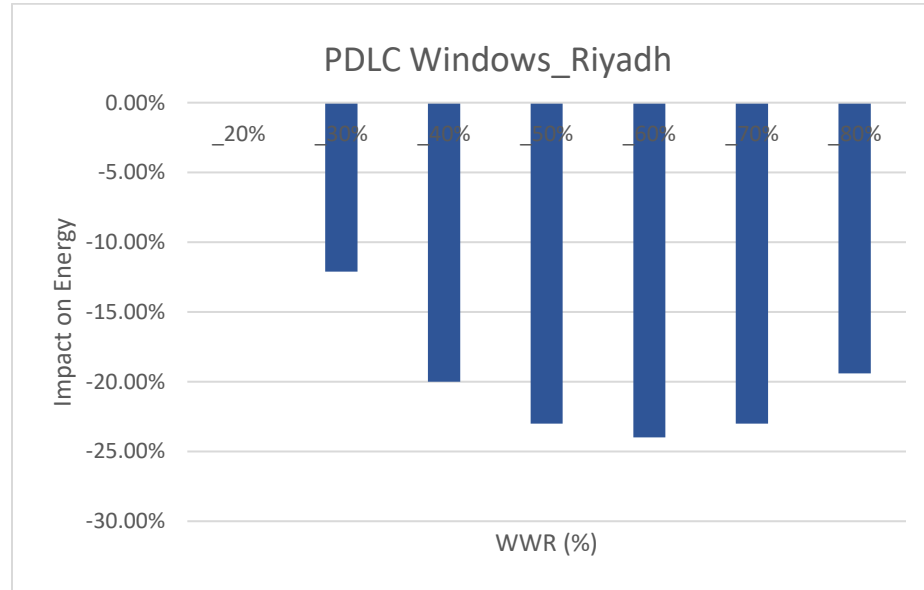


Figure 45: Percentages of energy fall with PDLC window at different sizes in Riyadh

5.2.5 Suspended Particle Devices (SPD) Windows

i. SPD in Coastal hot-humid climate (Jeddah)

SPD windows show similar patterns of energy consumption as well as overall energy saving. Like the previously discussed windows, SPD offers slight change in cooling energy with change in WWR while shows exponential decline in overall lighting energy consumption as the WWR increases as can be deduced from figure 46.

The highest EUI is at 20% WWR due to overreliance on artificial lighting while the lowest EUI is at 70% WWR due to substantial reduction in lighting energy and moderation of cooling energy. The figures 47 and 48 gave more highlights on energy performance in this section.

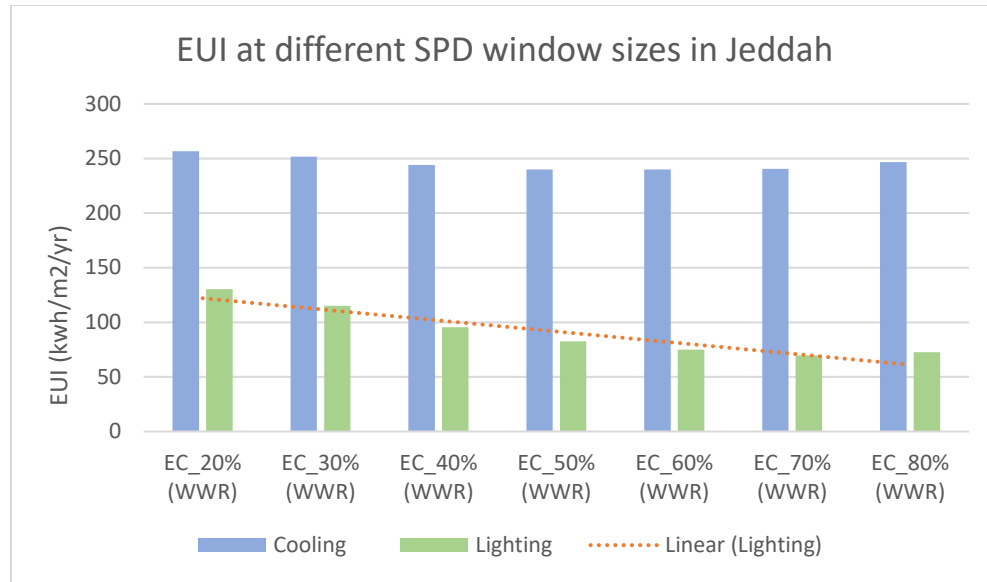


Figure 46: Electric consumption with SPD windows at different sizes in Jeddah

According to figure 47, energy saving with SPD in Jeddah is achieved from 40% WWR and higher. The optimum WWR is 70%, which offers total annual energy 310 kwh/m2/yr, saving up to 14% compared to the 360 kwh/m2/yr in the base case. When the WWR is below 40% the total energy consumption shows an increase which is not the desire.

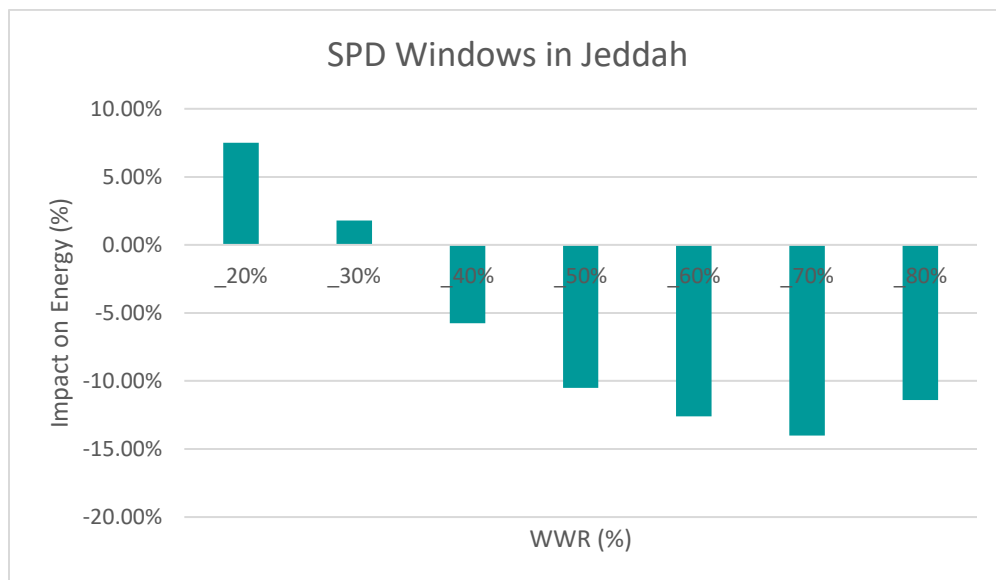


Figure 47: Percentages of energy change with SPD window at different sizes in Jeddah

ii. SPD in Mediterranean climate (Taif)

Energy profile in Taif with SPD windows is shown in figure 48 below. While the window size affects both cooling and lighting energy, the lighting energy shows greater change than the cooling energy under increment in window size.

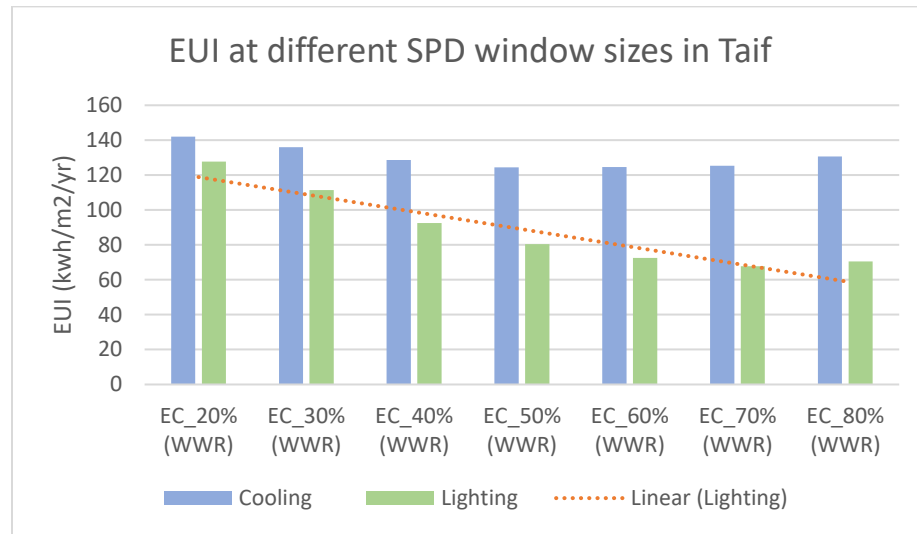


Figure 48: Electric consumption with SPD windows at different sizes in Taif

However, energy savings are achieved from 40% WWR and above. The optimum window size is 70% with maximum energy saving of 21%. Thanks to the optimum performance.

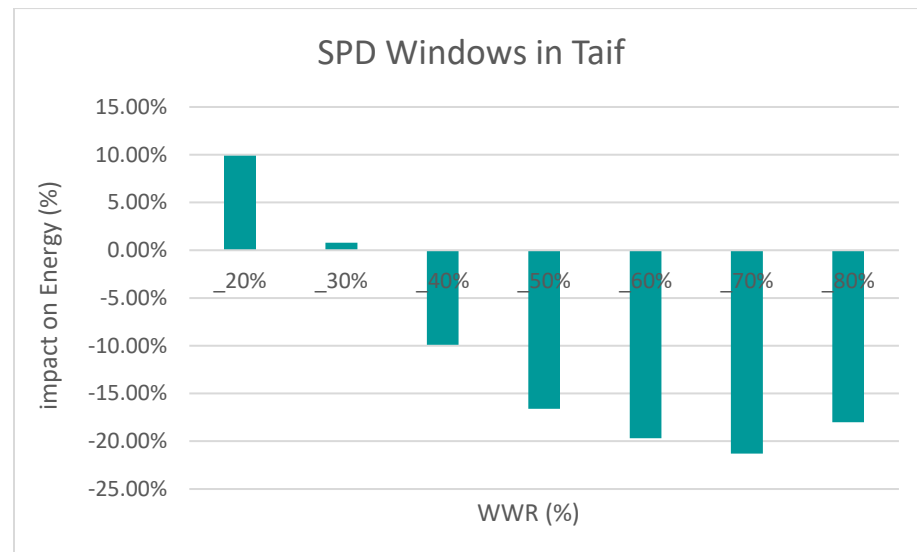


Figure 49: Percentages of energy change with SPD window at different sizes in Taif

iii. *SPD in hot-dry desert climate (Riyadh)*

Figure 51 below shows cooling and lighting energy patterns at different widow sizes.

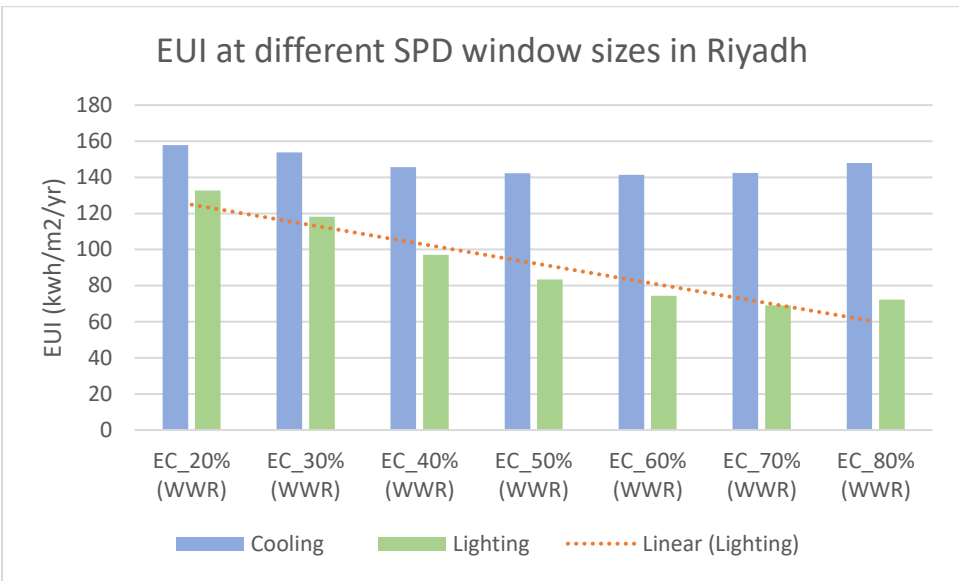


Figure 50: Electric consumption with SPD windows at different sizes in Riyadh

Increment in energy consumption is seen at 20 & 30% WWR, while reduction is seen at the WWR attains 40% and higher, 70% proves to offer the maximum saving of about 19% EUI

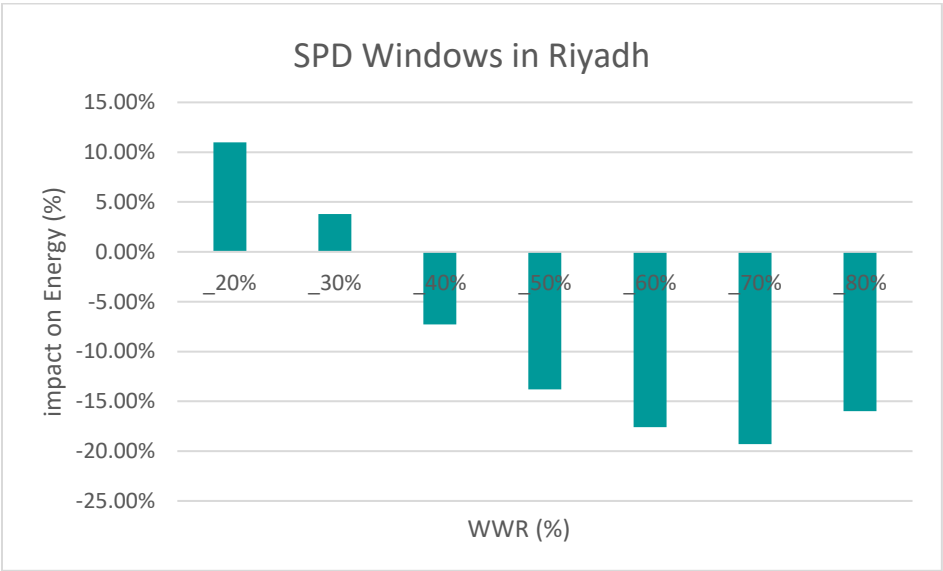


Figure 51: Percentages of energy change with SPD window at different sizes in Riyadh

5.2.6 Thermochromic (TC) Windows

i. Thermochromic window in Coastal hot-humid climate (Jeddah)

TC window shows significant decline in lighting energy consumption as the WWR increases from 20-80%. TC windows show energy saving when WWR is 40% and greater. Optimum energy saving of 11% is achieved at 60% WWR.

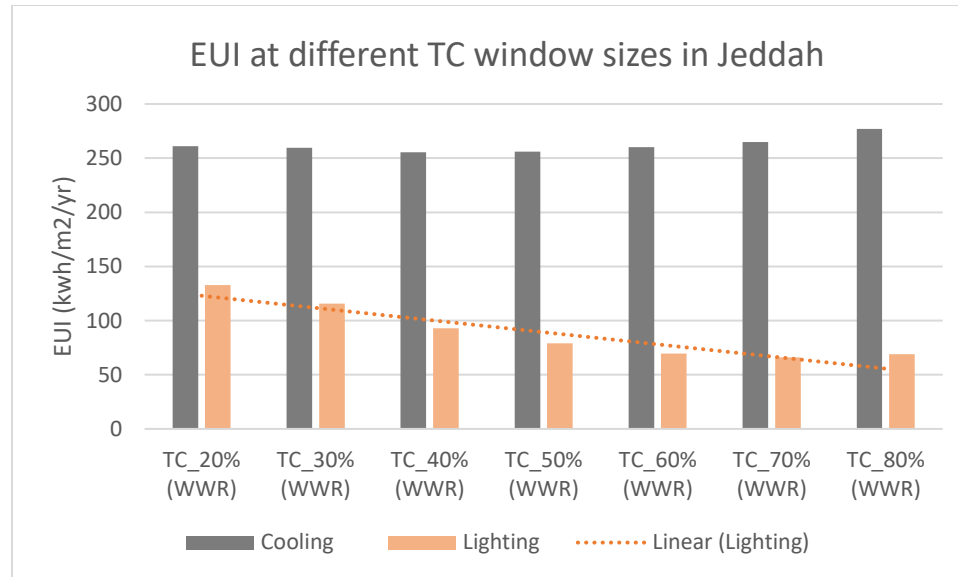


Figure 52: Electric consumption with TC windows at different sizes in Jeddah

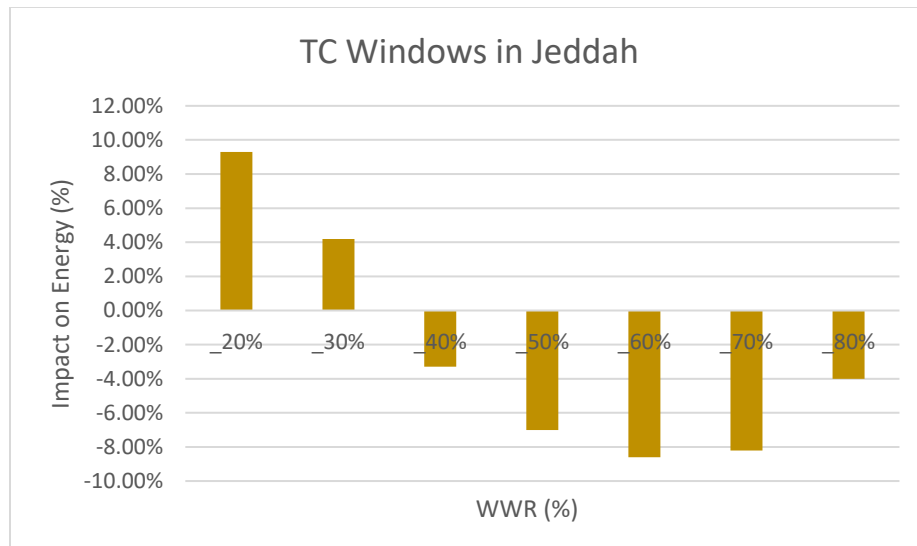


Figure 53: Percentages of energy change with TC window at different sizes in Jeddah

ii. *Thermochromic window in Mediterranean Climate (Taif)*

Notable rise in cooling energy is seen with an increase in the window size while decrease in is lighting energy is shown as the window size increase. Maximum total energy saving is 9% which is achieved at 60% WWR

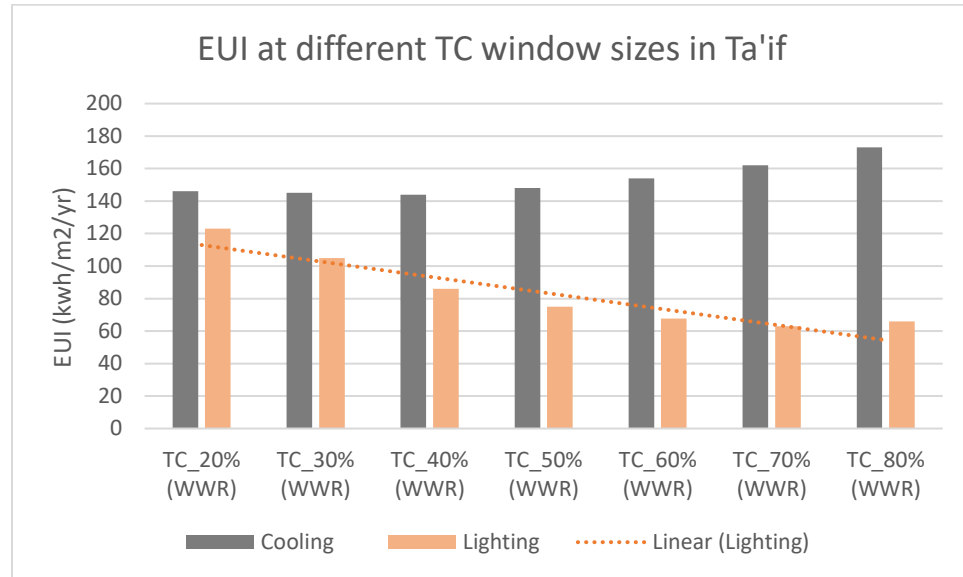


Figure 54: Electric consumption with TC windows at different sizes in Taif

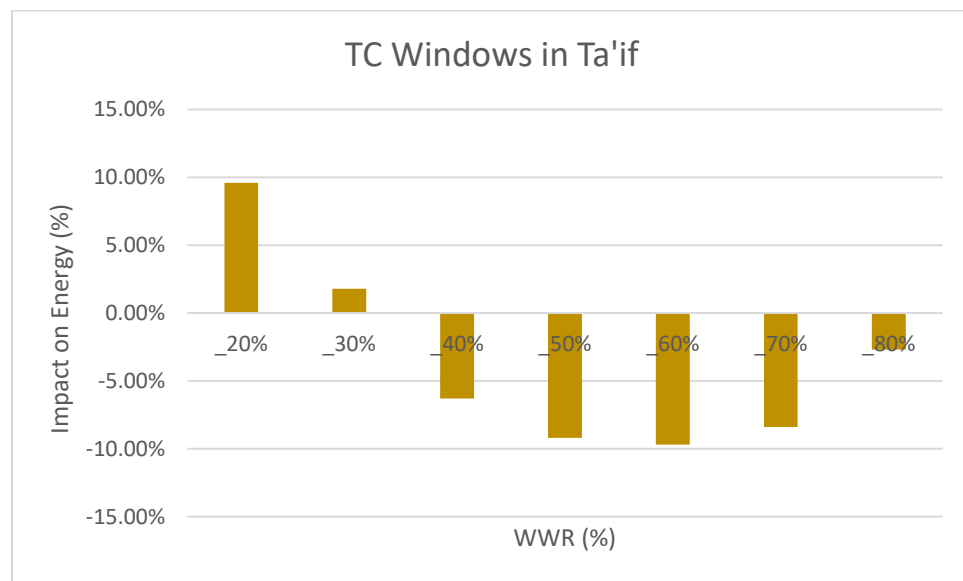


Figure 55: Percentages of energy change with TC window at different sizes in Taif

iii. *Thermochromic window in hot-dry desert climate (Riyadh)*

The results show similar trends in the other locations. Energy saving begins at 40% WWR and attains a maximum of about 12% at 60% WWR. Linear decline in lighting energy is seen as the WWR increases.

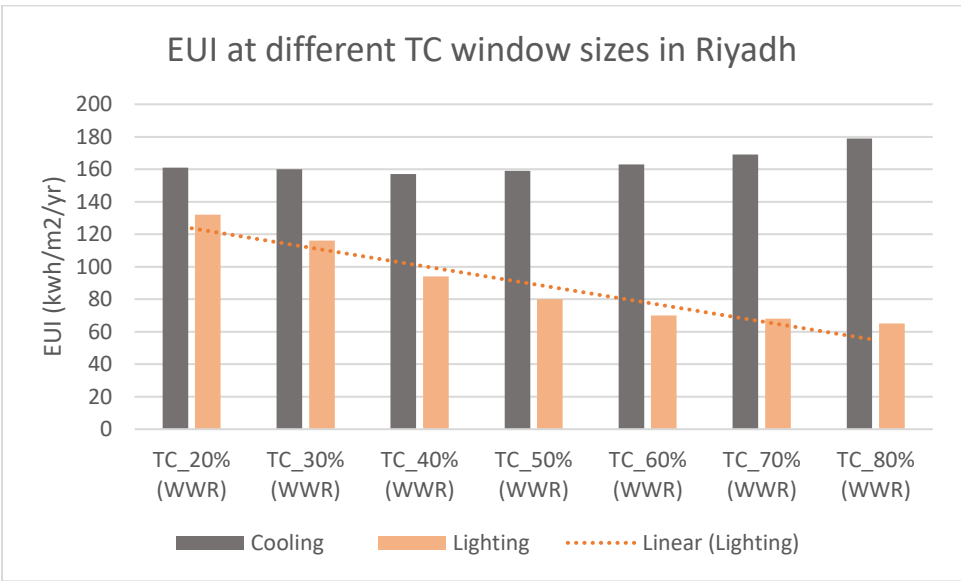


Figure 56: Electric consumption with TC windows at different sizes in Riyadh

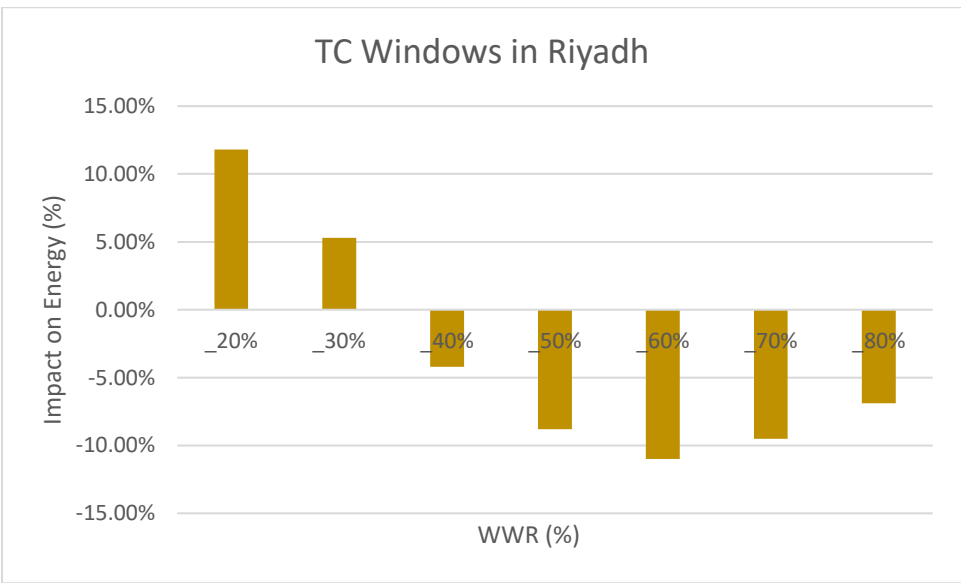


Figure 57: Percentages of energy change with TC window at different sizes in Riyadh

5.3 Peak Load Reduction

Smart windows do not only save energy but also offer an overall reduction in cooling peak loads and subsequent shift in the peak load hour in some of the cases. This will directly impact decisions on HVAC design where reduction in the peak loads will influence reduction in the HVAC sizing which will yield cost reduction in the entire building life cycle. The figures below show the reduction in peak cooling loads with the smart windows under different climate zones.

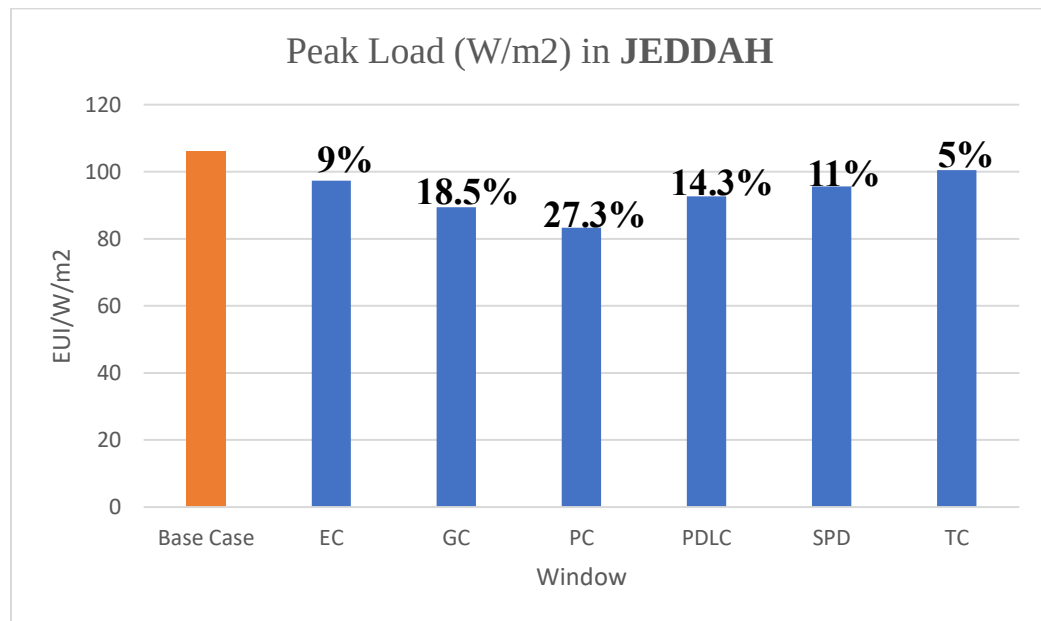


Figure 58: Reduction in peak cooling load with smart windows in Jeddah

The highest reduction in the peak load and hence in HVAC sizing is 27.3% (with PC window) while the lowest is 5% (with TC window). The peak cooling hour in Jeddah is found to be around 9am, 10am and 12pm and usually occur on 9th of September or around 10-15th of August. The peak hour of 9am or 10am can be due to the humid nature of the Jeddah climate, which is humid, where significant load is seen in the early hours due to the dehumidification need.

In Taif, peak load occurs on 28th or 29th of June around 2pm afternoon hours. The maximum of 25% peak reduction is seen with PC and minimum is 3% with TC windows.

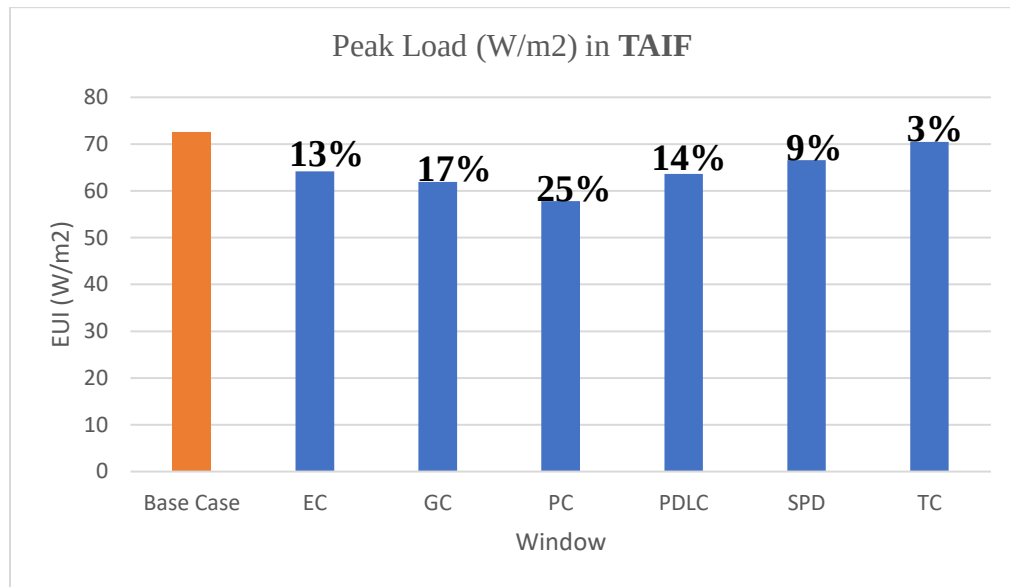


Figure 59: Reduction in peak cooling load with smart windows in Taif

In Riyadh, the maximum reduction in the peak load is 14% found with PC windows while the minimum reduction is 9% found with TC windows. These occur in July, August or September and Usually between 2-4 pm, thus the reduction in HVAC sizing and cost.

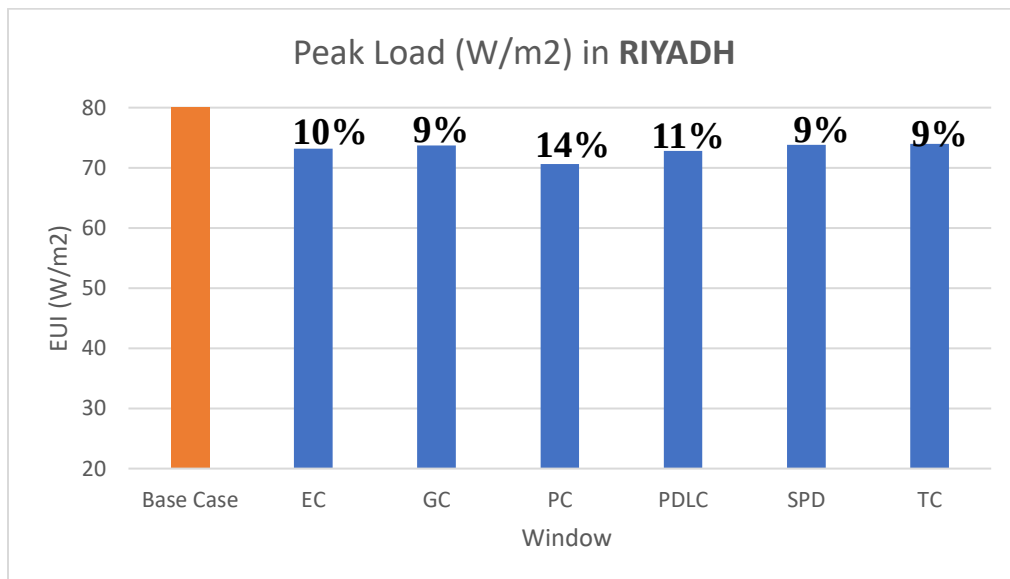


Figure 60: Reduction in peak cooling load with smart windows in Taif

5.4 Daylight Performance Analysis

Daylight performance analysis is important in predicting areas with inadequate daylight, sufficient daylight and those that may experience overheating. Standards like the International Standards Organization (**ISO 10916:2014**) and **LEED** (Leadership in Energy and Environmental Design) in **LEED V4.1 guide** describe *Spatial Daylight Autonomy (sDA)*, *Annual Sunlight Exposure (ASE)* and *Useful Daylight Illuminance (UDI)* as the three basic daylight performance metrics used in annual daylight calculation. While ISO describes the functions of three metrics, the LEED v4.1 guide provides the threshold for measuring the performances under each metric.

According to (LEED v4.1 BUILDING DESIGN AND CONSTRUCTION Getting Started Guide for Beta Participants, 2024): Daylight analysis involves several key parameters that help assess the availability and quality of natural light in a building (Calculation of the Impact of Daylight Utilization on the Net and Final Energy Demand for Lighting COPYRIGHT PROTECTED DOCUMENT, 2014).

5.4.1 Daylight Performance Metrics

According to According to the Leadership in Energy and Environmental Design (LEED) guideline and (ISO 10916:2014). Annual daylight calculation metrics are: Spatial daylight autonomy (sDA), Annual sunlight exposure (ASE) and Useful Daylight Illuminance (UDI). These parameters play a crucial role in evaluating visual comfort, energy efficiency, and overall building performance. sDA is considered the most important, while both UDI and ASE give additional explanation of the daylight performance. Here's a humanized overview of these metrics and the description of their interpretations:

1. Spatial Daylight Autonomy (sDA)

This is considered the primary metric for evaluating daylight sufficiency, it measures the percentage of a space's floor area that receives sufficient daylight for a specific portion of annual occupied hours. ≥ 300 lux for at least 50% of occupied day hours. It describes the reliability of space in daylight for the period it is occupied.

2. Useful Daylight Illuminance (UDI)

This gives additional insight on daylight performance by measuring the percentage of occupied hours during which the natural illuminance falls within a defined useful range (typically 100–2000 lux). It indicates how often daylight is neither too dim (ineffective) nor too bright (causing glare). It gives more insight into the usefulness of daylight in each space.

3. Annual Sunlight Exposure (ASE)

This is a metric that quantifies the amount of direct sunlight a space receives throughout the year. It is used to evaluate the potential for **glare and overheating**, which can negatively impact occupant comfort and energy efficiency in a building. This helps with sizing of HVAC and arrangement of office functions

- ASE is the percentage of the **floor area** that receives **more than 1000 lux** of direct sunlight for **at least 250 hours per year**.
- It is expressed as a **percentage (%)** of the total analyzed floor area.

5.4.2 Daylight Mapping

Daylight performance results from the three metrics are expressed using daylight color mapping and using the LEED daylight rating scale. The color mapping shows the density and percentages of light in the spaces, however, when different windows are assessed over different locations, daylight rating system suffices as it's difficult to visually figure out differences if many similar color maps are compared. Maps are displayed below for the purpose of illustration.

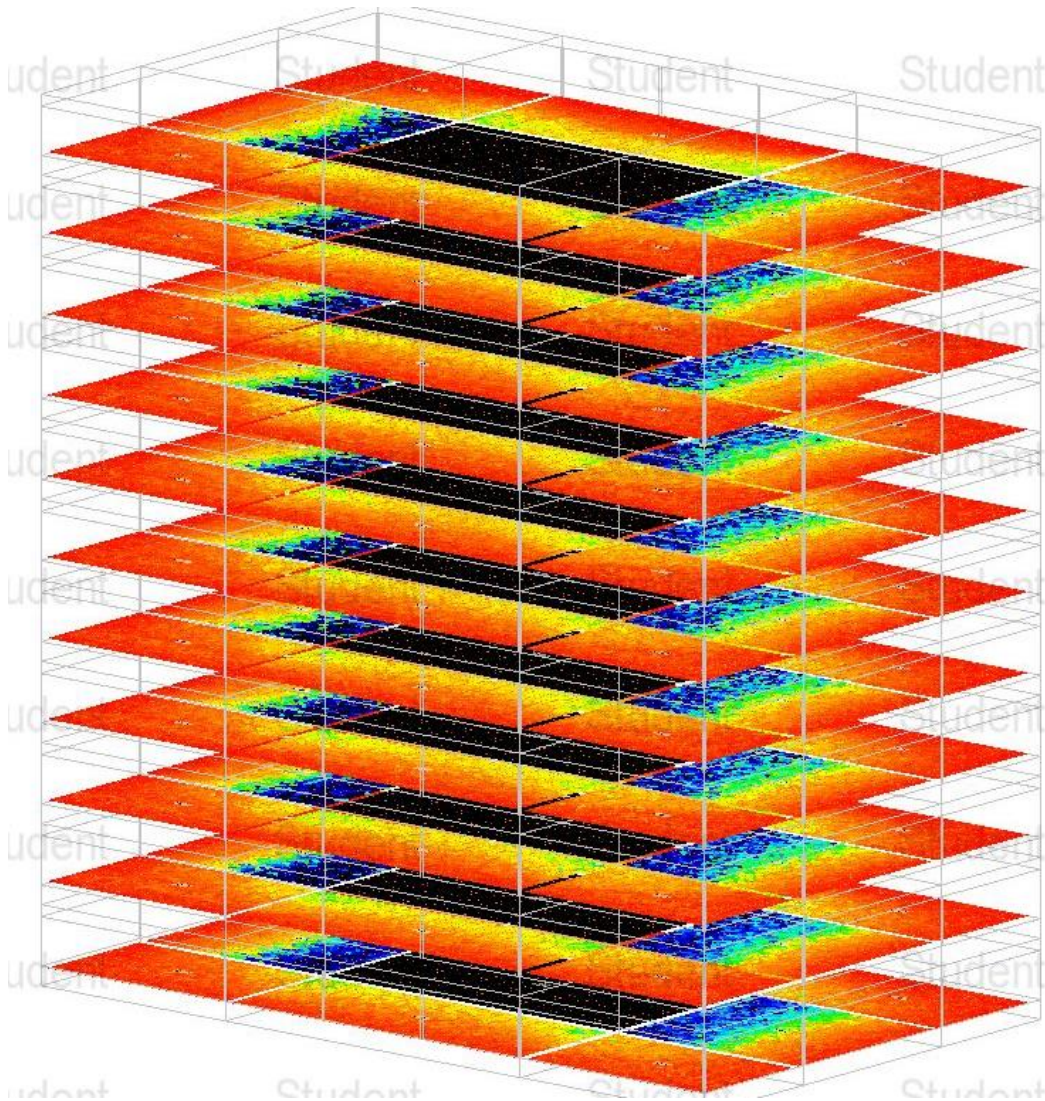


Figure 61: Whole building sDA mapping

Although it's difficult to observe differences from the color maps, there are slight differences with each window under each climate. The figures below show the intensity of daylight mapping, EC at 70% WWR in Jeddah was used for the purpose of illustration and visualization of the densities for summer solstice day and winter solstice day.

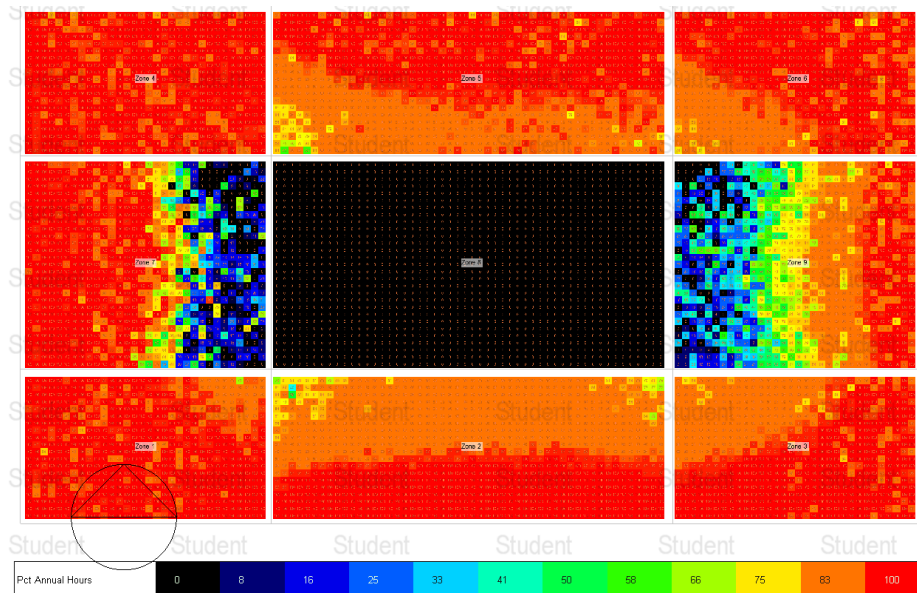


Figure 62: sDA map for EC at 70% WWR, June 21 Jeddah

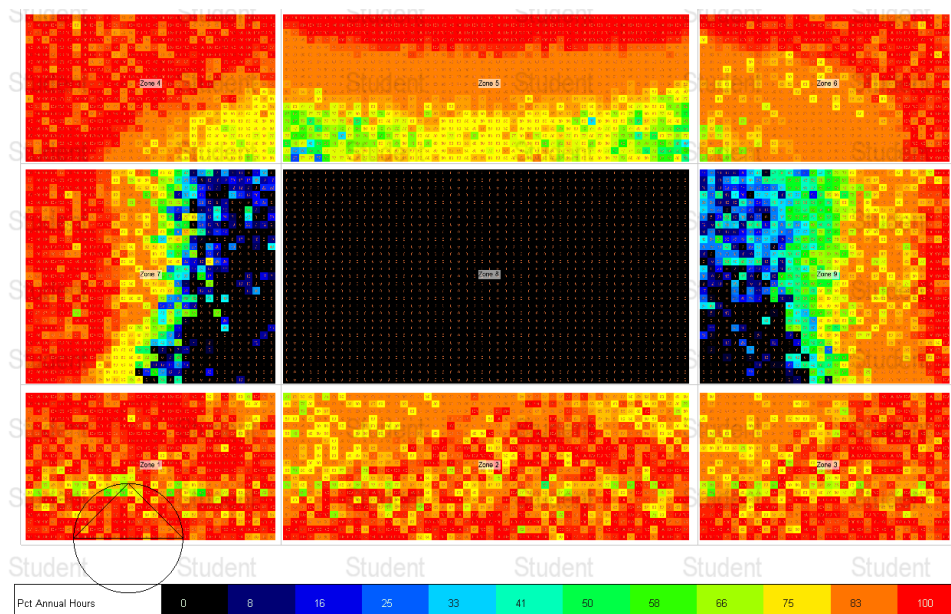


Figure 63: sDA map for EC at 70% WWR, December 21 Jeddah

Since all the floors are identical and sDA found same across the floors, a single floor is used to represent the rest in plan.

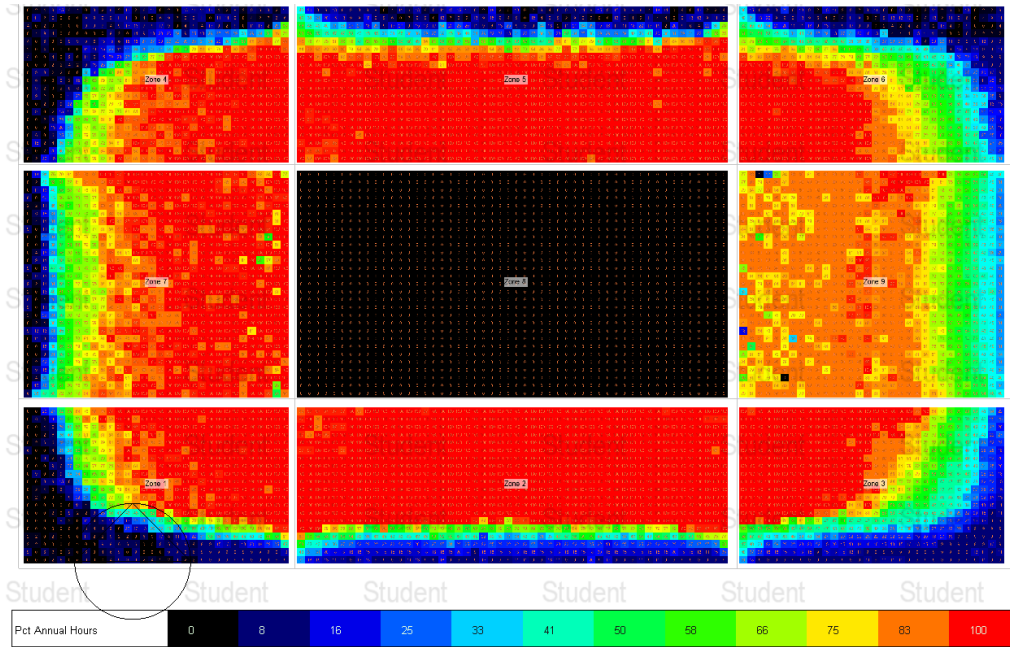


Figure 64: UDI map for EC at 70% WWR, June 21 Jeddah

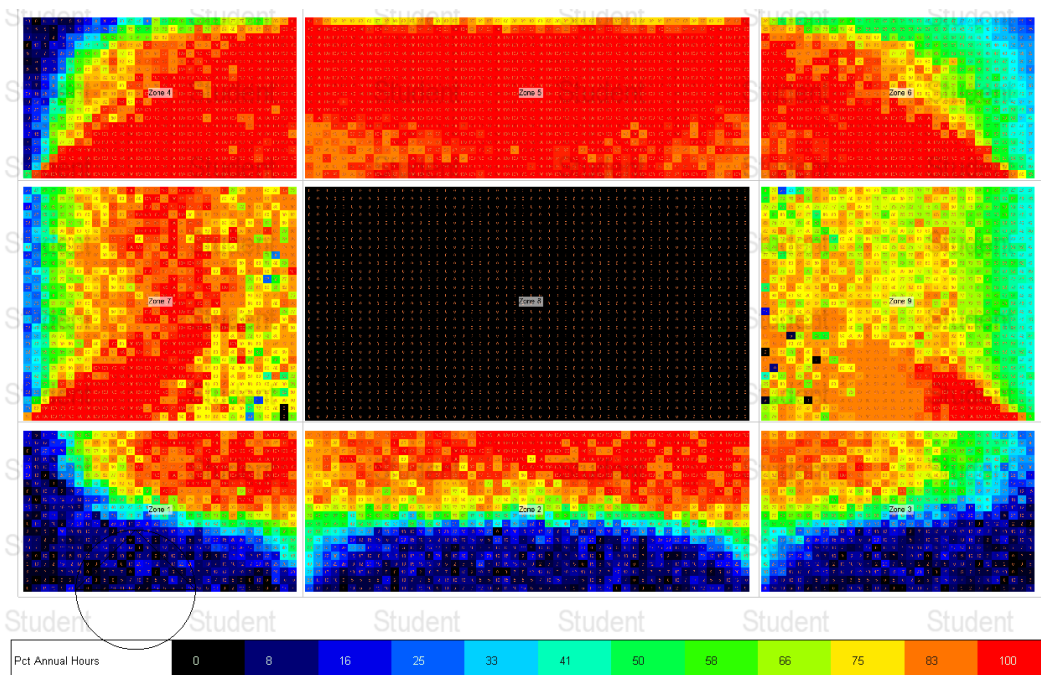


Figure 65Figure 62: UDI map for EC at 70% WWR, December 21 Jeddah

5.4.3 Daylight Performance Rating

Spatial daylight autonomy (sDA) shows the percentages of occupied space that receives the minimum threshold of 300lx for at least 50% of the occupied hours (300/50), greater than or equals to 55% show reliability of the space on daylight.

Table 23: LEED daylight rating for sDA

	sDA Range	Rating	Interpretation
1	sDA $\geq$ 75%	✓ Excellent	Most of the space is well lit by natural light.
2	sDA 55-75%	✓ Good	Good but some areas may need supplemental lighting
3	sDA < 55%	✗ Poor	The space relies heavily on artificial lighting.

To further describe the daylight performance of the windows, each at its optimum WWR, sDA (Spatial Daylight Autonomy) measures the percentage of floor area that receives sufficient daylight (at least 300 lux) for a specified percentage of the operating hours per year (typically 50% of the time). An sDA of 75% means that 75% of the space receives at least 300 lux for at least 50% of the hours occupied in a year. sDA describes the extent to which space can rely in daylight.

Useful daylight Illuminance (UDI) describes the percentage % of occupied time within which the daylighting falls within the useful range (100 lux to 2000 lux). This range Minimum 40% UDI is considered viable. The sufficiency of the daylight increases accordingly. Greater than or equal to 80% UDI is considered excellent.

LEED v4.1 BD+C defines UDI to range from 100 lux – 200 lux, it further added that:

- **UDI-low (< 100 lux):** Indicates underlit areas needing supplemental artificial lighting.
- **UDI-high (> 2000 lux):** Indicates excessive daylight exposure, which may cause glare and overheating.

. According to ISO guidelines 2024 and LEED v4.1, the following describes the UDI and sDA in performance:

Table 24: LEED daylight rating for UDI

	UDI Range	Rating	Interpretation
1	UDI $\geq$ 80%	✓ Excellent	The space is well lit for most of the time occupied, reducing the need for artificial lighting while minimizing glare risks
2	UDI 60–80%	✓ Good	A well-balanced daylight environment, but some areas may need adjustments to optimize light distribution
3	UDI 40–60%	- Moderate	Daylight is present, but some spaces may be too dark or too bright, requiring lighting control strategies.
4	UDI < 40%	✗ Poor	The space is either too dim or experiences excessive glare, heavily relying on artificial lighting.

5.4.4 Daylight Performance with EC windows

Except for zone 7 and zone 9 which represent direct west and east, all other zones give excellent sDA while the zones 7 & 9 show good performance, but not uniformly distributed according to the LEED rating. The UDI in zones 1 and 3 are lower but still good enough, although lacks uniformity. All other zones show good UDI

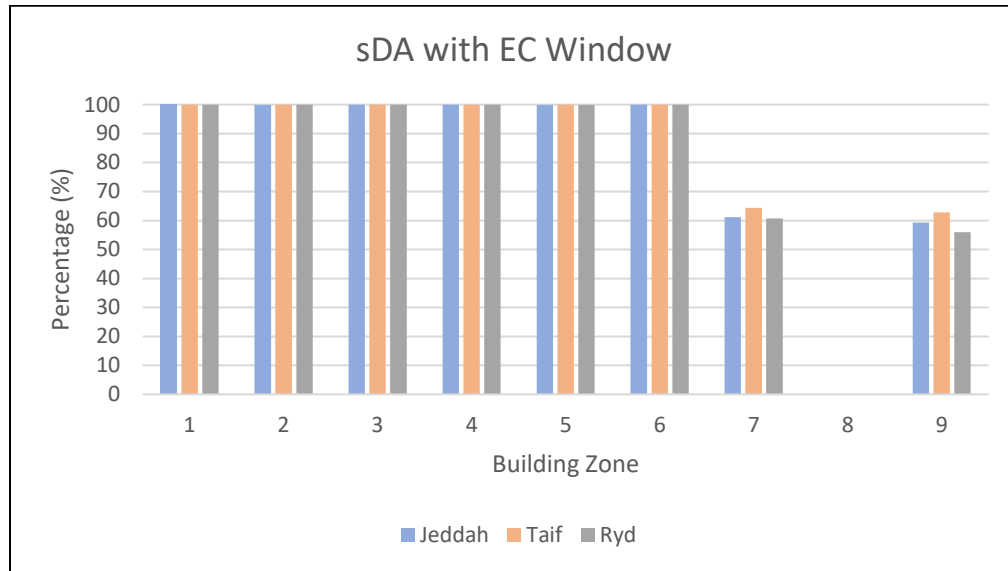


Figure 66: sDA with Electrochromic windows

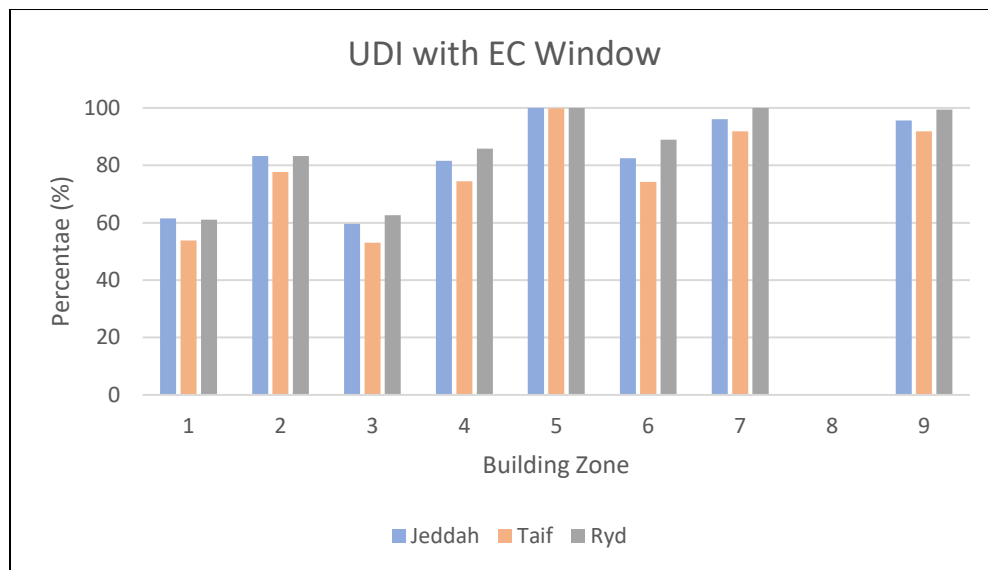


Figure 67: UDI with Electrochromic windows

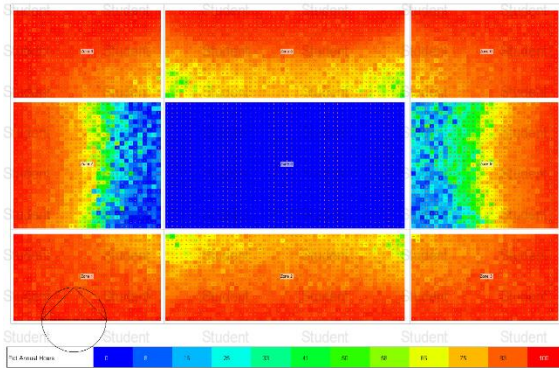


Figure 68: Annual sDA map (EC)

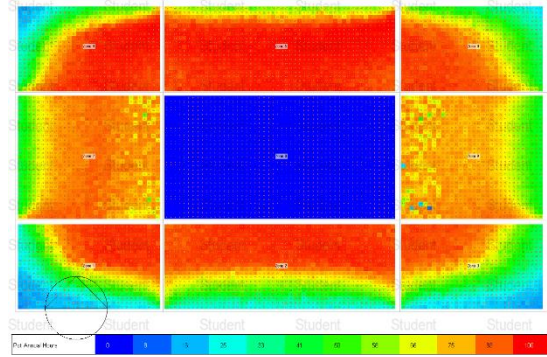


Fig 65b: Annual UDI map (EC)

5.4.5 Daylight Performance with GC windows

Like the trend under electrochromic, gasochromic also shows high daylight performance across the building perimeter except for zones 7 and 9. These zones are about 10m deep and receive sunlight only from one direction, thus the intensity diminishes as one moves away from the envelope boundary. The UDI also follows the same pattern as that of electrochromic window. Zone 1 and three may be prone to glare due to excessive daylight.

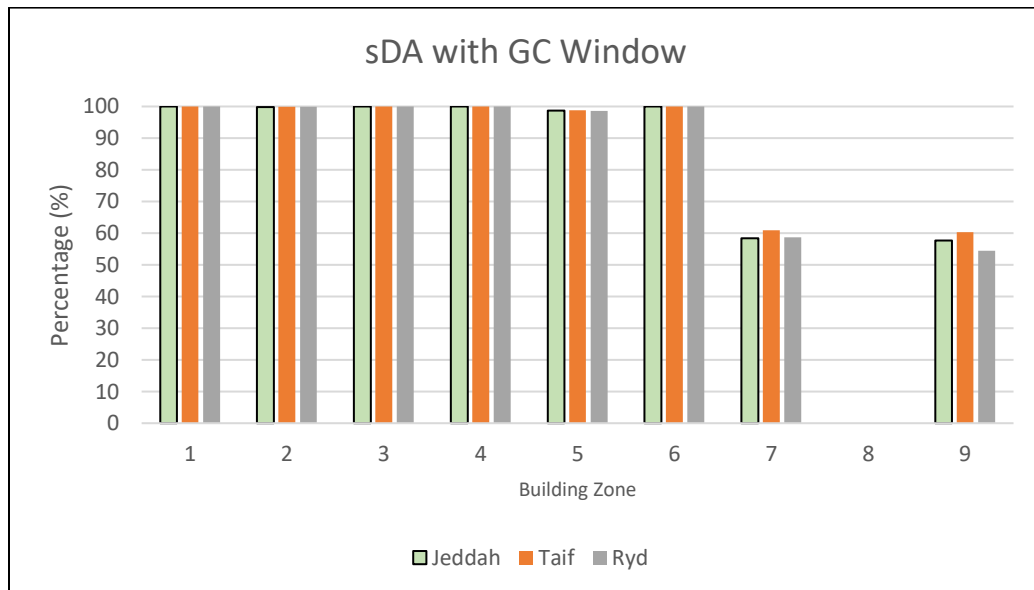


Figure 69: sDA with gasochromic windows

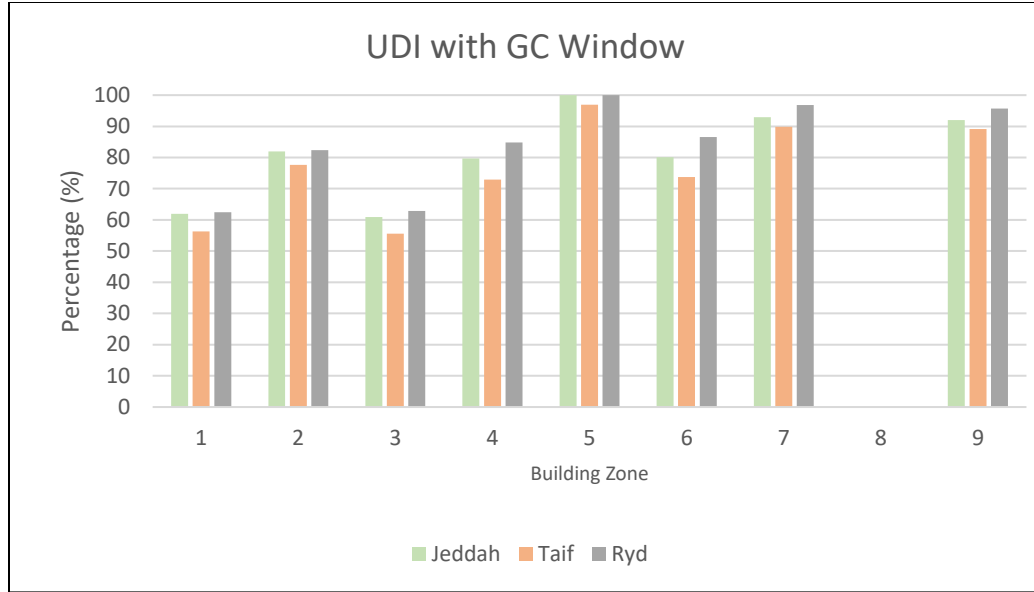


Figure 70: UDI with gasochromic windows

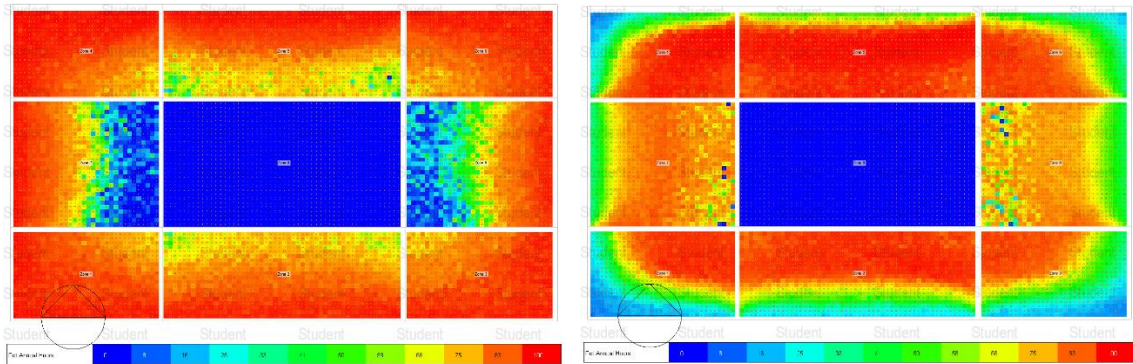


Figure 71a: Annual sDA map (GC)

Fig 69b: Annual UDI map (GC)

5.4.6 Daylight Performance with PC windows

From the following figures 73 and 74, photochromic windows also show improved daylight performance but tend to be reduced in zones 7 and 9. As regard to UDI, zones 1 and 3 have lesser values that the remaining zones which means they might experience higher than 2000 lux of daylight at some portions and are therefore prone to glare for less than 40% of the occupied period.

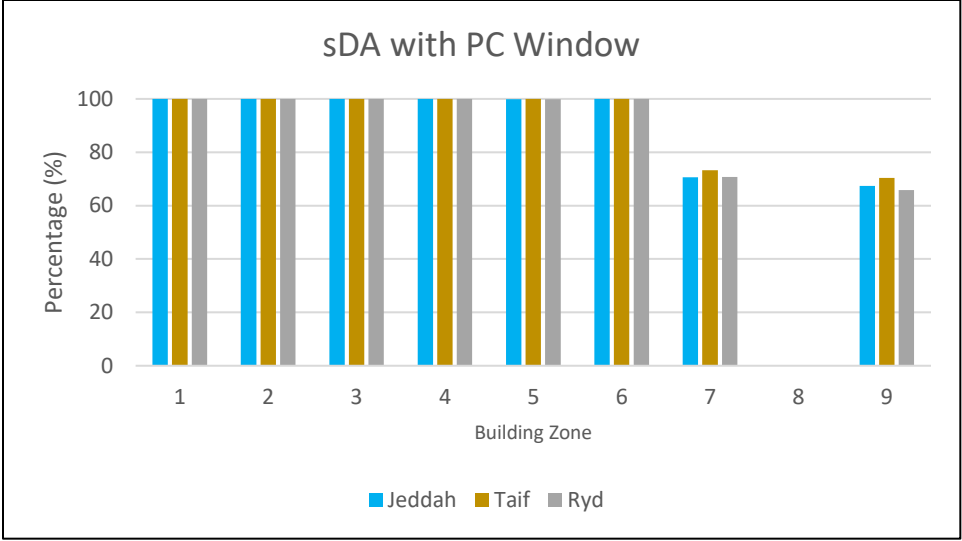


Figure 72: UDI with photochromic windows

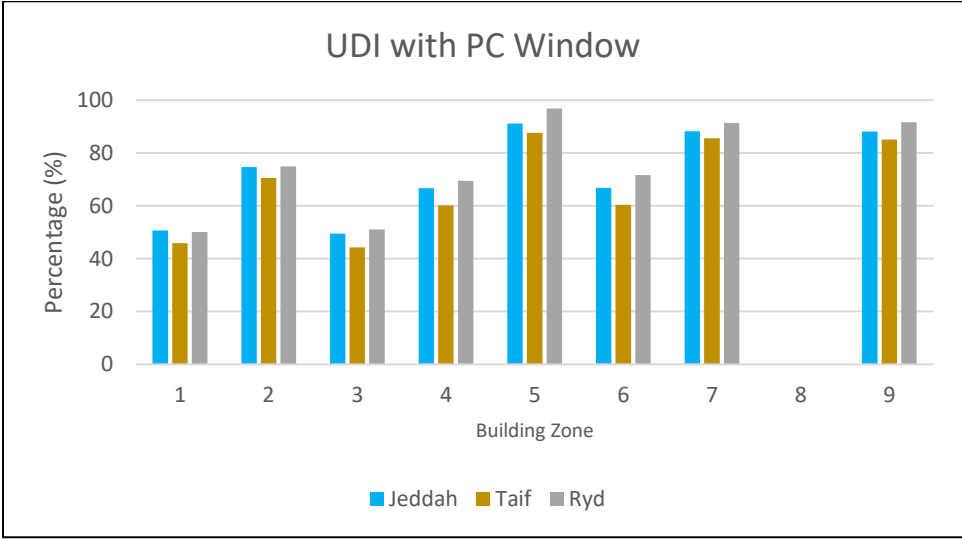


Figure 73: UDI with photochromic windows

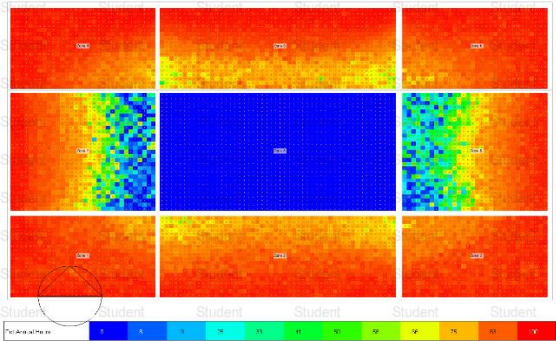


Figure 74 a: Annual sDA map (PC)

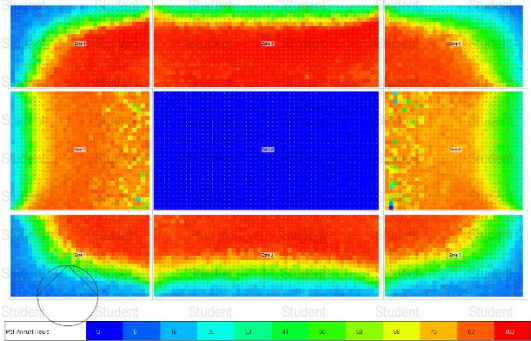


Fig 71b: Annual UDI map (PC)

5.4.7 Daylight Performance with PDLC windows

Like the previous windows, there is excellent sDA except for zones 7 & 9 which show good performance, but not uniformly distributed according to the LEED rating. The UDI in zones 1 and 3 are lower but still good enough, although lacks uniformity. All other zones show good UDI

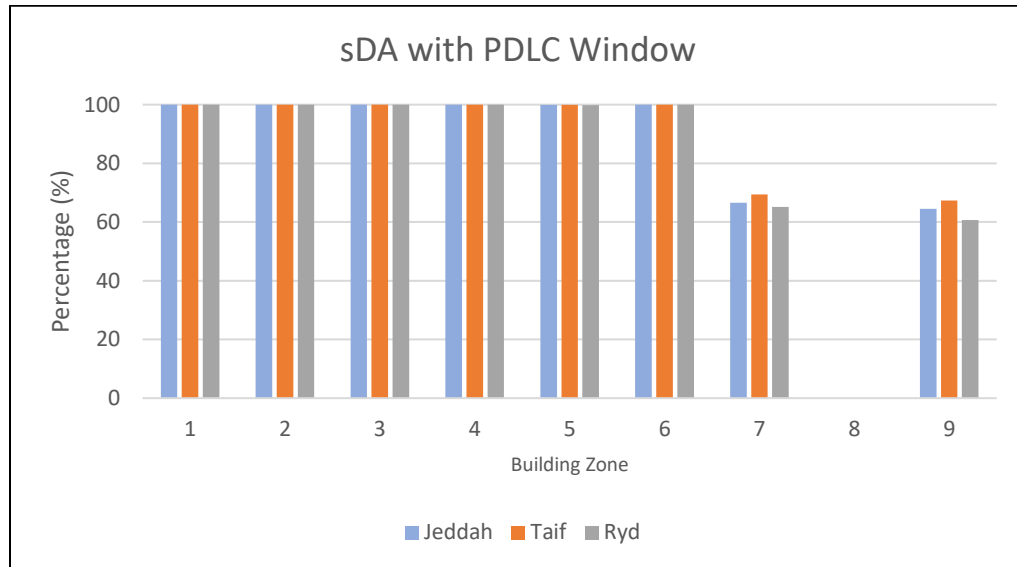


Figure 75: UDI with PDLC windows

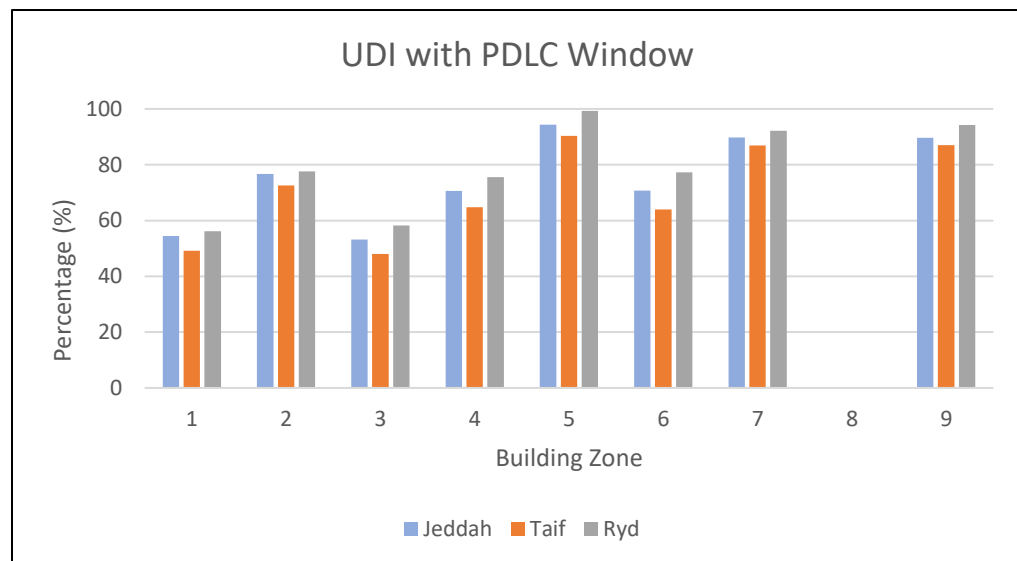


Figure 76: UDI with PDLC windows

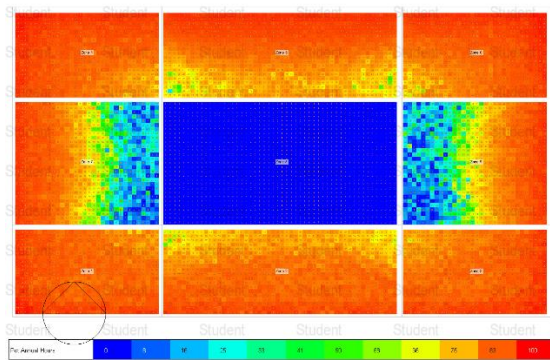


Figure 77 a: Annual sDA map (PDLC)

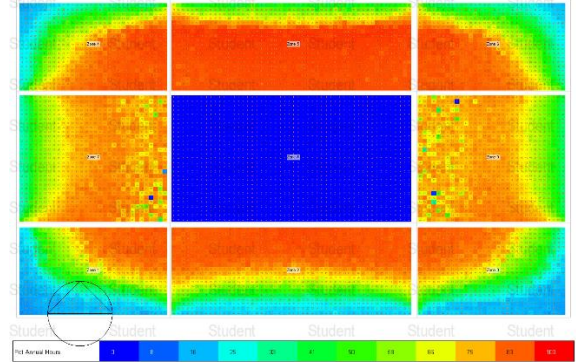


Fig 74b: Annual UDI map (PDLC)

5.4.8 Daylight Performance with SPD windows

Lower sDA is seen in zone 7 and zone 9 with SPD windows, whereas it shows improved UDI at zone 1 and zone 3, which were a bit lower in the case of the previous windows. Therefore, except for the core zone, all other zones achieved LEED requirement for daylighting.

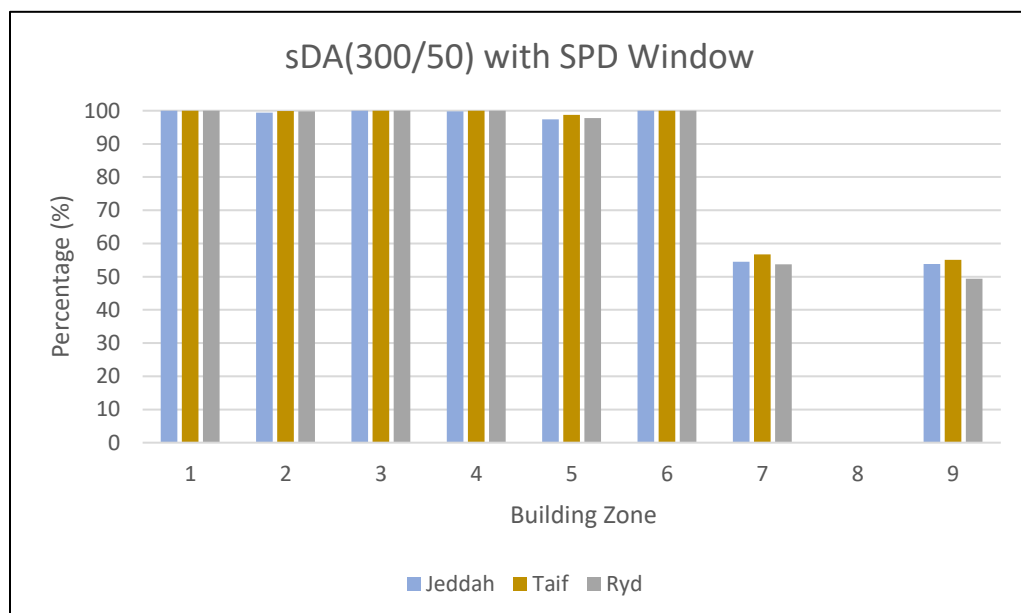


Figure 78: UDI with SPD windows

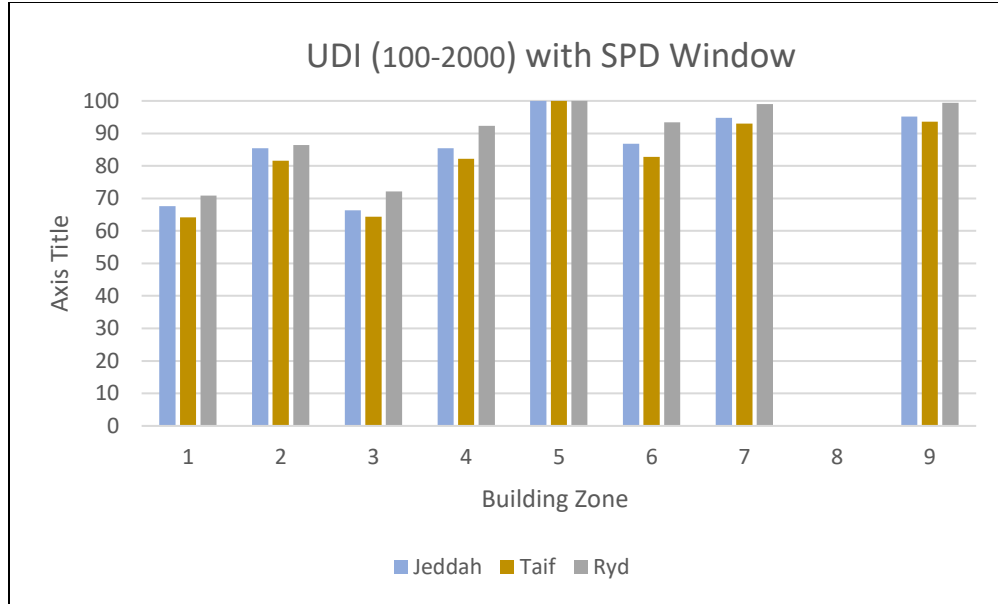


Figure 79: UDI with SPD windows

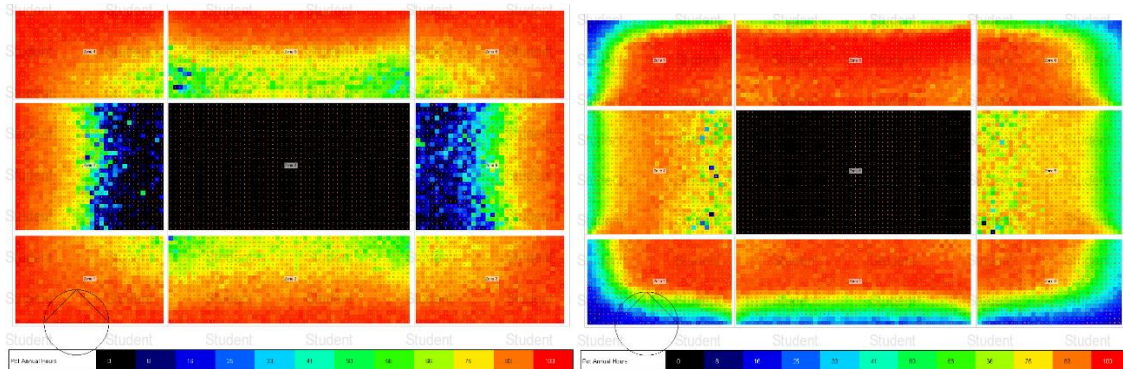


Figure 80a: Annual sDA map (SPD)

Fig 77b: Annual UDI map (SPD)

5.4.9 Daylight Performance with TC windows

As can be seen in figure 78 which follows, lower sDA is seen in zones 7 and 9 with the thermochromic windows, which predicts that the zones require supplement of artificial lighting in most of the occupied period. Looking at the UDI, excellent performance ($\geq 80\%$) is shown in all the perimeter zones except zone 1 and 3 which shows lower UDI between (60-80%) than the other zones which is still sufficient, see figure 83.

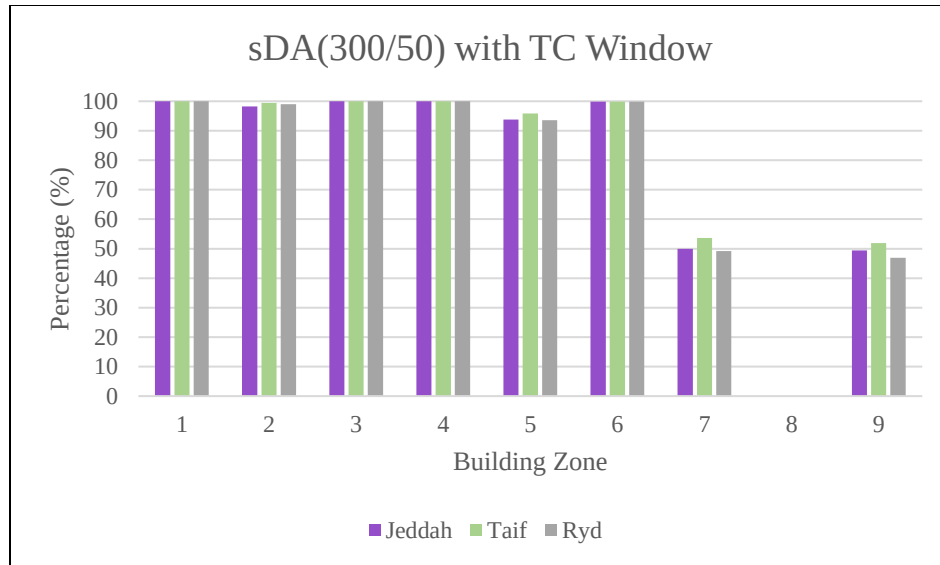


Figure 81: sDA with TC windows

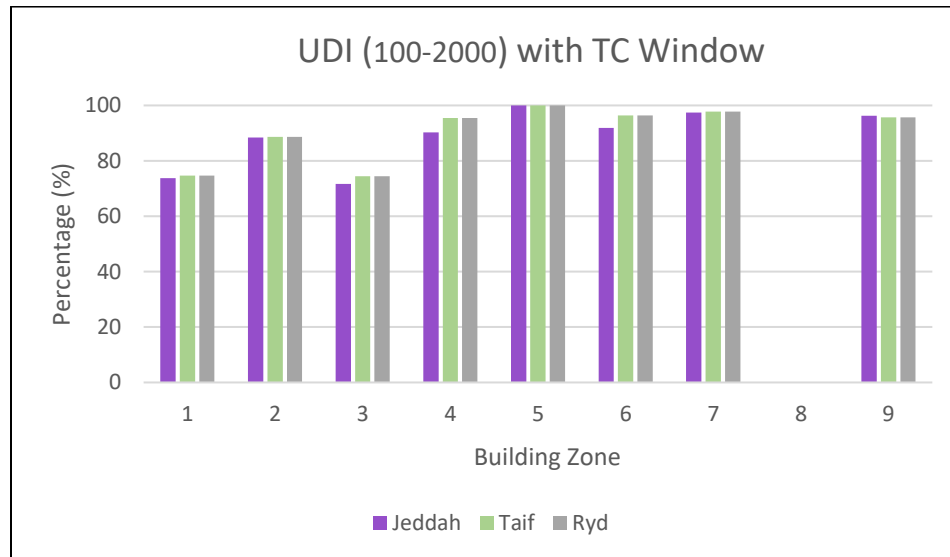


Figure 82: UDI with TC windows

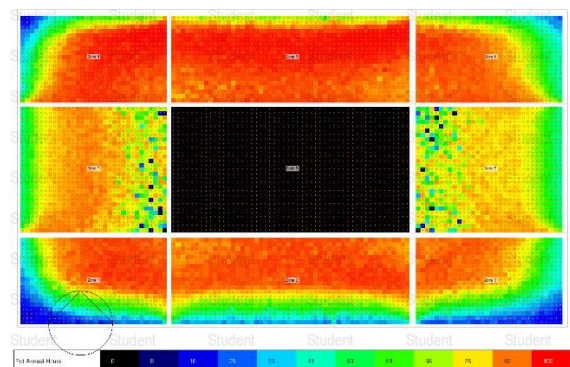
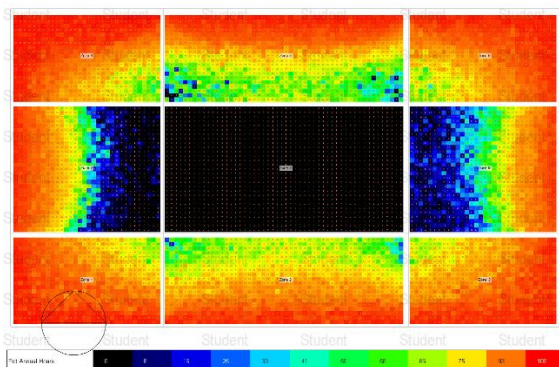


Figure 83a: Annual sDA map (SPD)

Fig 80b: Annual UDI map (SPD)

5.5 Daylight Performance of the Whole Building

The previous results show the daylight performance for each zone in the building under different windows across the 3 climates. However, this section describes the overall performance of the building and not for the individual zones. Figure 85 below shows that PC and LC windows offer greater daylight performance, although all the windows fall below the range 55-75% sDA which is generally considered good.

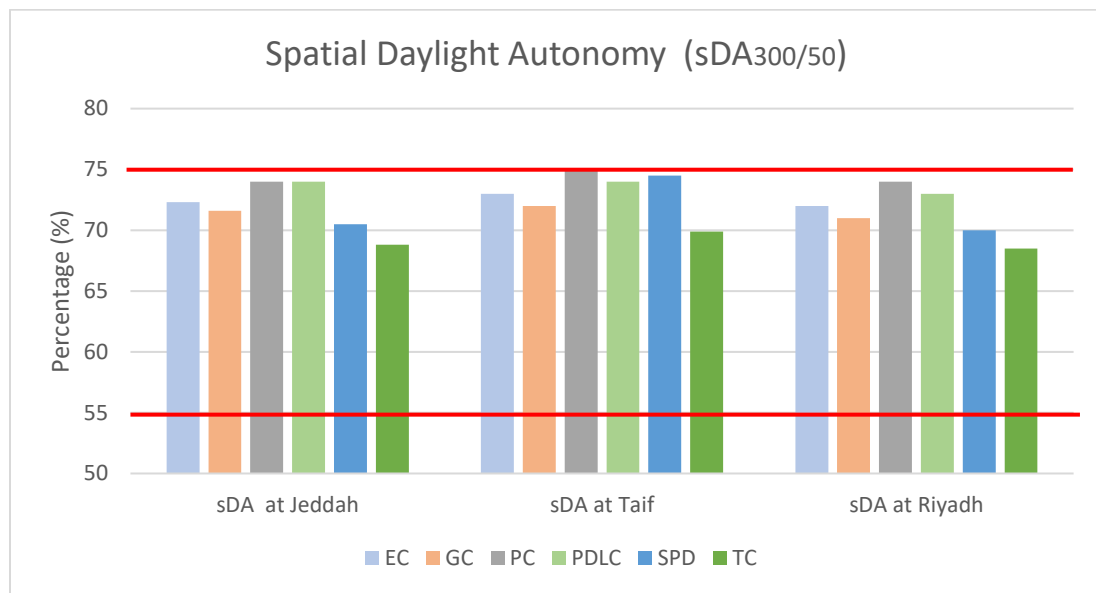


Figure 84: sDA for the whole building under different windows

Looking at the UDI which can be seen in the following figure, all the windows across all the locations offer good daylight performance. The overall UDI fall within the range 60-80% which is considered good by LEED v4.1.

Although all the windows provide acceptable daylighting levels, the figure shows that photochromic and liquid crystal windows offer greater performance than the corresponding electrochromic and gasochromic window.

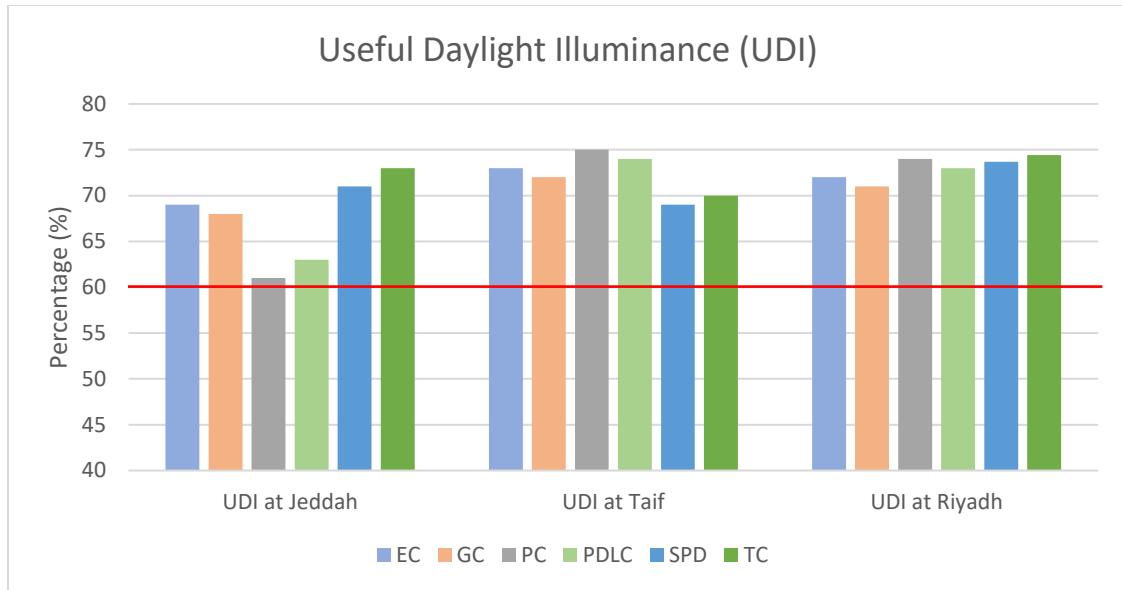


Figure 85: UDI for the whole building under different windows

However, the results earlier indicated that the core zone did not receive any daylight.

Therefore, the overall building performance will vary depending on whether the core zone has been included in the analysis or not. Figure 87 below compares the performance with and without including the core zone, an illustration of the case in Jeddah

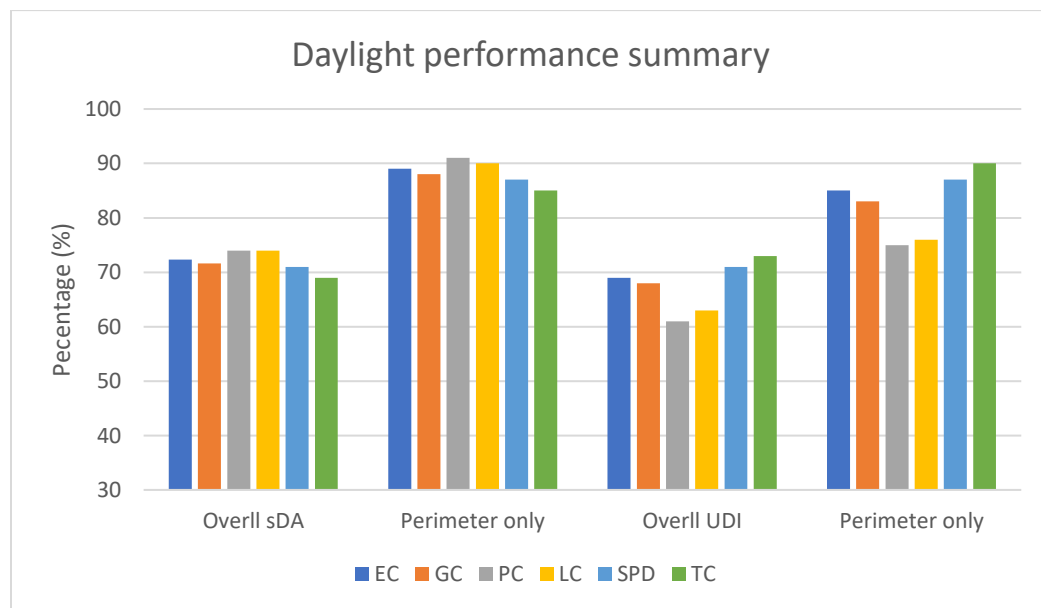


Figure 86: Overall sDA and UDI with and without the core zone

5.6 Cost Analysis

Considering the building case study which has a gross floor area of 8712 m², total annual energy consumed with each window under each climate can be easily calculated. This will translate to total cost of energy when calculated using the current electric tariff in the Kingdom of Saudi Arabia.

5.6.1 Energy Cost

According to the Saudi Electricity Company new tariff system since 2018 (<https://www.se.com.sa/en/OurServices/ColumnC/Bills-and-Consumption>), the following table summarized the cost per kWh across different building types and consumption tiers.

Table 25 : Electricity tariffs in Saudi Arabia

Tariff Sectors in Halala/kWh	Consumption Between 1-6000 kWh/month	Consumption >6000kWh/Month
Residential Sector	18	30
Commercial Sector	20	30
Agricultural and Charitable Organizations	16	20
Governmental Sector	32	32
Industrial Sector	18	18
Private Educational and Medical Facilities	18	18

Working with the optima WWR in each case, the following tables provide the total annual energy consumption, total reduction in the annual energy consumption relative to the base case and the corresponding CO₂ emissions reduction.

Table 26: Total annual electric consumption with each window at its optimum WWR in Jeddah

		Window	Optimum WWR (%)	EUI (kwh/m2/yr)	Energy Consumption (kWh/yr)	Energy Reduction (kWh/yr)	kgCO2 Reduction
JEDDAH	0	BC		360.4	3,139,805		
	1	PC	60	295.4	2,573,525	566,280	322,213.32
	2	PDLC	50/60	304.2	2,650,190	489,615	278,590.94
	3	EC	70	304.3	2,651,062	488,743	278,094.77
	4	SPD	70	310.1	2,701,591	438,214	249,343.77
	5	GC	60	313.4	2,730,341	409,464	232,985.02
	6	TC	60	329.5	2,870,604	269,201	153,175.37

Table 27: Total annual electric consumption with each window at its optimum WWR in Taif

		Window	Optimum WWR (%)	EUI (kwh/m2/yr)	Energy Consumption (kWh/yr)	Energy Reduction (kWh/yr)	kgCO2 Reduction
TA'IF	0	BC		245.5	2,138,796	-	-
	1	PC	60	185.6	1,616,947	521,849	296,932.08
	2	PDLC	50/60	189	1,646,568	492,228	280,077.73
	3	EC	70	218	1,899,216	239,580	136,321.02
	4	SPD	70	193.1	1,682,287	456,509	259,753.62
	5	GC	70	201	1,751,112	387,684	220,592.20
	6	TC	60	222	1,934,064	204,732	116,492.51

Table 28: Total annual electric consumption with each window at its optimum WWR in Riyadh

		Window	Optimum WWR (%)	EUI (kwh/m2/yr)	Energy Consumption (kWh/yr)	Energy Reduction (kWh/yr)	kgCO2 Reduction
RIYADH	0	BC		261.9	2,281,673		
	1	PC	60	196.5	1,711,908	569,765	324196.29
	2	PDLC	50/60	201/200	1,742,400	539,273	306846.34
	3	EC	70	226	1,968,912	312,761	177961.01
	4	SPD	70	211.5	1,842,588	439,085	249839.37
	5	GC	60	218.2	1,900,958	380,715	216626.84
	6	TC	60	233	2,029,896	251,777	143261.11

The following figures show total energy consumption with each optimum window size under each of the three different climate zones. The base case is indicated in each case and compared to the smart windows under study. The lowest and highest energy consumptions in Jeddah are achieved with PC and TC windows respectively.

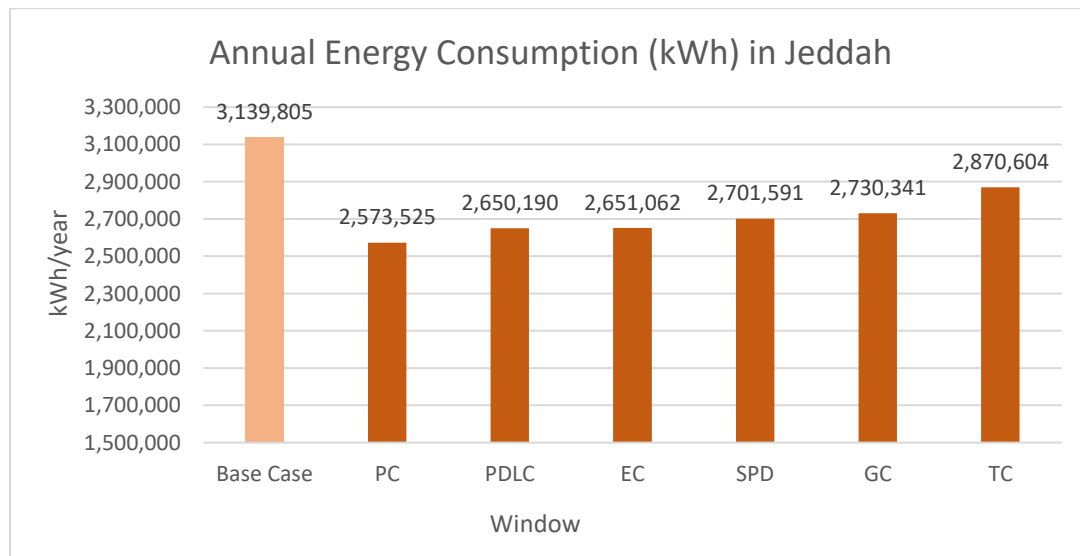


Figure 87: Annual Energy Consumption with different windows in Jeddah

Lowest consumptions can be seen with PC and PDLC windows whereas highest consumptions are seen under EC and TC windows under Taif climate.

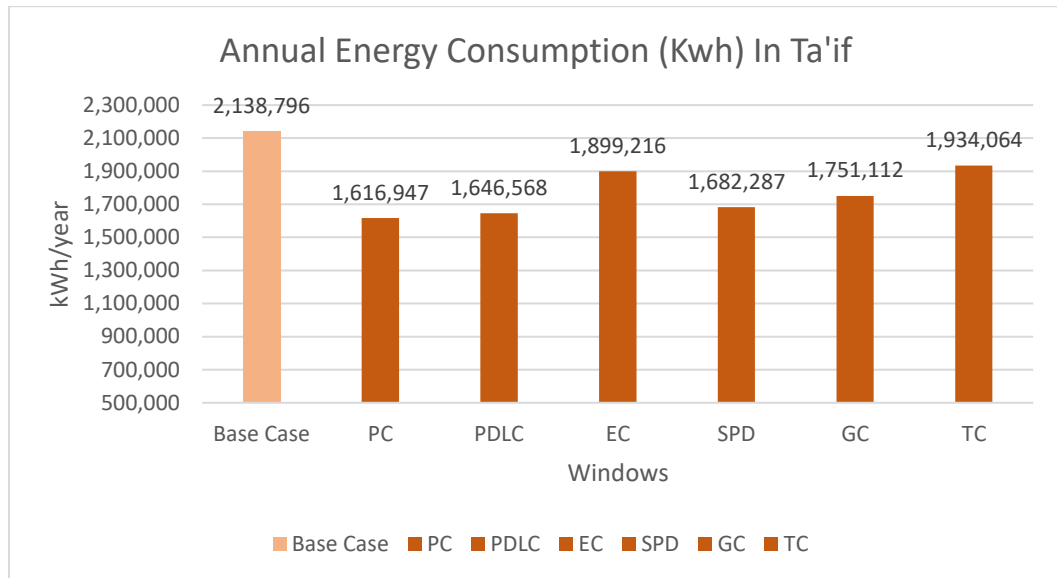


Figure 88: Annual Energy Consumption with different windows in Jeddah

The trend shows a similar pattern to the case in Taif. EC and TC show the highest total energy consumption while PC and PDL offer the lowest consumption rates under the climate of Riyadh.

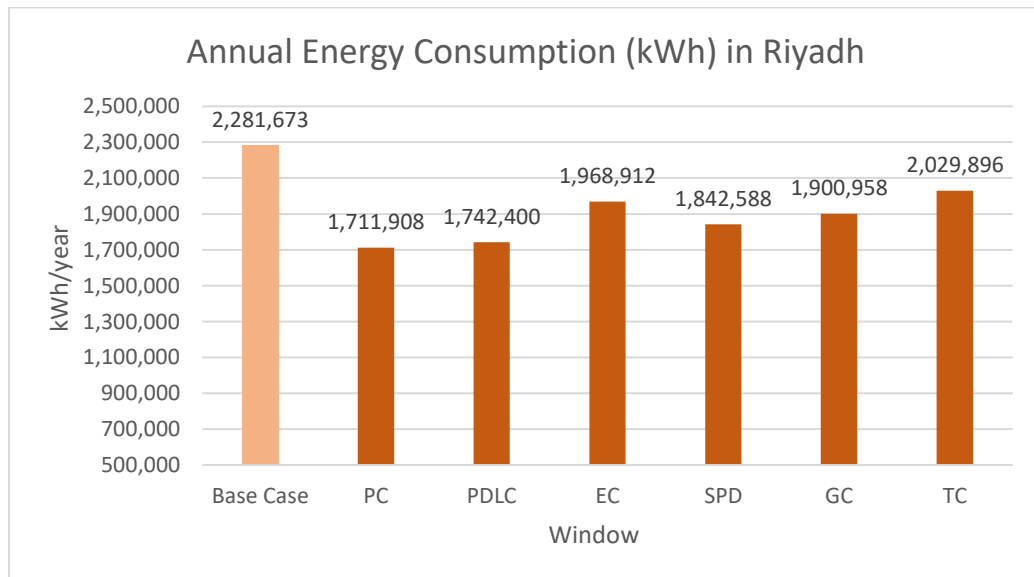


Figure 89: Annual Energy Consumption with different windows in Jeddah

5.6.2 Total Savings in Annual Energy Cost

The tables below show total savings in annual energy consumed by the building under each climate with different smart windows. This is translated to the total cost saving based on the current electric tariff per kWh from the Saudi electric company for residential and commercial buildings.

Table 29: Annual electric cost saving achievable in Jeddah

		Window	EUI (kwh/m2/yr)	Energy Savings (kWh/yr)	Unit cost (SAR/kWh)	Saving Cost (SAR)
JEDDAH	1	PC	295.4	566,280	0.3	169,884.00
	2	PDLC	304.2	489,615	0.3	146,884.50
	3	EC	304.3	488,743	0.3	146,622.90
	4	SPD	310.1	438,214	0.3	131,464.20
	5	GC	313.4	409,464	0.3	122,839.20
	6	TC	329.5	269,201	0.3	80,760.30

Table 30: Annual electric cost savings achievable in Ta'if

		Window	EUI (kwh/m2/yr)	Energy Savings (kWh/yr)	Unit cost (SAR/kWh)	Saving Cost (SAR)
TA' IF	1	PC	185.6	521,849	0.3	156,554.70
	2	PDLC	189	492,228	0.3	147,668.40
	3	EC	218	239,580	0.3	71,874.00
	4	SPD	193.1	456,509	0.3	136,952.70
	5	GC	201	387,684	0.3	116,305.20
	6	TC	222	204,732	0.3	61,419.60

Table 31: Annual electric cost saving achievable in Riyadh

		Window	EUI (kwh/m2/yr)	Energy Savings (kWh/yr)	Unit cost (SAR/kWh)	Saving Cost (SAR)
RIYADH	1	PC	196.5	569,765	0.3	170,929.50
	2	PDLC	201/200	539,273	0.3	161,781.90
	3	EC	226	312,761	0.3	93,828.30
	4	SPD	211.5	439,085	0.3	131,725.50
	5	GC	218.2	380,715	0.3	114,214.50
	6	TC	233	251,777	0.3	75,533.10

5.6.3 Estimated Costs of Windows

Cost of different smart windows were obtained from suppliers mainly across Saudi Arabia and UAE. All prices are based on double-glazed units, involving only glass without an aluminum frame and installation cost.

Table 32: Smart windows price per squared meter

Double glazed Unit				
Window	Cost (\$/m2)	Cost (SAR/m2)	Added Cost (SAR/m2)	Source (Company)
Base case 6-12-6	180	675	---	IW glass (iwglass.net)
PC	293	1100	425	IF smart glass https://ifsmartglass.com/switchable
PDLC	380	1400	725	Smart Glass Masters https://smartglassmaster
EC 6-13-6	283	1061	386	SmartGlass World 16-13-6
SPD 6-12-6	320	1200	525	Combo Glass (comboglass.com)
GC	300	1125	450	Smart Glass World
TC	267	1000	325	Smart Glass Masters https://smartglassmaster

5.6.4 Simple Payback Period (SPP) based on initial

Considering the total area of the building (22x36m), the perimeter of the building façade is 116 m. The building has 11 floors of 3.7m height each, total height is therefore 40.7 m. This implies that the total façade area is 4721 m². Therefore, the area of window depends on the optimum WWR at that location. It can be seen from the results that optimum WWR at all cases ranges between 50-70% depending on the location applied. Considering the total façade area, the corresponding window areas are 2361 m², 2833 m² and 3305 m² at 50%, 60% & 70% WWR respectively. Table 33 below summarizes optimum WWR for each of the six smart windows and under each of the three climate zones.

Table 33: Optimal WWR using smart windows under different climates

LOCATION	OPTIMUM WWR					
	PC	PDLC	EC	SPD	GC	TC
JEDDAH	60	50	70	70	60	60
TA'IF	60	50	70	70	70	60
RIYADH	60	50	70	70	60	60

Calculating the SPP requires selecting the optimum WWR, calculating the corresponding cost, estimating additional cost in relation to the cost of base case, and comparing with the total cost of energy saved using the window. The simple payback period is accompanied by the average durability of the windows. In Jeddah, the longest payback period is 13 years with SPD smart window, in Taif the longest payback period is up to 17 years with EC

window, while the longest payback period in Riyadh is 13.6 years, with electrochromic window. However, durability of the windows will help in understanding if the SPP is worth investing or otherwise. The tables 34, 35 and 36 show the estimated simple payback period based on the initial costs. It took account of the difference in the cost of smart windows and the cost of ordinary windows, while comparing with their net energy cost saving.

Table 34: Simple payback calculation for smart windows under Jeddah climate

		Window	Window area(m2)	Added Unit Cost (SAR/m2)	Cost Added (SAR)	Cost saved (SAR)	SPP (years)	Durability (years)
JEDDAH	1	PC	2833	426	1,204,025	169,884.00	7	10
	2	PDLC	2361	725	1,711,725	146,884.50	11.7	10
	3	EC	3305	386	1,275,730	146,622.90	8.7	30
	4	SPD	3305	525	1,735,125	131,464.20	13.2	20
	5	GC	2833	450	1,274,850	122,839.20	10.4	10
	6	TC	2833	325	920,725	80,760.30	11.4	20

Table 35: Simple payback calculation for smart windows under Taif climate

		Window	Window area (m2)	Added Unit Cost (SAR/m2)	Cost Added (SAR)	Cost saved (SAR)	SPP (years)	Durability (years)
TA' IF	1	PC	2833	425	1,204,025	156,554.70	7.7	10
	2	PDLC	2361	725	1,711,725	147,668.40	11.6	10
	3	EC	3305	386	1,275,730	71,874.00	17.7	30
	4	SPD	3305	525	1,735,125	136,952.70	12.7	20
	5	GC	3305	450	1,487,250	116,305.20	12.7	10
	6	TC	2833	325	920,725	61,419.60	15	20

Table 36: Simple payback calculation for smart windows under Jeddah climate

		Window	Window area (m2)	Added Unit Cost (SAR/m2)	Cost Added (SAR)	Cost saved (SAR)	SPP (years)	Durability (years)
RIYADH	1	PC	2833	425	1,204,025	170,929.50	7	10
	2	PDLC	2361	725	1,711,725	161,781.90	10.5	10
	3	EC	3305	386	1,275,730	93,828.30	13.6	30
	4	SPD	3305	525	1,735,125	131,725.50	13.2	20
	5	GC	2833	450	1,274,850	114,214.50	11.2	10
	6	TC	2833	325	920,725	75,533.10	12	20

According to the results, in all the locations, PDLC and GC windows are not favorable for investors as the windows do not return their investments over their expected durability of their smart features.

The unit cost of electricity used in the analysis is based on the current tariff. Also, the cost of smart windows is expected to decrease overtime when they experience mass production. However, tariffs are subject to changes over time. Although at the moment, PDLC and GC smart windows show less energy savings than their initial installation costs, they may still offer cost benefit in the future if electric tariff increases, or relative initial costs are reduced upon the tables below projects.

Nevertheless, further economic analysis indicates that even the PDLC and GC windows will be worth investing in future when electric tariff increases by up to 20% or smart window cost reduces by 10% or more.

Table 37 Payment period for PDLC and GC windows upon 20% rise in electric tariff

		Window	Window area (m2)	Added Unit Cost (SAR/m2)	Cost Added (SAR)	Cost saved (SAR)	SPP (years)	Durability (years)
Jeddah	1	PDLC	2361	725	1,711,725	176,260	9.7	10
	2	GC	2833	450	1,274,850	147,406	8.6	10
Taif	1	PDLC	2361	725	1,711,725	177,202	9.6	10
	2	GC	3305	450	1,487,250	139,566	10.7	10
Riyadh	1	PDLC	2361	725	1,711,725	194,138	8.8	10
	2	GC	2833	450	1,274,850	137,057	9.3	10

Table 38: Payment period for PDLC and GC windows upon a 10% drop in the price of smart windows

		Window	Window area (m2)	Added Unit Cost (SAR/m2)	Cost Added (SAR)	Cost saved (SAR)	SPP (years)	Durability (years)
Jeddah	1	PDLC	2361	585	1,381,184	146,885	9.4	10
	2	GC	2833	338	957,554	122,839	7.8	10
Taif	1	PDLC	2361	585	1,381,184	147,668	9.4	10
	2	GC	3305	338	1,117,090	116,305	9.6	10
Riyadh	1	PDLC	2361	585	1,381,184	161,782	8.5	10
	2	GC	2833	338	957,554	114,215	8.4	10

5.7 Carbon Emissions Reduction

According to report by the SEC, total CO₂ emission associated with Saudi electricity generation has declined significantly from 703 gCO₂/kwh in 2019 to 569 gCO₂/kwh IN 2022. This is in line with the Saudi Green Initiative (SGI) launched in 2021, which intends to reduce carbon emissions by 278 million tons per annum (mtpa) by 2030, net zero emissions by 2060. Figure 88 shows the annal CO₂ reduction based on the most recent metric.

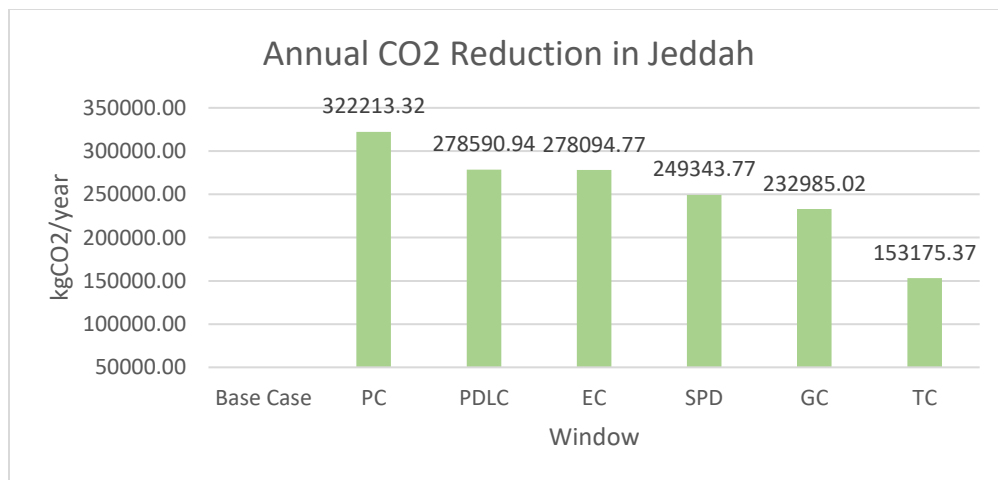


Figure 90: Annual CO₂ emission reduction in Jeddah

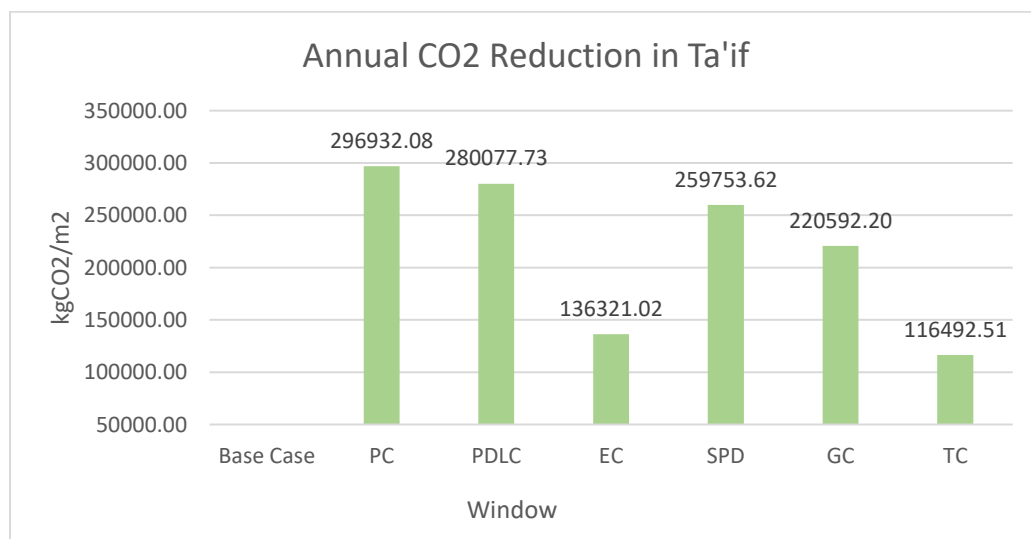


Figure 91: Annual CO₂ emission reduction in Ta'if

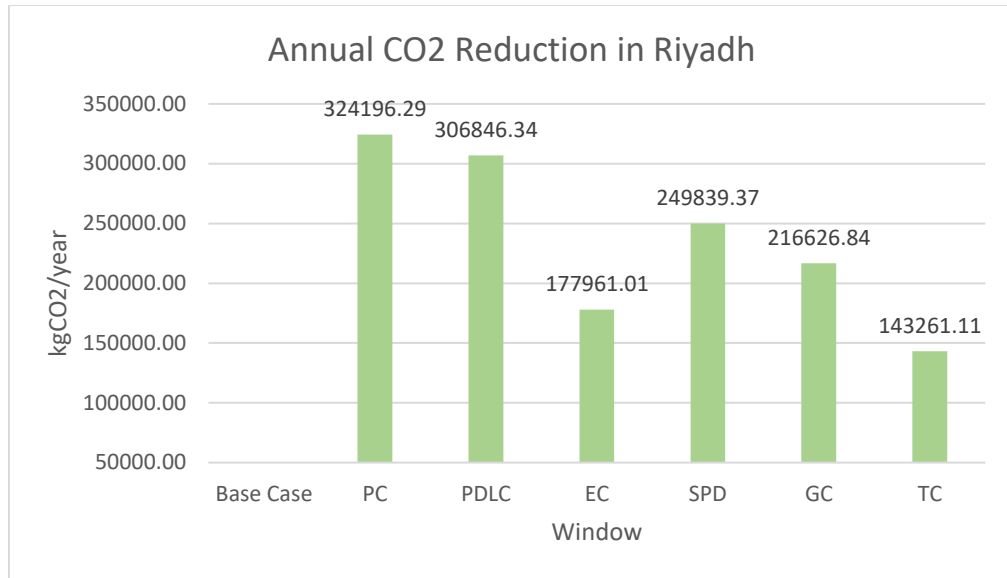


Figure 92: Annual CO₂ emission reduction in Riyadh

CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 Energy Performance Summary

i. Energy profile with different smart windows under Jeddah climate

EC and GC windows offer similar reductions in annual energy demand in Jeddah while PC and LC window offer greater reductions in energy demand as shown in figure 91 below:

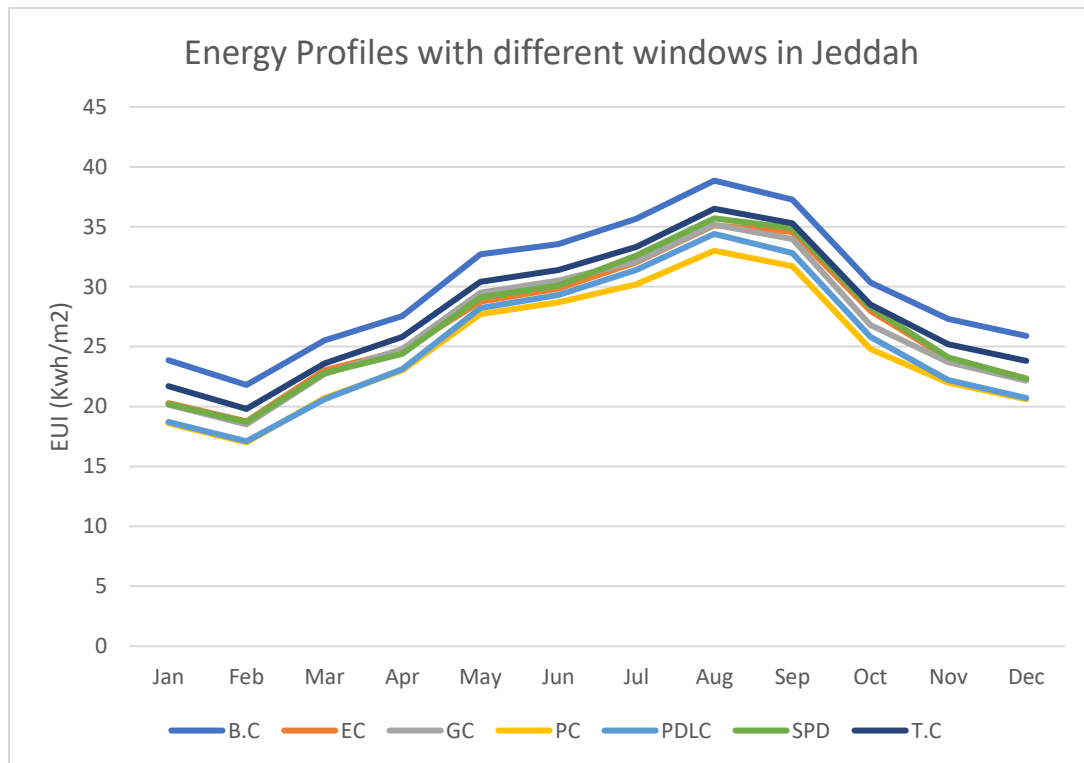


Figure 93: Energy profiles with smart windows under the climate of Jeddah

However, the above comparison is only at the same WWR of 50% relative to the base case scenario. Thus, the 95 figure shows the energy performance at different WWR.

The chart below compares the energy performances of EC, GC, PC, PDLC, SD and TC windows at different WWR. PC and PDLC windows show better energy performance than EC and GC at all window sizes, whereas GC offers more energy consumption than EC at

lower WWR but tend to consume more energy than the EC as the window size increases. TC windows show the least total reduction energy consumption, while GC and SPD savings are very similar, thanks to the significant reduction in energy consumption offered by PC and PDLC windows.

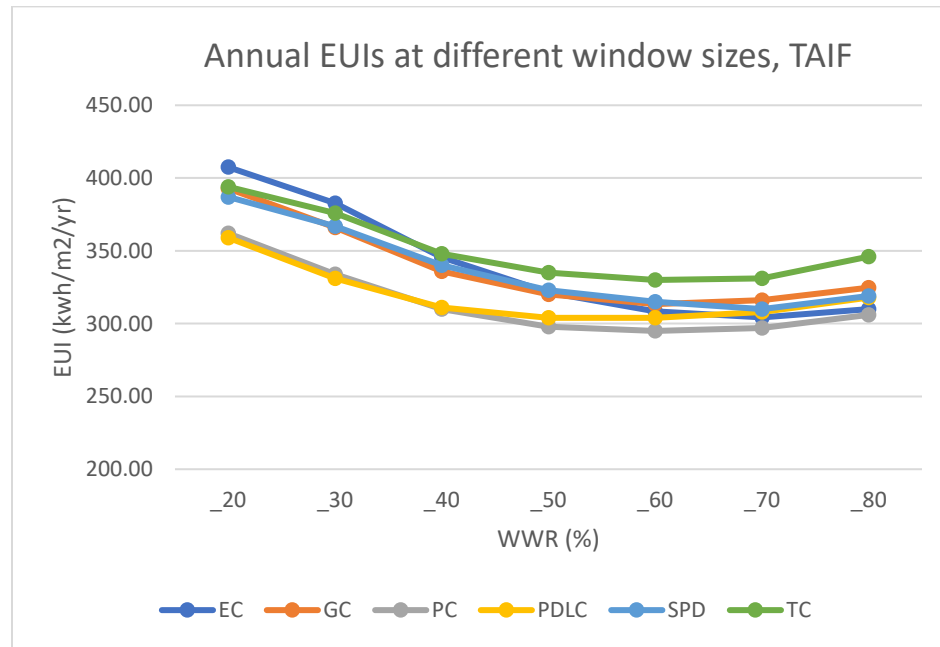


Figure 94: Annual EUIs for smart windows at different sizes in Jeddah

ii. Energy profile with different smart windows under the climate of Taif

Under this climate, PC window provides greatest energy savings, followed by PDLC. As regards electrochromic windows, significant reduction in energy consumption is only notable during summer months, this could be attributed to the fact that electrochromic windows respond to increased solar radiation. Thermochromic shows consistent profile pattern with the base case although it offers lower energy consumption than all the other windows. See figure 96.

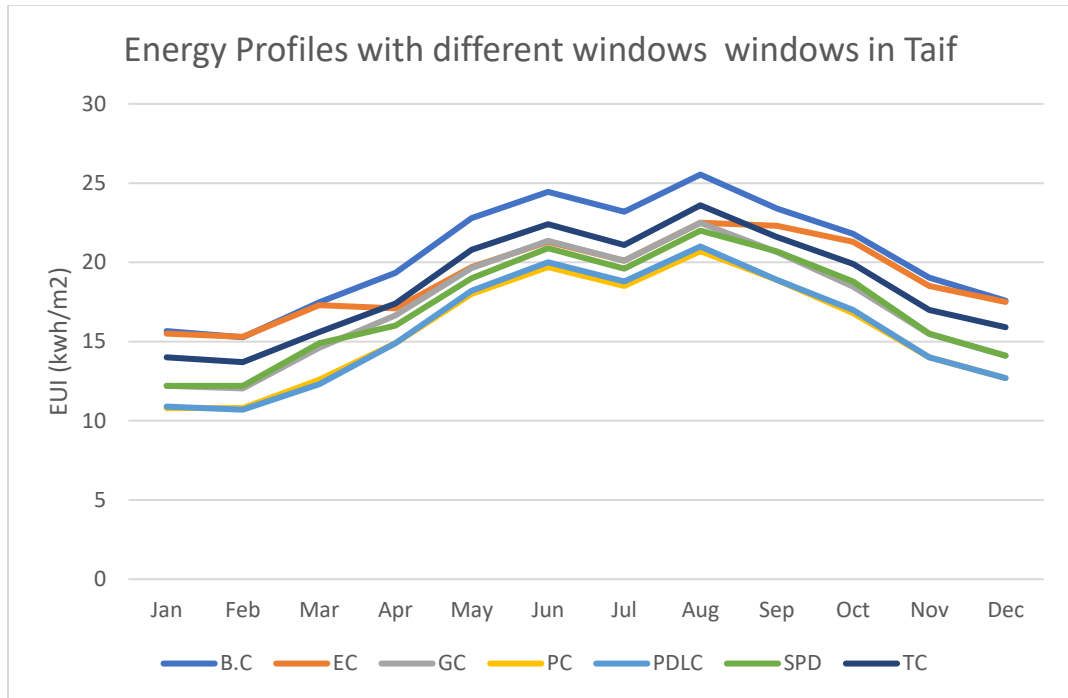


Figure 95: Energy profiles with smart windows under the climate of Taif

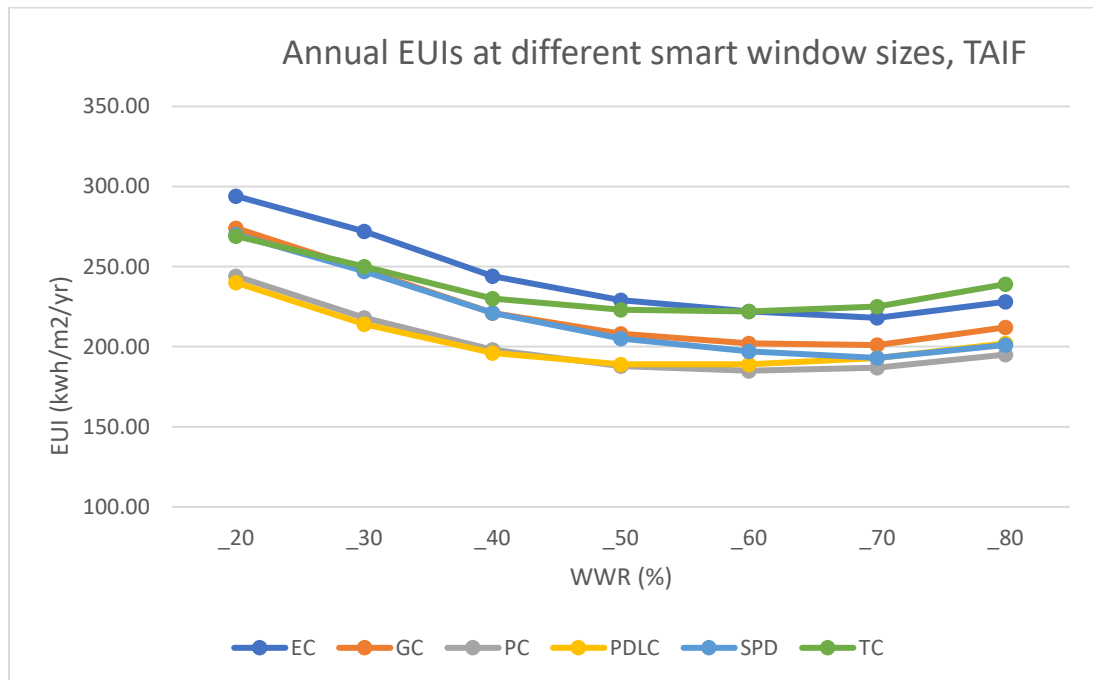


Figure 96: Annual EUIs for smart windows at different sizes in Taif

iii. Energy profile with different smart windows under the Riyadh climate

Relative to the base case under this climate, the greatest reduction in energy profile is achieved by photochromic windows, followed by PDLC, whereas EC windows offer significant energy savings only between April and September. Others TC, GC and SPD also offer good savings as shown in figure 98 below.

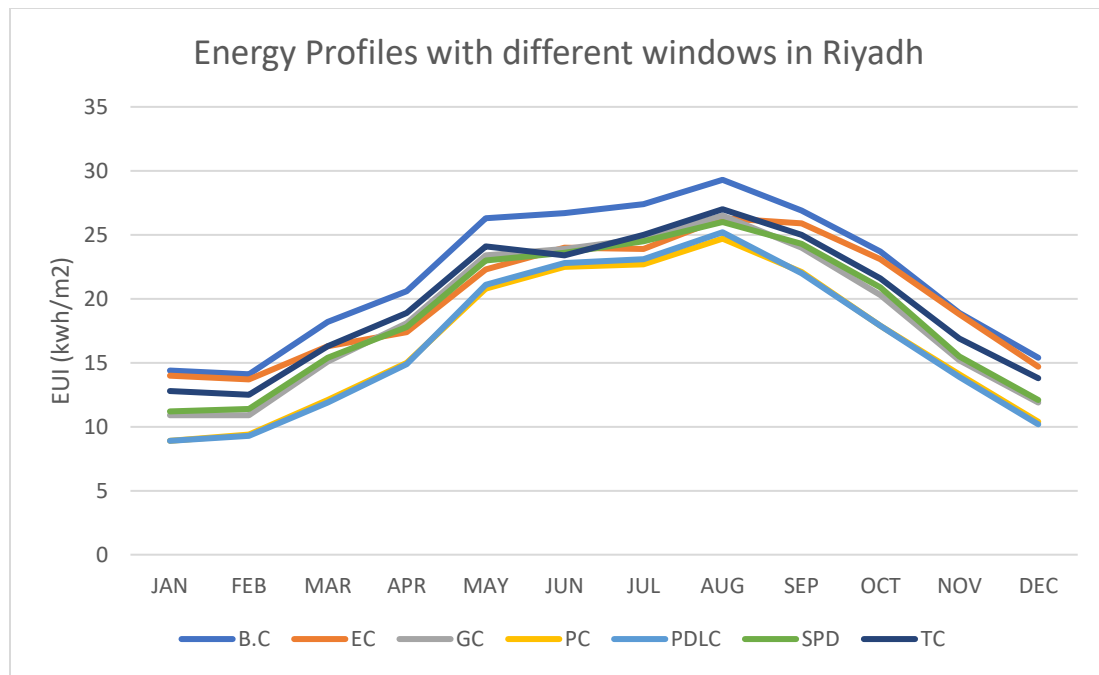


Figure 97: energy profiles with smart windows under the climate of Riyadh

Like the case in Jeddah, the total annual energy profile showed that: at all windows sizes under this climate, PC and PDLC offer the least energy demand, followed by Gasochromic, then electrochromic, yet all windows lower the building total energy consumption relative to the base case window including the TC. Electrochromic window offers energy saving between march to October, this can be due to the solar radiation compared to the winter months.

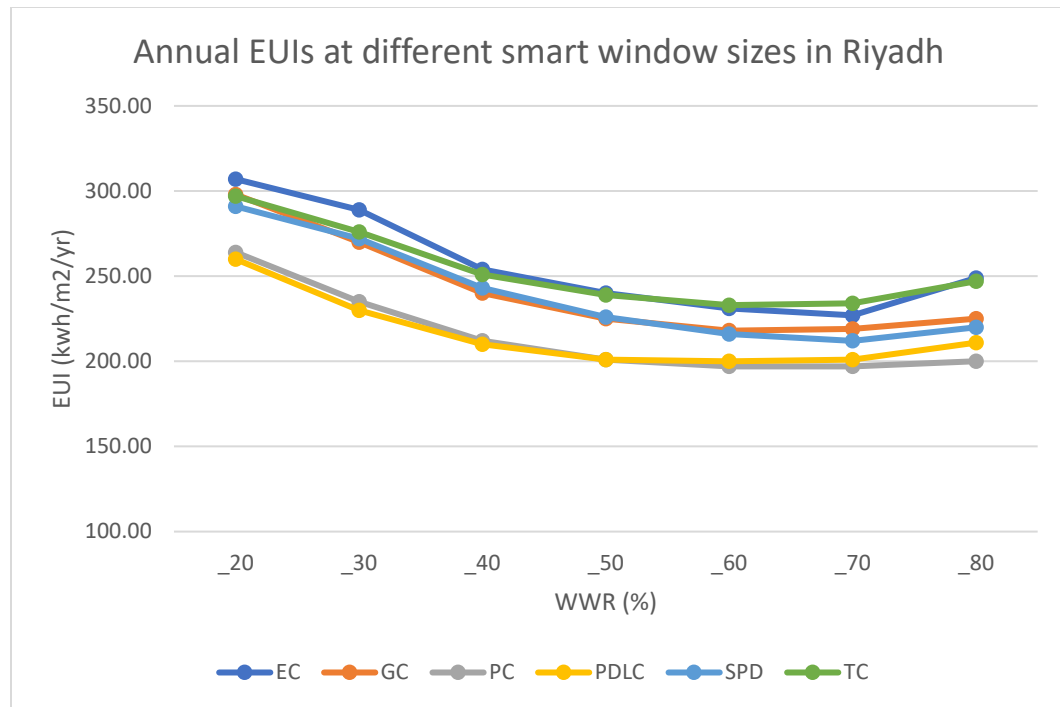


Figure 98: Annual EUIs for smart windows at different sizes in Riyadh

iv. Energy Saving Per Optimum Size

Table 19 below shows the summary of the optimum WWR for EC, GC, PC, PDLC, TC and SPD windows, their corresponding annual EUIs and the potential energy savings at the optimum WWR. The optimum WWR ranges between 50 to 70 %.

PC windows show the highest energy savings in all the three climate zones, followed by PDLC. As for the EC and GC, the performance varies from one location to the other. Gasochromic windows are better than electrochromic windows in Taif and Riyadh but not in Jeddah. Thermochromic performs best in Riyadh whereas SPD offers best performance in Taif.

Another important takeaway from the charts is that smart windows don't perform well in winters and therefore won't be good in cold climates. Its greater performance in Jeddah over Taif and Riyadh proves that because Jeddah climates don't have winters at all.

Table 39: Optimal WWR for different smart windows under the three different climates

		Window	Optimum WWR (%)	EUI at the Optimum	Base Case EUI (kwh/m2/yr)	Mxm Energy Saving
Jeddah	1	Electrochromic	70	304.3	360.4	15.6 %
	2	Gasochromic	60	313.4	360.4	13%
	3	Photochromic	60	295.4	360.4	18%
	4	PDLC	50/60	304.4	360.4	15.5%
	5	SPD	70	310.1	360.4	14%
	6	Thermochromic	60	329.5	360.4	8.6%
Ta'if	1	Electrochromic	70	218	245.5	11.1%
	2	Gasochromic	70	201	245.5	18%
	3	Photochromic	60	185.6	245.5	24%
	4	PDLC	50/60	189	245.5	23%
	5	SPD	70	193.1	245.5	21.3%
	6	Thermochromic	60	222	245.5	9.7%
Riyadh	1	Electrochromic	70	226	261.9	13.7%
	2	Gasochromic	60	218.2	261.9	16.7%
	3	Photochromic	60	196.5	261.9	25%
	4	PDLC	50/60	201/200	261.9	23.1/23.8%
	5	SPD	70	211.5	261.9	19.2%
	6	Thermochromic	60	233	261.9	11%

6.2 Daylight Performance Summary

This section summarizes the daylight performance of the windows, each at its optimum WWR. sDA (Spatial Daylight Autonomy) measures the percentage of floor area that receives sufficient daylight (at least 300 lux) for a specified percentage of the operating hours per year (typically 50% of the occupied time). sDA describes the extent to which a space can rely on daylight in line with ISO guidelines 2024.

6.2.1 Daylight Summary under different windows

The overall daylight performance for the whole building for both sDA and UDI falls within the acceptable range. If the core zone is excluded in the analysis, the overall performance tends to increase as the core zone receives no daylight and thus, doesn't contribute to the overall analysis

Table 40: Daylight Performance Summary with Electrochromic (70% WWR)

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	544.74	72.3%	519.95	69%
	Excluding Core Zone	613.49	544.74	88.8%	519.95	84.8%
Taif	Original Total (All Zones)	753.82	550.70	73%	489.28	64.9%
	Excluding Core Zone	613.49	550.70	89.7%	489.28	79.8%
Riyadh	Original Total (All Zones)	753.82	541.58	71.9%	534.64	70.9%
	Excluding Core Zone	613.49	541.58	88%	534.64	87.1%

Table 41: Daylight Performance Summary with Gasochromic Windows

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	539.69	71.6%	511.33	67.8%
	Excluding Core Zone	613.49	539.69	88%	511.33	83.3%
Taif	Original Total (All Zones)	753.82	544.34	72.2%	484.23	64.2%
	Excluding Core Zone	613.49	544.34	88.7%	484.23	78.9%
Riyadh	Original Total (All Zones)	753.82	537.18	71.3%	526.88	69.9%
	Excluding Core Zone	613.49	537.18	87.6%	526.88	85.9%

Table 42: Daylight Performance Summary with Photochromic Windows

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	560	74.3	458.21	60.8
	Excluding Core Zone	613.49	560	91.3	458.21	74.7
Taif	Original Total (All Zones)	753.82	564.93	74.94	431.67	57.27
	Excluding Core Zone	613.49	564.93	92.1	431.67	70.4
Riyadh	Original Total (All Zones)	753.82	558.7	74.1%	475.02	63.02
	Excluding Core Zone	613.49	558.7	91.1	475.02	77.4

Table 43: Daylight Performance Summary with PDL Windows

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	553.95	73.5	475.28	63.05
	Excluding Core Zone	613.49	553.95	90.3	475.28	77.5
Taif	Original Total (All Zones)	753.82	558.79	74.13	448.55	59.5
	Excluding Core Zone	613.49	558.79	91.1	448.55	73.
Riyadh	Original Total (All Zones)	753.82	549.39	72.9	498.08	66.1
	Excluding Core Zone	613.49	549.39	89.6	498.08	81.2

Table 44: Daylight Performance Summary with SPD Windows

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	531.18	70.5	533.49	70.8
	Excluding Core Zone	613.49	531.18	86.6	533.49	87
Taif	Original Total (All Zones)	753.82	536.16	74.5	519	69
	Excluding Core Zone	613.49	536.16	91.8	519	84.6
Riyadh	Original Total (All Zones)	753.82	527.573	70	555.5	73.7
	Excluding Core Zone	613.49	527.573	86	555.5	90.5

Table 45: Daylight Performance Summary with TC Windows

	Metric	Total Floor Area (m ²)	Total sDA Area (m ²)	Overall sDA (%)	Total UDI Area (m ²)	Overall, UDI (%)
Jeddah	Original Total (All Zones)	753.82	518.79	68.8%	552.55	73.3
	Excluding Core Zone	613.49	518.79	84.6	522.55	90
Taif	Original Total (All Zones)	753.82	527.2	70	528.2	70
	Excluding Core Zone	613.49	527.2	86	528.2	86
Riyadh	Original Total (All Zones)	753.82	516.48	68.5	560.73	74.4
	Excluding Core Zone	613.49	516.48	84.2	560.73	91.4

6.2.2 Key Observations:

1. sDA (Spatial Daylight Autonomy) Performance:

- At all climate zones and with all the smart windows, greater than 70% of the total spaces meet sDA thresholds, meaning that daylight is sufficient for at least 50% of the hours occupied in most areas.
- If zone 8 (which has 0% sDA) is excluded, performance increases to above 80% in all instances, indicating strong daylight autonomy.
- Zones 1-7 and 9 generally have high sDA values, meaning artificial lighting requirements are reduced in these areas.
- Zone 8 is a central-core space with no direct daylight contribution.

2. UDI (Useful Daylight Illuminance) Performance:

- At least about 60% of the total area falls within the useful daylight range (100–2000 lux) in all instances.
- Excluding Zone 8, UDI performance improves to at least 70%, confirming effective daylight utilization.
- Zones 5, 7, and 9 exhibit the highest UDI percentages (>80%) in most instances, indicating well-balanced daylight distribution.
- Zones 1 and 3 show lower UDI values (less than 60%), which may require daylight-enhancing strategies (e.g., light shelves or increased reflectivity).

6.3 Cost Payback Summary

This section summarizes unit cost for each window, durability and the payback period under each of the three locations representing different climate zones as can be seen in table 46 below

Table 46: Summary of unit cost and payback period for different smart windows

s/n	Window	Unit Cost (SAR/m2)	Simple Payback Period			Durability
			Jeddah	Taif	Riyadh	
	Base Case	675				
1	PC	1100	7	7.7	7	10
2	PDLC	1400	11.7	11.6	10.5	10
3	EC	1061	8.7	17.7	13.6	30
4	SPD	1200	13.2	12.7	13.2	20
5	GC	1125	10.4	12.7	11.2	10
6	TC	1000	11.4	15	12	20

6.4 Conclusions

The energy and daylight performance of six smart windows (EC, GC, PC, PDLC, SPD and TC) were evaluated under three (3) different climate zones: hot-humid (Jeddah), hot-dry (Riyadh) and moderate/ Mediterranean (Taif). The results show that smart windows offer several benefits over conventional double-glazed windows: they reduce the need for conventional window shadings, control solar heat gain into space, improve energy efficiency in buildings, reduce glare risk in space, optimize daylight utilization and help improve environmental sustainability (lower equivalent CO₂ emission) associated with power generation.

Under these three climate zones, the results of this study indicate that smart windows affect cooling and lighting energy usage in buildings. However, energy is saved only when the proper WWR is used. This implies that at certain WWR (typically 20% & 30%), smart windows often result in an overall increase in total annual energy consumption. Significant energy is saved (between 10% to 25%) by using smart windows when the WWR attains 40% or higher. Optimum WWR across all the three climate zones is between 50-70%. Therefore, utilizing these six smart windows with their optimum WWR (as shown in table 33) in the summary section of this study could promote the Saudi Green Initiative (SGI) and the goal number 7 (Affordable and clean energy) of the UN SDGs.

However, the results showed that smart windows are less effective during winter and are therefore not suitable for application under cold climates. In addition to energy cost savings, smart windows can reduce the peak load in the building which enables reduction of HVAC sizing and therefore reduction in initial installation cost. Up to 25% peak load

reduction is achieved with PC in Jeddah & Taif, while maximum peak load reduction in Riyadh is 14%.

Smart windows, when used with optimum WWR as mentioned in table 33, will significantly decrease the total annual energy consumed: EC reduces 11%-15%, GC reduces 13%-18%, PC reduces 18%-25%, PDLC reduces 15-23%, SPD reduces 14%-21% and TC reduces 8%-11% energy, depending on the location. Improved daylight regulation offered by the smart windows will enhance visual comfort of occupants by minimizing glare risk for up to 70% of the occupied period as shown in Figure 86, particularly in office buildings where the occupancy period is mainly in the day hours.

However, based on available data from manufacturers as shown previously in Table 9, the smart properties are only promising for identified durability period typically: 30 years (for EC), 20 years for (SPD & TC) and 10 years (for PC, GC and PDLC). After such durability period, windows smart characteristics may deteriorate and, therefore, negatively affect their performance and the obtained benefits. This will affect the decision and choice of specific smart windows especially when compared with their initial costs. For example: gasochromic and PDLC show longer payback period than their expected smart lifespan in all the three studied regions. EC windows proved to be best in Jeddah because of its shortest payback period as shown in table 46, considering its durability as well as cost and benefit. PC, SPD and TC also save more cost on energy and their payback periods are lower than their service lives as indicated in table 46.

This durability is based on present available smart windows data as reported by their manufacturers, although with advancement in technology, their durability may be improved in the future.

Moreover, the payback calculation is based on the present cost of smart windows and present electric tariffs which are subject to change and may affect future payback calculations. For example, even the PDLC and GC windows may still offer cost saving in future (whenever there is up to 20% increase in electric tariffs or at least 10% reduction in the cost of smart windows).

6.5 Recommendation

Based on the study findings, four basic recommendations are made to different stakeholders in the construction sector.:

- i. Developers/ facility managers may consider the use of smart windows particularly in office and commercial buildings for energy efficiency improvement and environmental conservation, but should consider optimum WWR, installation costs and the respective lifetime.
- ii. Designers should understand the behavior of smart windows to enable them to specify suitable smart window and optimum WWR 50% for PDLC, 60% for PC, TC and GC and 70% for EC and SPD windows under hot-humid, hot-dry and moderate climate) and select suitable HVAC system sizing considering the peak loads, their project scope and climate zone.
- iii. EC, PC, SPD and TC may be considered in building façade, bearing in mind their durability and its implications for HVAC system efficiency
- iv. PDLC and GC may be used for spaces with privacy demands such as meeting rooms and ICUs hospital and not for cost saving at the present time, but may be considered for the cost saving in the future

6.6 Limitations of the Study

Smart windows are classified as active and passive, active smart windows consume some little DC or AC voltage (10-100V) to switch to tint state, this Power consumed by active smart windows is not considered by the software and could therefore affect the accuracy of the calculations, although not significantly. Another limitation is that it does not cover other climate zones such temperate climates. The cost analysis is based on initial cost only and not an LCC approach, this limits the understanding of the overall economic benefits of the systems. All the energy saving potentials of smart windows are only achievable when they are appropriately integrated with building management systems (BMS) and therefore, developers need to consider their project intent and scope before taking any decision.

6.7 Suggestion for Future Studies

Smart window technology is an emerging technology, having some products already available in the market while other technologies are still at research level. This study assessed only the smart windows that are commercially available at the time of conducting the study. Further studies can look at the performance of the other smart window technologies which are currently at research level once they become available to develop guidelines on their efficient usage across given climate zones.

The study concentrated more on the technical performance of smart windows in terms of energy saving and daylight improvement. The sustainability aspect is limited to CO₂ equivalent reduction and initial cost only. To further reveal smart windows life cycle performance, future studies should focus on LCCA of the smart windows.

Moreover, for a wider understanding of their holistic performance, future studies should engage other climate zones not investigated in this study.

APPENDICES

APPENDIX I: Energy Simulation Results

W1: ELECTROCHROMIC, JEDDAH

EC (20% WWR) Jeddah					EC (30% WWR) Jeddah				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.2	13423.73	13777.73	29836.66	Jan	2635.2	12201.04	13300.1	28136.34
Feb	2419.2	12151.14	13309.37	27879.71	Feb	2419.2	10974.11	12832.42	26225.73
Mar	2743.2	13161.35	17097.67	33002.22	Mar	2743.2	11862.2	16578.82	31184.22
Apr	2484	11640.39	20462.29	34586.68	Apr	2484	10316.66	19898.19	32698.85
May	2743.2	11907.61	25032.72	39683.53	May	2743.2	10063.86	24228.01	37035.07
Jun	2635.2	11438.76	26252.16	40326.12	Jun	2635.2	9615.61	25474.58	37725.39
Jul	2592	11091.22	28385.05	42068.27	Jul	2592	9206.877	27652.82	39451.7
Aug	2743.2	11807.71	30677.08	45227.99	Aug	2743.2	9947.811	29915.58	42606.6
Sep	2592	12061.28	29207.43	43860.71	Sep	2592	10692.49	28693.01	41977.5
Oct	2635.2	12833.79	21692.16	37161.15	Oct	2635.2	11621.89	21337.16	35594.25
Nov	2028	13084.9	17712.73	32825.63	Nov	2028	11760.37	17191.14	30979.51
Dec	2592	13207.09	16051.08	31850.17	Dec	2592	11916.01	15511.92	30019.93
SUM	30842.4	147808.97	259657.47	438308.84	SUM	30842.4	130178.93	252613.75	413635.1

40% WWR Jeddah					EC (50% WWR) Jeddah				
Month	Room Electricity	Lighting	Cooling (Electricity)	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
Jan	2635.2	10112.41	12333.33	25080.94	Jan	2635.2	8582.209	11704.51	22921.92
Feb	2419.2	9165.46	12005.39	23590.05	Feb	2419.2	7500.376	11274.56	21194.14
Mar	2743.2	9746.217	15594.71	28084.13	Mar	2743.2	8122.412	14899.9	25765.51
Apr	2484	7882.493	18609.79	28976.28	Apr	2484	6599.13	18065.82	27148.95
May	2743.2	7593.723	23013	33349.92	May	2743.2	6234.789	22517.41	31495.4
Jun	2635.2	7183.837	24293.88	34112.92	Jun	2635.2	5960.805	23875.66	32471.67
Jul	2592	6906.557	26630.47	36129.03	Jul	2592	5802.15	26216.05	34610.2
Aug	2743.2	7701.653	28934.78	39379.63	Aug	2743.2	6586.203	28550	37879.4
Sep	2592	8706.446	27846.94	39145.39	Sep	2592	7324.714	27232.92	37149.63
Oct	2635.2	9600.431	20640.58	32876.21	Oct	2635.2	8005.758	19975.02	30615.98
Nov	2028	9979.075	16385.39	28392.47	Nov	2028	8338.54	15666.1	26032.64
Dec	2592	10052.58	14638.82	27283.4	Dec	2592	8420.509	13926.32	24938.83
SUM	30842.4	104630.88	240927.08	376400.4	sum	30842.4	87477.595	233904.3	352224.3

EC 60% WWR Jeddah					70% WWR				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.2	7599.526	11417.21	21651.936	Jan	2635.2	7538.3	11370.19	21543.69
Feb	2419.2	6593.073	11006.27	20018.543	Feb	2419.2	6429.625	10915.79	19764.615
Mar	2743.2	7027.561	14560.62	24331.381	Mar	2743.2	6306.781	14415.58	23465.561
Apr	2484	5873.808	17894.44	26252.248	Apr	2484	5373.784	17839.86	25697.644
May	2743.2	5656.318	22528.47	30927.988	May	2743.2	5131.566	22556.48	30431.246
Jun	2635.2	5387.271	23850.67	31873.141	Jun	2635.2	5313.272	23893.61	31842.082
Jul	2592	5213.614	26105.35	33910.964	Jul	2592	5065.338	26064.11	33721.448
Aug	2743.2	5939.278	28423.35	37105.828	Aug	2743.2	5888.113	28305.71	36937.023
Sep	2592	6484.534	26933.95	36010.484	Sep	2592	6559.916	26724.86	35876.776
Oct	2635.2	7000.493	19626.06	29261.753	Oct	2635.2	6765.349	19380.36	28780.909
Nov	2028	7186.776	15246.71	24461.486	Nov	2028	6901.392	15097.8	24027.192
Dec	2592	7309.469	13549.93	23451.399	Dec	2592	7013.633	13449.24	23054.873
SUM	30842.4	77271.721	231143.03	339257.15	SUM	30842.4	74287.069	230013.59	335143.06
80% WWR Jeddah					JEDDAH BASE CASE				
Month	Room Electricity	Lighting	Cooling Electricit	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.2	7369.766	11888.97	21893.94	Jan	2635.20	7595.64	16276.65	26507.49
Feb	2419.2	6316.999	11380.57	20116.77	Feb	2419.20	6462.34	15342.09	24223.63
Mar	2743.2	6753.66	15035.5	24532.36	Mar	2743.20	6665.28	18857.68	28266.16
Apr	2484	5708.983	18368.33	26561.31	Apr	2484.00	5777.24	21771.66	30032.90
May	2743.2	5443.35	23196.86	31383.41	May	2743.20	5730.05	26976.97	35450.22
Jun	2635.2	5186.959	24524.51	32346.67	Jun	2635.20	5355.74	28185.87	36176.81
Jul	2592	5006.987	26810.44	34409.43	Jul	2592.00	5222.12	30450.98	38265.10
Aug	2743.2	5766.722	29156.82	37666.74	Aug	2743.20	5925.37	32925.66	41594.23
Sep	2592	6229.98	27483.5	36305.48	Sep	2592.00	6053.01	31220.66	39865.67
Oct	2635.2	6676.994	20067.52	29379.71	Oct	2635.20	6750.87	23598.32	32984.39
Nov	2028	6910.28	15702.03	24640.31	Nov	2028.00	7275.32	20037.99	29341.31
Dec	2592	7100.115	14006.11	23698.23	Dec	2592.00	7433.93	18466.53	28492.46
SUM	30842.4	74470.795	237621.2	342934.4	SUM	30842.40	76246.91	284111.06	391200.37

W1: ELECTROCHROMIC, TA'IF

EC at Taif (20% WWR)					EC at Taif (30% WWR)				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.20	13435.88	6483.72	22554.80	Jan	2635.20	12594.93	6229.13	21459.26
Feb	2419.20	12166.32	7542.41	22127.93	Feb	2419.20	11249.46	7288.65	20957.31
Mar	2743.20	13366.67	9416.49	25526.36	Mar	2743.20	12297.91	9127.72	24168.83
Apr	2484.00	10689.93	12311.10	25485.03	Apr	2484.00	9037.99	11608.13	23130.12
May	2743.20	11528.09	15125.07	29396.36	May	2743.20	9567.74	14298.58	26609.52
Jun	2635.20	11106.95	16764.66	30506.81	Jun	2635.20	9150.83	15988.03	27774.06
Jul	2592.00	10964.65	15811.10	29367.75	Jul	2592.00	9023.67	15026.88	26642.55
Aug	2743.20	11765.38	17291.86	31800.44	Aug	2743.20	9954.64	16585.08	29282.92
Sep	2592.00	12201.26	15440.95	30234.21	Sep	2592.00	10730.33	14882.63	28204.96
Oct	2635.20	12593.75	13365.26	28594.21	Oct	2635.20	11506.95	13025.82	27167.97
Nov	2028.00	13003.42	9788.34	24819.76	Nov	2028.00	12076.48	9588.27	23692.75
Dec	2592.00	13255.92	8638.11	24486.03	Dec	2592	12347.16	8311.891	23251.051
Total	30842.40	146078.22	147979.06	324899.68	Total	30842.4	129538.09	141960.818	302341.31
EC at Taif (40% WWR)					EC Taif (50% WWR)				
Month	Room Electricity	Lighting	Cooling (Electricity)	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
Jan	2635.20	11195.59	5724.71	19555.50	Jan	2635.20	10129.17	5389.87	18154.24
Feb	2419.20	9944.92	6795.57	19159.69	Feb	2419.20	8886.00	6447.38	17752.57
Mar	2743.20	10447.42	8365.50	21556.12	Mar	2743.20	9281.23	8034.50	20058.93
Apr	2484.00	7316.25	10867.82	20668.07	Apr	2484.00	6453.80	10666.76	19604.56
May	2743.20	7453.46	13395.95	23592.61	May	2743.20	6511.54	13233.06	22487.80
Jun	2635.20	7132.93	15165.04	24933.17	Jun	2635.20	6268.84	15056.70	23960.74
Jul	2592.00	6947.74	14159.95	23699.69	Jul	2592.00	6070.70	14026.33	22689.03
Aug	2743.20	7907.10	15721.59	26371.89	Aug	2743.20	6981.49	15567.18	25291.87
Sep	2592.00	9225.98	14308.40	26126.38	Sep	2592.00	8260.84	14074.66	24927.50
Oct	2635.20	10119.74	12512.81	25267.75	Oct	2635.20	9077.38	12213.04	23925.62
Nov	2028.00	10749.67	9186.35	21964.02	Nov	2028.00	9659.76	8879.36	20567.12
Dec	2592	11081.77	7872.201	21545.97	Dec	2592.00	9999.55	7507.21	20098.76
Total	30842.4	109522.57	134075.9	274440.9	Total	30842.4	97580.3	131096	259518.7

EC Taif 60% WWR					EC Taif 70% WWR				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.20	9476.83	5303.92	17415.94	Jan	2635.20	8988.84	5319.25	16943.29
Feb	2419.20	8259.71	6338.15	17017.06	Feb	2419.20	7898.62	6362.01	16679.83
Mar	2743.20	8467.63	7842.30	19053.13	Mar	2743.20	8020.03	7882.15	18645.37
Apr	2484.00	5983.47	10686.57	19154.04	Apr	2484.00	5745.55	10877.62	19107.17
May	2743.20	6014.89	13343.31	22101.40	May	2743.20	5729.57	13591.91	22064.68
Jun	2635.20	5798.73	15176.05	23609.98	Jun	2635.20	5537.08	15427.81	23600.09
Jul	2592.00	5572.26	14123.16	22287.42	Jul	2592.00	5313.94	14367.02	22272.96
Aug	2743.20	6432.39	15637.50	24813.09	Aug	2743.20	6124.36	15856.86	24724.42
Sep	2592.00	7730.21	14093.93	24416.14	Sep	2592.00	7361.41	14219.95	24173.36
Oct	2635.20	8427.91	12141.17	23204.28	Oct	2635.20	7980.07	12219.07	22834.34
Nov	2028.00	8947.41	8787.12	19762.53	Nov	2028.00	8486.55	8854.25	19368.80
Dec	2592.00	9482.15	7411.19	19485.33	Dec	2592.00	8720.54	7350.41	18662.95
SUM	30842.4	90593.581	130884.36	252320.34	SUM	30842.4	85906.554	132328.31	249077.26
EC Taif 80% WWR					TA'IF BASE CASE				
Month	Room Electricity	Lighting	Cooling (Electricity)	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.20	9342.34	5764.91	17742.44	Jan	2635.20	7359.91	8303.89	18299.00
Feb	2419.20	8129.72	6728.61	17277.52	Feb	2419.20	6149.46	9124.18	17692.84
Mar	2743.20	8355.15	8356.02	19454.37	Mar	2743.20	6665.99	10802.67	20211.86
Apr	2484.00	6030.17	11377.96	19892.13	Apr	2484.00	5257.76	14077.14	21818.90
May	2743.20	5920.38	14134.38	22797.96	May	2743.20	5572.82	17225.64	25541.66
Jun	2635.20	5760.64	15989.51	24385.35	Jun	2635.20	5285.63	19149.27	27070.10
Jul	2592.00	5477.03	14868.24	22937.27	Jul	2592.00	5091.71	18093.18	25776.89
Aug	2743.20	6346.89	16411.23	25501.32	Aug	2743.20	5904.43	19637.21	28284.84
Sep	2592.00	7649.34	14747.01	24988.35	Sep	2592.00	5955.05	17444.60	25991.65
Oct	2635.20	8318.53	12735.15	23688.88	Oct	2635.20	6476.39	15337.91	24449.50
Nov	2028.00	8811.01	9372.31	20211.32	Nov	2028.00	6902.27	12125.76	21056.03
Dec	2592.00	9116.45	7797.02	19505.46	Dec	2592.00	7077.52	10505.06	20174.58
SUM	30842.4	89257.644	138282.34	258382.4	SUM	30842.40	73698.95	171826.51	276367.86

W1: ELECTROCHROMIC, RIYADH

EC (20% WWR) RIYADH					EC (30% WWR) RIYADH				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.2	13545.19	4417.042	20597.432	Jan	2635.2	12696.5	4289.939	19621.639
Feb	2419.2	12029.19	5711.159	20159.549	Feb	2419.2	11176.91	5448.677	19044.787
Mar	2743.2	13362.79	8430.317	24536.307	Mar	2743.2	12207.7	8056.382	23007.282
Apr	2484	11143.01	12140.19	25767.2	Apr	2484	9757.233	11645.82	23887.053
May	2743.2	11984.82	17740.95	32468.97	May	2743.2	10274.18	17136.01	30153.39
Jun	2635.2	11823.71	19599.84	34058.75	Jun	2635.2	10271.86	19099.22	32006.28
Jul	2592	11311.06	19545.21	33448.27	Jul	2592	9695.369	19019.01	31306.379
Aug	2743.2	12325.16	21244.66	36313.02	Aug	2743.2	10787.24	20768.66	34299.1
Sep	2592	12592.64	18569.74	33754.38	Sep	2592	11529.88	18307.55	32429.43
Oct	2635.2	13473.32	14185.37	30293.89	Oct	2635.2	12559.69	13994.99	29189.88
Nov	2028	13602.13	9389.344	25019.474	Nov	2028	12735.08	9226.351	23989.431
Dec	2592	13405.67	5682.027	21679.697	Dec	2592	12589.3	5421.452	20602.752
	30842.4	150598.69	156655.85	338096.94		30842.4	136280.94	152414.061	319537.4
EC 40% WWR RIYADH					EC (50% WWR) RIYADH				
Month	Room Electricity	Lighting	Cooling (Electricity)	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
Jan	2635.2	11590.33	3969.174	18194.7	Jan	2635.2	10390.54	3634.049	16659.79
Feb	2419.2	10032.29	5128.008	17579.5	Feb	2419.2	8910.418	4753.674	16083.29
Mar	2743.2	10484.7	7433.029	20660.93	Mar	2743.2	9225.277	7038.017	19006.49
Apr	2484	7900.543	10837.9	21222.44	Apr	2484	6872.475	10529.63	19886.11
May	2743.2	7752.81	16028.98	26524.99	May	2743.2	6545.56	15723.11	25011.87
Jun	2635.2	7615.451	17911.89	28162.54	Jun	2635.2	6370.395	17583.65	26589.25
Jul	2592	7220.61	17948.08	27760.69	Jul	2592	6156.654	17737.88	26486.53
Aug	2743.2	8256.019	19666.05	30665.27	Aug	2743.2	6989.901	19343.09	29076.19
Sep	2592	9627.871	17519.33	29739.2	Sep	2592	8598.995	17267.46	28458.46
Oct	2635.2	11136.24	13515.53	27286.97	Oct	2635.2	9938.529	13171.2	25744.93
Nov	2028	11379.71	8792.399	22200.11	Nov	2028	10322.91	8522.359	20873.27
Dec	2592	11382.93	4925.56	18900.49	Dec	2592	10149.46	4503.796	17245.26
	30842.4	114379.5	143675.93	288897.8	sum	30842.4	100471.11	139807.9	271121.4

EC 60% WWR RIYADH					70% WWR RIYADH				
Month	Room Electricity	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
Jan	2635.2	9656.714	3545.108	15837.022	Jan	2635.2	9058.238	3493.885	15187.323
Feb	2419.2	8238.128	4670.645	15327.973	Feb	2419.2	7779.49	4702.026	14900.716
Mar	2743.2	8498.905	6924.952	18167.057	Mar	2743.2	7978.011	6929.376	17650.587
Apr	2484	6272.049	10497.76	19253.809	Apr	2484	5899.989	10596.58	18980.569
May	2743.2	5985.6	15813.78	24542.58	May	2743.2	5646.921	16029.35	24419.471
Jun	2635.2	5768.083	17637.63	26040.913	Jun	2635.2	5445.022	17855.07	25935.292
Jul	2592	5604.073	17833.6	26029.673	Jul	2592	5300.333	18070.4	25962.733
Aug	2743.2	6360.384	19398.22	28501.804	Aug	2743.2	6068.238	19623.39	28434.828
Sep	2592	7897.615	17206.03	27695.645	Sep	2592	7457.44	17292.85	27342.29
Oct	2635.2	9121.335	13028.13	24784.665	Oct	2635.2	8536.104	13013.27	24184.574
Nov	2028	9514.894	8386.841	19929.735	Nov	2028	8982.002	8379.062	19389.064
Dec	2592	9301.192	4292.316	16185.508	Dec	2592	8636.758	4161.157	15389.915
	30842.4	92218.972	139235.01	262296.38		30842.4	86788.546	140146.416	257777.36

EC 80% WWR RIYADH					RIYADH BASE CASE				
Month	Room Electricity	Lighting	Cooling Electricity	Total	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
Jan	2635.2	9554.907	3956.758	16146.87	Jan	2635.20	7400.03	6980.26	17015.49
Feb	2419.2	8148.879	5113.795	15681.87	Feb	2419.20	6431.58	7684.52	16535.30
Mar	2743.2	8353.823	7391.287	18488.31	Mar	2743.20	6720.20	11507.29	20970.69
Apr	2484	6192.622	11102.62	19779.24	Apr	2484.00	5436.02	15149.01	23069.03
May	2743.2	5865.481	16583.39	25192.07	May	2743.20	5729.88	20583.49	29056.57
Jun	2635.2	5622.92	18381.04	26639.16	Jun	2635.20	5364.12	21329.69	29329.01
Jul	2592	5472.678	18592.96	26657.64	Jul	2592.00	5254.60	22112.80	29959.40
Aug	2743.2	6388.68	20221.98	29353.86	Aug	2743.20	5922.33	23334.60	32000.13
Sep	2592	7749.515	17824.53	28166.05	Sep	2592.00	6158.49	20728.87	29479.36
Oct	2635.2	8903.137	13547.32	25085.66	Oct	2635.20	6801.88	16964.71	26401.79
Nov	2028	9350.46	8859.389	20237.85	Nov	2028.00	7613.85	11257.89	20899.74
Dec	2592	9235.817	4668.606	16496.42	Dec	2592.00	7499.10	7947.56	18038.66
	30842.4	90838.92	146243.68	267925	SUM	30842.40	76332.08	185580.68	292755.16

W2: GASOCHROMIC, JEDDAH

GC (20% WWR) JEDDAH					GC (30% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	
JAN	2635.2	12267.63	13846.68	28749.51	JAN	2635.2	10722.57	13538.31	26896.08
FEB	2419.2	11040.81	13342.21	26802.22	FEB	2419.2	9534.218	13015.54	24968.96
MAR	2743.2	12026.57	17226.88	31996.65	MAR	2743.2	10095.45	16733.43	29572.08
APR	2484	10505.77	20462.56	33452.33	APR	2484	8728.389	19963	31175.39
MAY	2743.2	10472.17	24971.28	38186.65	MAY	2743.2	8362.716	24418.75	35524.67
JUN	2635.2	10039.27	26252.18	38926.65	JUN	2635.2	7876.776	25696.6	36208.58
JUL	2592	9638.929	28317.03	40547.959	JUL	2592	7593.69	27804.4	37990.09
AUG	2743.2	10363	30605.79	43711.99	AUG	2743.2	8387.468	30165.8	41296.47
SEP	2592	10944.4	29260.39	42796.79	SEP	2592	9096.77	28832.25	40521.02
OCT	2635.2	11706.03	21634.95	35976.18	OCT	2635.2	10061.84	21246.59	33943.63
NOV	2028	11869.7	17811.79	31709.49	NOV	2028	10253.25	17521.89	29803.14
DEC	2592	12050.34	16145.81	30788.15	DEC	2592	10453.74	15831.94	28877.68
	30842.4	132924.6	259877.55	423644.569		30842.4	111166.9	254768.5	396777.8

GC (40% WWR) JEDDAH					GC (50% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	Total	MONTH	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	8541.12	12834.58	24010.9	JAN	2635.2	7410.65	12734.11	22780
FEB	2419.2	7589.96	12413.9	22423.1	FEB	2419.2	6326.26	12187.41	20932.9
MAR	2743.2	8064.04	16150.69	26957.9	MAR	2743.2	6756.16	15960.38	25459.7
APR	2484	6646.22	19233.77	28364	APR	2484	5645.91	19157.52	27287.4
MAY	2743.2	6466.81	23919.83	33129.8	MAY	2743.2	5519.67	23976.12	32239
JUN	2635.2	6110.05	25258.73	34004	JUN	2635.2	5247.84	25275.38	33158.4
JUL	2592	5948.62	27237.31	35777.9	JUL	2592	5129.39	26991.98	34713.4
AUG	2743.2	6700.64	29607.35	39051.2	AUG	2743.2	5839.91	29334.71	37917.8
SEP	2592	7355.1	28244.88	38192	SEP	2592	6217.38	27759.47	36568.8
OCT	2635.2	7958.19	20653.18	31246.6	OCT	2635.2	6670.3	20125.14	29430.6
NOV	2028	8247.61	16939.15	27214.8	NOV	2028	6980.74	16712.1	25720.8
DEC	2592	8459.05	15229.12	26280.2	DEC	2592	7153.11	14991.48	24736.6
	30842.4	88087.4	247722.49	366652		30842.4	74897.3	245205.8	350946

GC (60% WWR) JEDDAH					GC (70% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6849.675	12793.58	22278.455	JAN	2635.2	6449.201	13277.56	22361.96
FEB	2419.2	5765.962	12214.31	20399.472	FEB	2419.2	5682.89	12640.42	20742.51
MAR	2743.2	5927.078	15894.5	24564.778	MAR	2743.2	5971.919	16305.63	25020.75
APR	2484	5067.197	19178.64	26729.837	APR	2484	4565.819	19529.34	26579.16
MAY	2743.2	5017.899	24185.2	31946.299	MAY	2743.2	4586.25	24732.21	32061.66
JUN	2635.2	4746.198	25437.88	32819.278	JUN	2635.2	4683.941	25958	33277.14
JUL	2592	4631.683	27077.25	34300.933	JUL	2592	4409.84	27580.85	34582.69
AUG	2743.2	5253.828	29356.03	37353.058	AUG	2743.2	4756.133	29848.93	37348.26
SEP	2592	5510.609	27667.6	35770.209	SEP	2592	5291.451	28053.44	35936.89
OCT	2635.2	5976.579	20088.2	28699.979	OCT	2635.2	5496.225	20420.84	28552.27
NOV	2028	6386.044	16723.46	25137.504	NOV	2028	6899.7	17069.09	25996.79
DEC	2592	6603.89	15041.14	24237.03	DEC	2592	6518.865	15412.88	24523.75
	30842.4	67736.642	245657.79	344236.83		30842.4	65312.23	250829.19	346983.8

GC (80% WWR) JEDDAH					JEDDAH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6624.21	13900.93	23160.34	Jan	2635.20	7595.64	16276.65	26507.49
FEB	2419.2	5544.977	13243.24	21207.42	Feb	2419.20	6462.34	15342.09	24223.63
MAR	2743.2	5619.877	17039.08	25402.16	Mar	2743.20	6665.28	18857.68	28266.16
APR	2484	4847.632	20240.77	27572.4	Apr	2484.00	5777.24	21771.66	30032.90
MAY	2743.2	4786.66	25554.74	33084.6	May	2743.20	5730.05	26976.97	35450.22
JUN	2635.2	4498.111	26792.16	33925.47	Jun	2635.20	5355.74	28185.87	36176.81
JUL	2592	4421.844	28477.03	35490.87	Jul	2592.00	5222.12	30450.98	38265.10
AUG	2743.2	5019.513	30805.04	38567.75	Aug	2743.20	5925.37	32925.66	41594.23
SEP	2592	5238.786	28930.22	36761.01	Sep	2592.00	6053.01	31220.66	39865.67
OCT	2635.2	5721.745	21159.81	29516.76	Oct	2635.20	6750.87	23598.32	32984.39
NOV	2028	6122.562	17763.65	25914.21	Nov	2028.00	7275.32	20037.99	29341.31
DEC	2592	6339.466	16086.82	25018.29	Dec	2592.00	7433.93	18466.53	28492.46
	30842.4	64785.38	259993.49	355621.3	SUM	30842.40	76246.91	284111.06	391200.37

W2: GASOCHROMIC, TA'IF

GC (20% WWR) TA'IF					GC (30% WWR) TA'IF				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONT H	Room Electricit y	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	11956.32	6085.768	20677.288	JAN	2635.2	10269	5620.353	18524.55
FEB	2419.2	10772.66	7185.46	20377.32	FEB	2419.2	9149.437	6758.059	18326.7
MAR	2743.2	12209.35	9396.154	24348.704	MAR	2743.2	10475.26	8952.994	22171.45
APR	2484	9512.94	12135.47	24132.41	APR	2484	7783.505	11661.84	21929.35
MAY	2743.2	9760.71	14689.65	27193.56	MAY	2743.2	7892.982	14276.94	24913.12
JUN	2635.2	9729.511	16686.76	29051.471	JUN	2635.2	7870.476	16338.56	26844.24
JUL	2592	9426.229	15617.64	27635.869	JUL	2592	7566.464	15250.61	25409.07
AUG	2743.2	10230.9	17155.7	30129.8	AUG	2743.2	8368.01	16815.12	27926.33
SEP	2592	11027.01	15465.67	29084.68	SEP	2592	9163.708	15044.03	26799.74
OCT	2635.2	11247.8	13171.47	27054.47	OCT	2635.2	9518.298	12742.86	24896.36
NOV	2028	11420.92	9553.353	23002.273	NOV	2028	9603.001	9157.813	20788.81
DEC	2592	11703.15	8279.332	22574.482	DEC	2592	9901.117	7806.938	20300.06
	30842.4	128997.5	145422.42	305262.33		30842.4	107561.258	140426.12	278829.8

GC (40% WWR) TA'IF					GC (50% WWR) TA'IF				
MONT H	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	8253.61	5009.862	15898.7	JAN	2635.2	7257.58	4942.868	14835.6
FEB	2419.2	7221.37	6142.817	15783.4	FEB	2419.2	6064.97	5971.656	14455.8
MAR	2743.2	8317.7	8271.836	19332.7	MAR	2743.2	6722.14	7884.485	17349.8
APR	2484	6311.97	11304	20100	APR	2484	5375.45	11274.86	19134.3
MAY	2743.2	6349.85	14053.52	23146.6	MAY	2743.2	5455.9	14198.69	22397.8
JUN	2635.2	6232.81	16019.22	24887.2	JUN	2635.2	5290.64	16073.43	23999.3
JUL	2592	5960.88	14948.98	23501.9	JUL	2592	5071.68	15029.86	22693.5
AUG	2743.2	6700.11	16509.83	25953.1	AUG	2743.2	5874.32	16615	25232.5
SEP	2592	7270.43	14577.26	24439.7	SEP	2592	6145.55	14506.21	23243.8
OCT	2635.2	7600.82	12217.9	22453.9	OCT	2635.2	6419.9	12042.91	21098
NOV	2028	7742.77	8744.646	18515.4	NOV	2028	6721.61	8761.229	17510.8
DEC	2592	8038.74	7311.947	17942.7	DEC	2592	6883.18	7225.245	16700.4
	30842.4	86001.1	135111.818	251955		30842.4	73282.9	134526.44	238652

GC (60% WWR) TA'IF					GC (70% WWR) TA'IF				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6659.301	5103.365	14397.866	JAN	2635.2	6327.169	5362.744	14325.11
FEB	2419.2	5489.936	6080.769	13989.905	FEB	2419.2	5201.27	6332.787	13953.26
MAR	2743.2	5738.275	7841.224	16322.699	MAR	2743.2	5235.913	8031.135	16010.25
APR	2484	4699.125	11384.68	18567.805	APR	2484	4275.82	11655.75	18415.57
MAY	2743.2	4887.146	14530.03	22160.376	MAY	2743.2	4518.874	14969.23	22231.3
JUN	2635.2	4742.727	16374.09	23752.017	JUN	2635.2	4330.497	16783.13	23748.83
JUL	2592	4549.835	15326.01	22467.845	JUL	2592	4176.089	15737.22	22505.31
AUG	2743.2	5272.177	16856.85	24872.227	AUG	2743.2	4812.466	17223.53	24779.2
SEP	2592	5424.376	14643.97	22660.346	SEP	2592	4997.844	14959.95	22549.79
OCT	2635.2	5768.606	12152.43	20556.236	OCT	2635.2	5393.054	12444.36	20472.61
NOV	2028	6080.97	8923.533	17032.503	NOV	2028	5744.323	9231.094	17003.42
DEC	2592	6282.849	7367.748	16242.597	DEC	2592	5909.235	7608.174	16109.41
	30842.4	65595.323	136584.69	233022.4		30842.4	60922.554	140339.10	232104.1

GC (80% WWR) TA'IF					TA'IF BASE CASE				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6497.024	5921.507	15053.73	Jan	2635.20	7359.91	8303.89	18299.00
FEB	2419.2	5341.795	6821.62	14582.62	Feb	2419.20	6149.46	9124.18	17692.84
MAR	2743.2	5465.39	8623.801	16832.39	Mar	2743.20	6665.99	10802.67	20211.86
APR	2484	4542.189	12356.94	19383.13	Apr	2484.00	5257.76	14077.14	21818.90
MAY	2743.2	4718.08	15760.63	23221.91	May	2743.20	5572.82	17225.64	25541.66
JUN	2635.2	4557.243	17578.69	24771.13	Jun	2635.20	5285.63	19149.27	27070.10
JUL	2592	4357.888	16482.19	23432.08	Jul	2592.00	5091.71	18093.18	25776.89
AUG	2743.2	5083.692	18033.57	25860.46	Aug	2743.20	5904.43	19637.21	28284.84
SEP	2592	5224.044	15695.55	23511.59	Sep	2592.00	5955.05	17444.60	25991.65
OCT	2635.2	5591.382	13125.98	21352.56	Oct	2635.20	6476.39	15337.91	24449.50
NOV	2028	5942.885	9903.18	17874.07	Nov	2028.00	6902.27	12125.76	21056.03
DEC	2592	6117.707	8165.517	16875.22	Dec	2592.00	7077.52	10505.06	20174.58
	30842.4	63439.32	148469.175	242750.9	SUM	30842.40	73698.95	171826.51	276367.86

W2: GASOCHROMIC, RIYADH

GC (20% WWR)					GC (30% WWR)				
MONT H	Room Electricit y	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	12226.65	5024.607	19886.457	JAN	2635.2	10565.96	4608.476	17809.64
FEB	2419.2	10925.09	5712.976	19057.266	FEB	2419.2	9421.914	5336.569	17177.68
MAR	2743.2	12278.91	9788.329	24810.439	MAR	2743.2	10460.54	9349.096	22552.84
APR	2484	10542.04	13766.64	26792.68	APR	2484	8617.394	13203	24304.39
MAY	2743.2	10877.19	18663.17	32283.56	MAY	2743.2	8444.427	18026.53	29214.16
JUN	2635.2	10460.09	19430.27	32525.56	JUN	2635.2	7876.658	18747.15	29259.01
JUL	2592	10166.15	20157.08	32915.23	JUL	2592	7716.105	19564.24	29872.35
AUG	2743.2	11141.8	21329.93	35214.93	AUG	2743.2	8883.651	20870.76	32497.61
SEP	2592	11509.91	18772.79	32874.7	SEP	2592	9779.011	18531.99	30903
OCT	2635.2	11965.83	14551.21	29152.24	OCT	2635.2	10339.2	14353.31	27327.71
NOV	2028	12257.5	8906.258	23191.758	NOV	2028	10761.63	8653.025	21442.66
DEC	2592	12139.51	5796.807	20528.317	DEC	2592	10566.78	5413.464	18572.24
	30842.4	136490.67	161900.07	329233.14		30842.4	113433.27	156657.61	300933.3
GC (40% WWR)					GC (50% WWR)				
MONT H	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONT H	Room Electricit y	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	8476.7	3997.476	15109.4	JAN	2635.2	7084.74	3785.554	13505.5
FEB	2419.2	7458.52	4781.04	14658.8	FEB	2419.2	6254.46	4606.379	13280
MAR	2743.2	8155.22	8632.87	19531.3	MAR	2743.2	6686.4	8386.175	17815.8
APR	2484	6735.35	12652.17	21871.5	APR	2484	5566.53	12497.73	20548.3
MAY	2743.2	6470.69	17622.41	26836.3	MAY	2743.2	5558.59	17822.35	26124.1
JUN	2635.2	6076.25	18456.18	27167.6	JUN	2635.2	5231.97	18714.52	26581.7
JUL	2592	5960.49	19287.39	27839.9	JUL	2592	5168.56	19547.36	27307.9
AUG	2743.2	6988.24	20487.52	30219	AUG	2743.2	5927.93	20579.86	29251
SEP	2592	7637.35	17968.13	28197.5	SEP	2592	6184.39	17787.7	26564.1
OCT	2635.2	8138.28	13793.9	24567.4	OCT	2635.2	6678.65	13598.91	22912.8
NOV	2028	8645.89	8063.581	18737.5	NOV	2028	7290.44	7882.089	17200.5
DEC	2592	8341.12	4758.437	15691.6	DEC	2592	7205.49	4699.804	14497.3
	30842.4	89084.1	150501.104	270428		30842.4	74838.1	149908.43	255589

GC (60% WWR)					GC (70% WWR)				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6427.41	3903.401	12966.011	JAN	2635.2	6019.648	4106.511	12761.36
FEB	2419.2	5578.774	4683.303	12681.277	FEB	2419.2	5193.832	4886.796	12499.83
MAR	2743.2	5837.433	8456.798	17037.431	MAR	2743.2	5329.052	8695.46	16767.71
APR	2484	4837.7	12594.61	19916.31	APR	2484	4354.081	12830.09	19668.17
MAY	2743.2	4951.263	18170.79	25865.253	MAY	2743.2	4539.244	18616.74	25899.18
JUN	2635.2	4618.362	19055.35	26308.912	JUN	2635.2	4218.796	19516.38	26370.38
JUL	2592	4535.182	19843.18	26970.362	JUL	2592	4146.589	20300.69	27039.28
AUG	2743.2	5246.497	20857.76	28847.457	AUG	2743.2	4718.855	21231.05	28693.11
SEP	2592	5349.333	17901.67	25843.003	SEP	2592	4840.551	18212.36	25644.91
OCT	2635.2	5833.109	13679.89	22148.199	OCT	2635.2	5389.06	14017.89	22042.15
NOV	2028	6548.733	7987.439	16564.172	NOV	2028	6141.449	8271.523	16440.97
DEC	2592	6522.86	4769.34	13884.2	DEC	2592	6146.436	4987.457	13725.89
	30842.4	66286.656	151903.53	249032.59		30842.4	61037.593	155672.947	247552.9

GC (80% WWR)					RIYADH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6242.664	4604.385	13482.25	Jan	2635.20	7400.03	6980.26	17015.49
FEB	2419.2	5370.977	5361.688	13151.87	Feb	2419.20	6431.58	7684.52	16535.30
MAR	2743.2	5561.867	9338.872	17643.94	Mar	2743.20	6720.20	11507.29	20970.69
APR	2484	4593.451	13513.01	20590.46	Apr	2484.00	5436.02	15149.01	23069.03
MAY	2743.2	4732.568	19403.94	26879.71	May	2743.20	5729.88	20583.49	29056.57
JUN	2635.2	4399	20302.64	27336.84	Jun	2635.20	5364.12	21329.69	29329.01
JUL	2592	4321.405	21080.96	27994.37	Jul	2592.00	5254.60	22112.80	29959.40
AUG	2743.2	4949.867	22049.12	29742.19	Aug	2743.20	5922.33	23334.60	32000.13
SEP	2592	5098.806	18984.56	26675.37	Sep	2592.00	6158.49	20728.87	29479.36
OCT	2635.2	5583.202	14720.04	22938.44	Oct	2635.20	6801.88	16964.71	26401.79
NOV	2028	6363.852	8875.909	17267.76	Nov	2028.00	7613.85	11257.89	20899.74
DEC	2592	6342.377	5497.054	14431.43	Dec	2592.00	7499.10	7947.56	18038.66
	30842.4	63560.04	163732.18	258134.6	SUM	30842.40	76332.08	185580.68	292755.16

W3: PHOTOCHROMIC, JEDDAH

PC (20% WWR)					PC (30% WWR)				
MONT H	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	Total
JAN	2635.2	11060.52	12925.72	26621.44	JAN	2635.2	9288.539	12427.73	24351.47
FEB	2419.2	9823.03	12468.28	24710.51	FEB	2419.2	8090.395	11955.34	22464.94
MAR	2743.2	10299.94	15978.85	29021.99	MAR	2743.2	8461.643	15486.79	26691.63
APR	2484	9140.407	19392.03	31016.437	APR	2484	7083.817	18616.5	28184.32
MAY	2743.2	8950.519	23720.42	35414.139	MAY	2743.2	6993.023	23154.77	32890.99
JUN	2635.2	8479.396	24985.1	36099.696	JUN	2635.2	6634.853	24524.87	33794.92
JUL	2592	8178.59	27114.23	37884.82	JUL	2592	6451.46	26639.54	35683
AUG	2743.2	8849.954	29369.59	40962.744	AUG	2743.2	7157.836	28966.47	38867.51
SEP	2592	9162.635	27941.37	39696.005	SEP	2592	7503.81	27548.84	37644.65
OCT	2635.2	10288.55	20625.1	33548.85	OCT	2635.2	8450.158	20200.42	31285.78
NOV	2028	10646	16881.77	29555.77	NOV	2028	8727.464	16321.9	27077.36
DEC	2592	10803.62	15220.82	28616.44	DEC	2592	8930.156	14685.85	26208.01
	30842.4	115683.16	246623.28	393148.84		30842.4	93773.15	240529.02	365144.6

PC (40% WWR)					PC (50% WWR)				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	7489.887	11869.11	21994.2	JAN	2635.2	6705.293	11907.23	21247.7
FEB	2419.2	6488.237	11478.68	20386.1	FEB	2419.2	5647.572	11423.08	19489.9
MAR	2743.2	6831.565	15044.13	24618.9	MAR	2743.2	5796.707	14930.72	23470.6
APR	2484	5663.012	18200.39	26347.4	APR	2484	4839.723	18166.91	25490.6
MAY	2743.2	5684.884	22831.64	31259.7	MAY	2743.2	4903.612	22878.13	30524.9
JUN	2635.2	5352.308	24100.51	32088	JUN	2635.2	4612.99	24117.4	31365.6
JUL	2592	5274.014	25882.28	33748.3	JUL	2592	4521.813	25664.61	32778.4
AUG	2743.2	5946.014	28145.86	36835.1	AUG	2743.2	5144.562	27858.14	35745.9
SEP	2592	6274.59	26706.69	35573.3	SEP	2592	5356.454	26326.03	34274.5
OCT	2635.2	6783.859	19248.1	28667.2	OCT	2635.2	5839.512	18949.37	27424.1
NOV	2028	7074.545	15834.51	24937.1	NOV	2028	6240.287	15766.5	24034.8
DEC	2592	7289.408	14211.17	24092.6	DEC	2592	6458.61	14169.22	23219.8
	30842.4	76152.3	233553.07	340548		30842.4	66067.1	232157.34	329067

PC (60% WWR)					PC (70% WWR)				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	6276.389	12176.94	21088.529	JAN	2635.2	6008.53	12500.87	21144.6
FEB	2419.2	5235.716	11627.71	19282.626	FEB	2419.2	4996.482	11940.18	19355.86
MAR	2743.2	5198.161	15109.79	23051.151	MAR	2743.2	4921.038	15461.53	23125.77
APR	2484	4315.751	18319.18	25118.931	APR	2484	3997.561	18584.52	25066.08
MAY	2743.2	4438.313	23205.69	30387.203	MAY	2743.2	4182.73	23636.65	30562.58
JUN	2635.2	4137.574	24472.56	31245.334	JUN	2635.2	3910.472	24971.79	31517.46
JUL	2592	4071.574	25998.3	32661.874	JUL	2592	3851.65	26555.29	32998.94
AUG	2743.2	4612.952	28187.25	35543.402	AUG	2743.2	4366.512	28773.27	35882.98
SEP	2592	4812.58	26573.77	33978.35	SEP	2592	4569.999	27118.49	34280.49
OCT	2635.2	5341.111	19143.98	27120.291	OCT	2635.2	5064.743	19592.25	27292.19
NOV	2028	5791.357	15981.94	23801.297	NOV	2028	5480.582	16289.2	23797.78
DEC	2592	5981.156	14364.58	22937.736	DEC	2592	5693.582	14681.39	22966.97
	30842.4	60212.63	235161.69	326216.724		30842.4	57043.88	240105.43	327991.7

PC (80% WWR)					JEDDAH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6152.625	13056.63	21844.46	Jan	2635.20	7595.64	16276.65	26507.49
FEB	2419.2	5103.969	12459.87	19983.04	Feb	2419.20	6462.34	15342.09	24223.63
MAR	2743.2	5059.763	16061.42	23864.38	Mar	2743.20	6665.28	18857.68	28266.16
APR	2484	4124.512	19137.94	25746.45	Apr	2484.00	5777.24	21771.66	30032.90
MAY	2743.2	4303.575	24294.33	31341.11	May	2743.20	5730.05	26976.97	35450.22
JUN	2635.2	4008.599	25627.14	32270.94	Jun	2635.20	5355.74	28185.87	36176.81
JUL	2592	3957.463	27248.61	33798.07	Jul	2592.00	5222.12	30450.98	38265.10
AUG	2743.2	4493.81	29521.5	36758.51	Aug	2743.20	5925.37	32925.66	41594.23
SEP	2592	4709.112	27813.81	35114.92	Sep	2592.00	6053.01	31220.66	39865.67
OCT	2635.2	5208.231	20202	28045.43	Oct	2635.20	6750.87	23598.32	32984.39
NOV	2028	5622.979	16858.51	24509.49	Nov	2028.00	7275.32	20037.99	29341.31
DEC	2592	5835.243	15247.75	23674.99	Dec	2592.00	7433.93	18466.53	28492.46
	30842.4	58579.88	247529.51	336951.8	SUM	30842.40	76246.91	284111.06	391200.37

W3: PHOTOCHROMIC, TAIF

PC (20% WWR)					PC (30% WWR)				
MONT H	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	Total
JAN	2635.2	10644.63	5223.01	18502.84	JAN	2635.2	9007.688	4729.734	16372.62
FEB	2419.2	9403.146	6356.292	18178.638	FEB	2419.2	7712.65	5794	15925.85
MAR	2743.2	10656.16	8367.972	21767.332	MAR	2743.2	8552.744	7642.042	18937.99
APR	2484	7972.721	10969.07	21425.791	APR	2484	6415.05	10529.72	19428.77
MAY	2743.2	8458.619	13631.82	24833.639	MAY	2743.2	6700.324	13179.49	22623.01
JUN	2635.2	8139.585	15490.79	26265.575	JUN	2635.2	6440.463	15127.56	24203.22
JUL	2592	8038.787	14539.46	25170.247	JUL	2592	6303.646	14131.79	23027.44
AUG	2743.2	8891.652	16090.12	27724.972	AUG	2743.2	7155.521	15699.56	25598.28
SEP	2592	9302.131	14225.58	26119.711	SEP	2592	7613.018	13834.57	24039.59
OCT	2635.2	9789.699	12077.42	24502.319	OCT	2635.2	8050.339	11573.89	22259.43
NOV	2028	10060.04	8647.45	20735.49	NOV	2028	8285.593	8216.112	18529.71
DEC	2592	10344.43	7495.179	20431.609	DEC	2592	8521.742	6914.995	18028.74
	30842.4	111701.6	133114.163	275658.163		30842.4	90758.778	127373.46	248974.6
PC (40% WWR)					PC (50% WWR)				
MONTH	Room Electricity	Lighting	Cooling (Electricity)		MONTH	Room Electricity	Lighting	Cooling Electricity	Total
JAN	2635.2	7353.089	4261.432	14249.7	JAN	2635.2	6593.771	4241.829	13470.8
FEB	2419.2	6172.705	5350.827	13942.7	FEB	2419.2	5439.64	5336.889	13195.7
MAR	2743.2	6758.45	7137.34	16639	MAR	2743.2	5629.893	6957.751	15330.8
APR	2484	5279.385	10323.16	18086.5	APR	2484	4559.275	10362.13	17405.4
MAY	2743.2	5518.942	13052.76	21314.9	MAY	2743.2	4823.412	13203.42	20770
JUN	2635.2	5248.043	14942.4	22825.6	JUN	2635.2	4595.453	15084.73	22315.4
JUL	2592	5086.476	13920.24	21598.7	JUL	2592	4441.346	14043.6	21076.9
AUG	2743.2	5906.958	15471.56	24121.7	AUG	2743.2	5146.024	15522.83	23412.1
SEP	2592	6229.194	13565.41	22386.6	SEP	2592	5341.016	13535.56	21468.6
OCT	2635.2	6539.047	11158.42	20332.7	OCT	2635.2	5693.201	11083.3	19411.7
NOV	2028	6791.125	7897.974	16717.1	NOV	2028	6036.918	7967.472	16032.4
DEC	2592	7030.613	6568.442	16191.1	DEC	2592	6226.352	6506.335	15324.7
	30842.4	73914	123649.965	228406		30842.4	64526.3	123845.85	219215

PC (60% WWR)					PC (70% WWR)				
MONT H	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONT H	Room Electricit y	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6185.105	4424.904	13245.209	JAN	2635.2	5933.729	4694.021	13262.95
FEB	2419.2	5060.169	5495.154	12974.523	FEB	2419.2	4851.816	5748.629	13019.65
MAR	2743.2	4984.865	7039.124	14767.189	MAR	2743.2	4679.331	7273.789	14696.32
APR	2484	4122.267	10568.46	17174.727	APR	2484	3922.277	10901.67	17307.95
MAY	2743.2	4388.904	13508.25	20640.354	MAY	2743.2	4174.951	13950.63	20868.78
JUN	2635.2	4184.913	15423.04	22243.153	JUN	2635.2	3950.029	15889.27	22474.5
JUL	2592	4029.298	14362.19	20983.488	JUL	2592	3826	14813.75	21231.75
AUG	2743.2	4663.637	15818	23224.837	AUG	2743.2	4425.012	16277.35	23445.56
SEP	2592	4853.94	13755.86	21201.8	SEP	2592	4613.635	14142	21347.64
OCT	2635.2	5259.349	11279.96	19174.509	OCT	2635.2	5022.805	11633.44	19291.45
NOV	2028	5612.693	8168.756	15809.449	NOV	2028	5356.833	8476.438	15861.27
DEC	2592	5786.899	6659.472	15038.371	DEC	2592	5525.35	6927.829	15045.18
	30842.4	59132.039	126503.17	216477.609		30842.4	56281.768	130728.816	217853

PC (80% WWR)					TAIF BASE CASE				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6056.966	5178.806	13870.97	Jan	2635.20	7359.91	8303.89	18299.00
FEB	2419.2	4946.715	6145.689	13511.6	Feb	2419.20	6149.46	9124.18	17692.84
MAR	2743.2	4826.363	7741.612	15311.18	Mar	2743.20	6665.99	10802.67	20211.86
APR	2484	4046.043	11433.44	17963.48	Apr	2484.00	5257.76	14077.14	21818.90
MAY	2743.2	4282.06	14573.54	21598.8	May	2743.20	5572.82	17225.64	25541.66
JUN	2635.2	4072.458	16546.1	23253.76	Jun	2635.20	5285.63	19149.27	27070.10
JUL	2592	3933.135	15427.74	21952.88	Jul	2592.00	5091.71	18093.18	25776.89
AUG	2743.2	4557.905	16933.47	24234.58	Aug	2743.20	5904.43	19637.21	28284.84
SEP	2592	4769.437	14752.31	22113.75	Sep	2592.00	5955.05	17444.60	25991.65
OCT	2635.2	5145.605	12177.28	19958.09	Oct	2635.20	6476.39	15337.91	24449.50
NOV	2028	5483.258	9002.168	16513.43	Nov	2028.00	6902.27	12125.76	21056.03
DEC	2592	5657.25	7435.595	15684.85	Dec	2592.00	7077.52	10505.06	20174.58
	30842.4	57777.2	137347.75	225967.3	SUM	30842.40	73698.95	171826.51	276367.86

W3: PHOTOCHROMIC, RIYADH

PC (20% WWR)					PC (30% WWR)				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electric	Lighting	Cooling (Electricity)	Total
JAN	2635.2	10944.99	3454.727	17034.917	JAN	2635.2	9139.771	2920.41	14695.38
FEB	2419.2	9614.674	4723.517	16757.391	FEB	2419.2	8016.872	4261.904	14697.98
MAR	2743.2	10779.91	7395.57	20918.68	MAR	2743.2	8956.18	6826.668	18526.05
APR	2484	8674.207	11057.24	22215.447	APR	2484	6845.375	10501.36	19830.74
MAY	2743.2	9109.205	16586.8	28439.205	MAY	2743.2	7043.135	16062.96	25849.3
JUN	2635.2	9168.142	18689.98	30493.322	JUN	2635.2	6882.456	18085.55	27603.21
JUL	2592	8540.81	18562.67	29695.48	JUL	2592	6578.939	18168.07	27339.01
AUG	2743.2	9499.854	20290.08	32533.134	AUG	2743.2	7380.789	19830.79	29954.78
SEP	2592	10058.04	17750.79	30400.83	SEP	2592	8029.791	17262.84	27884.63
OCT	2635.2	10831.48	13232.02	26698.7	OCT	2635.2	8930.556	12757.13	24322.89
NOV	2028	11014.83	8483.214	21526.044	NOV	2028	9058.002	7961.015	19047.02
DEC	2592	11216.11	4731.733	18539.843	DEC	2592	9582.7	4182.604	16357.3
	30842.4	119452.2	144958.341	295252.99		30842.4	96444.566	138821.3	266108.3
PC (40% WWR)					PC (50% WWR)				
MONTH	Room Electricity	Lighting	Cooling (Electricity)		MONTH	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	7367.673	2477.165	12480	JAN	2635.2	6468.332	2420.448	11524
FEB	2419.2	6418.151	3834.805	12672.2	FEB	2419.2	5588.004	3794.934	11802.1
MAR	2743.2	7090.472	6290.298	16124	MAR	2743.2	5964.953	6136.652	14844.8
APR	2484	5586.199	10255.55	18325.7	APR	2484	4737.876	10231.79	17453.7
MAY	2743.2	5696.948	15917.95	24358.1	MAY	2743.2	4823.186	16025.55	23591.9
JUN	2635.2	5419.456	17858.71	25913.4	JUN	2635.2	4568.129	17974.8	25178.1
JUL	2592	5358.264	18090.67	26040.9	JUL	2592	4505.885	18186.69	25284.6
AUG	2743.2	5986.677	19685.1	28415	AUG	2743.2	5002.656	19708.74	27454.6
SEP	2592	6403.954	16934.28	25930.2	SEP	2592	5242.185	16815.78	24650
OCT	2635.2	7014.708	12241.57	21891.5	OCT	2635.2	5797.436	12066.25	20498.9
NOV	2028	7416.741	7581.741	17026.5	NOV	2028	6506.371	7583.035	16117.4
DEC	2592	7795.365	3637.735	14025.1	DEC	2592	6880.276	3482.909	12955.2
	30842.4	77554.6	134805.574	243203		30842.4	66085.3	134427.58	231355

PC (60% WWR)					PC (70% WWR)				
MONTH	Room Electric	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	5895.912	2505.061	11036.173	JAN	2635.2	5637.853	2734.973	11008.03
FEB	2419.2	5114.362	3937.082	11470.644	FEB	2419.2	4859.215	4156.934	11435.35
MAR	2743.2	5395.705	6229.816	14368.721	MAR	2743.2	5048.573	6436.199	14227.97
APR	2484	4205.972	10385.81	17075.782	APR	2484	3896.853	10663.62	17044.47
MAY	2743.2	4338.966	16341.56	23423.726	MAY	2743.2	4075.056	16762.59	23580.85
JUN	2635.2	4133.33	18331.87	25100.4	JUN	2635.2	3848.396	18741.93	25225.53
JUL	2592	3997.432	18506.11	25095.542	JUL	2592	3769.43	18949.74	25311.17
AUG	2743.2	4470.963	20045.46	27259.623	AUG	2743.2	4158.986	20452.48	27354.67
SEP	2592	4670.661	17058.87	24321.531	SEP	2592	4296.485	17394.63	24283.12
OCT	2635.2	5256.514	12286.94	20178.654	OCT	2635.2	4892.06	12580.41	20107.67
NOV	2028	5967.519	7767.305	15762.824	NOV	2028	5655.043	8034.299	15717.34
DEC	2592	6243.842	3446.032	12281.874	DEC	2592	5905.532	3569.527	12067.06
	30842.4	59691.18	136841.92	227375.49		30842.4	56043.482	140477.332	227363.2
PC (80% WWR)					RIYADH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	5884.388	2516.97	11036.56	Jan	2635.20	7400.03	6980.26	17015.49
FEB	2419.2	4940.093	3541.157	10900.45	Feb	2419.20	6431.58	7684.52	16535.30
MAR	2743.2	5176.261	6207.88	14127.34	Mar	2743.20	6720.20	11507.29	20970.69
APR	2484	3821.144	12117.62	18422.76	Apr	2484.00	5436.02	15149.01	23069.03
MAY	2743.2	4074.233	16055.76	22873.19	May	2743.20	5729.88	20583.49	29056.57
JUN	2635.2	3802.144	18477.19	24914.53	Jun	2635.20	5364.12	21329.69	29329.01
JUL	2592	3715.583	20515.31	26822.89	Jul	2592.00	5254.60	22112.80	29959.40
AUG	2743.2	4136.256	21466.55	28346.01	Aug	2743.20	5922.33	23334.60	32000.13
SEP	2592	4293.535	18230.76	25116.3	Sep	2592.00	6158.49	20728.87	29479.36
OCT	2635.2	5123.538	12044.51	19803.25	Oct	2635.20	6801.88	16964.71	26401.79
NOV	2028	5794.47	6603.093	14425.56	Nov	2028.00	7613.85	11257.89	20899.74
DEC	2592	5963.413	3229.372	11784.79	Dec	2592.00	7499.10	7947.56	18038.66
	30842.4	56725.06	141006.172	228573.6	SUM	30842.40	76332.08	185580.68	292755.16

W4: Polymer Dispersed Liquid Crystal (PDLC), JEDDAH

PDLC 20%					PDLC 30%				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	10599.8	12678.98	25913.98	JAN	2635.2	8880.306	12207.95	23723.46
FEB	2419.2	9343.512	12170.81	23933.522	FEB	2419.2	7656.701	11677.56	21753.46
MAR	2743.2	10061.15	15798.98	28603.33	MAR	2743.2	8092.703	15196.19	26032.09
APR	2484	8992.925	19340.65	30817.575	APR	2484	6943.342	18620.51	28047.85
MAY	2743.2	8834.237	23794.88	35372.317	MAY	2743.2	6908.965	23314.12	32966.29
JUN	2635.2	8386.574	25059.6	36081.374	JUN	2635.2	6571.663	24664.09	33870.95
JUL	2592	8110.801	27376.19	38078.991	JUL	2592	6397.847	27003.52	35993.37
AUG	2743.2	8805.353	29625.17	41173.723	AUG	2743.2	7108.075	29307.51	39158.79
SEP	2592	9172.724	28228.68	39993.404	SEP	2592	7373.275	27790.83	37756.11
OCT	2635.2	9900.008	20803.17	33338.378	OCT	2635.2	8036.165	20339.69	31011.06
NOV	2028	10091.08	16532.38	28651.46	NOV	2028	8262.603	16033.48	26324.08
DEC	2592	10359.25	14939.59	27890.84	DEC	2592	8527.765	14402.17	25521.94
Sum	30842.4	112657.4	246349.08	389848.89	Sum	30842.4	90759.41	240557.62	362159.4

PDLC 40%					PDLC 50%				
MONT H	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	7363.586	11920.46	21919.246	JAN	2635.2	6619.73	12114.73	21369.66
FEB	2419.2	6276.437	11421.81	20117.447	FEB	2419.2	5530.78	11562.98	19512.96
MAR	2743.2	6457.2	14840.11	24040.51	MAR	2743.2	5598.473	14974.47	23316.143
APR	2484	5444.56	18260.65	26189.21	APR	2484	4688.836	18390.72	25563.556
MAY	2743.2	5545.441	23193.78	31482.421	MAY	2743.2	4746.695	23465.1	30954.995
JUN	2635.2	5209.558	24535.17	32379.928	JUN	2635.2	4479.74	24859.06	31974
JUL	2592	5139.837	26773.9	34505.737	JUL	2592	4402.669	27046.13	34040.799
AUG	2743.2	5806.5	29086.66	37636.36	AUG	2743.2	4996.142	29355.96	37095.302
SEP	2592	6010.48	27457.04	36059.52	SEP	2592	5154.919	27616	35362.919
OCT	2635.2	6484.641	19933.93	29053.771	OCT	2635.2	5704.921	20111.94	28452.061
NOV	2028	6901.124	15854.72	24783.844	NOV	2028	6171.432	16076.39	24275.822
DEC	2592	7152.67	14207.21	23951.88	DEC	2592	6366.652	14362.42	23321.072
Sum	30842.4	73792.034	237485.44	342119.87	Sum	30842.4	64460.989	239935.9	335239.289

PDLC 60%					PDLC 70%				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	6184.506	12482.19	21301.896	JAN	2635.2	5953.248	12956.36	21544.81
FEB	2419.2	5149.694	11889.19	19458.084	FEB	2419.2	4945.006	12344.34	19708.55
MAR	2743.2	5113.595	15343.62	23200.415	MAR	2743.2	4883.842	15844.7	23471.74
APR	2484	4203.451	18676.68	25364.131	APR	2484	3941.255	19081.85	25507.11
MAY	2743.2	4357.066	23976.96	31077.226	MAY	2743.2	4123.777	24569.52	31436.5
JUN	2635.2	4046.988	25355.02	32037.208	JUN	2635.2	3856.855	25980.82	32472.88
JUL	2592	3992.991	27609.56	34194.551	JUL	2592	3806.251	28326.33	34724.58
AUG	2743.2	4536.03	29903.51	37182.74	AUG	2743.2	4323.201	30603.04	37669.44
SEP	2592	4735.765	28105.14	35432.905	SEP	2592	4535.64	28765.12	35892.76
OCT	2635.2	5276.815	20515.24	28427.255	OCT	2635.2	5030.619	21111.87	28777.69
NOV	2028	5688.273	16442.73	24159.003	NOV	2028	5429.424	16911.19	24368.61
DEC	2592	5884.373	14688.07	23164.443	DEC	2592	5621.39	15155.82	23369.21
Sum	30842.4	59169.55	244987.91	334999.857	Sum	30842.4	56450.51	251650.96	338943.9
PDLC 80%					JEDDAH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	Total
JAN	2635.2	6073.24	13597.34	22305.78	Jan	2635.20	7595.64	16276.65	26507.49
FEB	2419.2	5046.768	12940.72	20406.688	Feb	2419.20	6462.34	15342.09	24223.63
MAR	2743.2	5010.277	16553.03	24306.507	Mar	2743.20	6665.28	18857.68	28266.16
APR	2484	4057.494	19708.12	26249.614	Apr	2484.00	5777.24	21771.66	30032.90
MAY	2743.2	4239.183	25370.24	32352.623	May	2743.20	5730.05	26976.97	35450.22
JUN	2635.2	3946.786	26758.71	33340.696	Jun	2635.20	5355.74	28185.87	36176.81
JUL	2592	3900.431	29172.49	35664.921	Jul	2592.00	5222.12	30450.98	38265.10
AUG	2743.2	4445.671	31461.6	38650.471	Aug	2743.20	5925.37	32925.66	41594.23
SEP	2592	4650.463	29582.82	36825.283	Sep	2592.00	6053.01	31220.66	39865.67
OCT	2635.2	5164.523	21862.19	29661.913	Oct	2635.20	6750.87	23598.32	32984.39
NOV	2028	5557.704	17616.82	25202.524	Nov	2028.00	7275.32	20037.99	29341.31
DEC	2592	5737.568	15829.42	24158.988	Dec	2592.00	7433.93	18466.53	28492.46
Sum	30842.4	57830.108	260453.5	349126.01	SUM	30842.40	76246.91	284111.06	391200.37

W4: Polymer Dispersed Liquid Crystal (PDLC), TA'IF

PDLC 20%					PDLC 30%				
MONTH	Room Electric	Lighting	Cooling Electricity	TOTAL	MONT H	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	10219.52	4993.736	17848.456	JAN	2635.2	8671.112	4581.98	15888.29
FEB	2419.2	8931.817	6090.45	17441.467	FEB	2419.2	7328.082	5618.068	15365.35
MAR	2743.2	10348.28	8153.764	21245.244	MAR	2743.2	8094.181	7332.982	18170.36
APR	2484	7937.713	10982.1	21403.813	APR	2484	6314.574	10491.28	19289.85
MAY	2743.2	8333.912	13629.57	24706.682	MAY	2743.2	6609.075	13246.35	22598.63
JUN	2635.2	8196.479	15576.21	26407.889	JUN	2635.2	6500.371	15282	24417.57
JUL	2592	7975.331	14584.96	25152.291	JUL	2592	6264.809	14261.32	23118.13
AUG	2743.2	8748.545	16064.97	27556.715	AUG	2743.2	7011.407	15745.71	25500.32
SEP	2592	9109.492	14096.99	25798.482	SEP	2592	7318.712	13650.8	23561.51
OCT	2635.2	9321.636	11835.96	23792.796	OCT	2635.2	7607.375	11389.84	21632.42
NOV	2028	9553.237	8366.526	19947.763	NOV	2028	7900.838	8008.583	17937.42
DEC	2592	9885.47	7249.016	19726.486	DEC	2592	8177.647	6745.229	17514.88
Sum	30842.4	108561.4	131624.25	271028.084	Sum	30842.4	87798.18	126354.14	244994.7
PDLC 40%					PDLC 50%				
MONTH	Room Electric	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electric	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	7205.842	4267.646	14108.688	JAN	2635.2	6481.371	4416.421	13532.992
FEB	2419.2	6004.939	5348.143	13772.282	FEB	2419.2	5316.559	5414.74	13150.499
MAR	2743.2	6326.655	6873.23	15943.085	MAR	2743.2	5389.242	6881.622	15014.064
APR	2484	5201.297	10335.04	18020.337	APR	2484	4425.349	10432.11	17341.459
MAY	2743.2	5429.458	13246.26	21418.918	MAY	2743.2	4675.007	13510.69	20928.897
JUN	2635.2	5209.908	15244.28	23089.388	JUN	2635.2	4437.14	15524.59	22596.93
JUL	2592	5011.088	14231.13	21834.218	JUL	2592	4285.241	14511	21388.241
AUG	2743.2	5776.706	15756.17	24276.076	AUG	2743.2	5011.245	16017.04	23771.485
SEP	2592	5941.57	13501.78	22035.35	SEP	2592	5149.444	13711.02	21452.464
OCT	2635.2	6293.98	11243.35	20172.53	OCT	2635.2	5568.016	11454.82	19658.036
NOV	2028	6635.696	7884.403	16548.099	NOV	2028	5935.174	8085.292	16048.466
DEC	2592	6887.466	6539.465	16018.931	DEC	2592	6125.73	6591.623	15309.353
Sum	30842.4	71924.61	124470.9	227237.9	Sum	30842.4	62799.52	126550.968	220192.89

PDLC 60%					PDLC 70%				
MONTH	Room Electric	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	6071.033	4675.342	13381.575	JAN	2635.2	5881.46	5067.282	13583.94
FEB	2419.2	4978.763	5692.734	13090.697	FEB	2419.2	4819.103	6080.87	13319.17
MAR	2743.2	4898.057	7112.702	14753.959	MAR	2743.2	4631.481	7490.197	14864.88
APR	2484	4070.663	10791.41	17346.073	APR	2484	3886.179	11235.72	17605.9
MAY	2743.2	4305.669	14002.3	21051.169	MAY	2743.2	4125.968	14588.9	21458.07
JUN	2635.2	4104.495	16061.58	22801.275	JUN	2635.2	3910.598	16674.47	23220.27
JUL	2592	3955.253	15019.52	21566.773	JUL	2592	3782.576	15608.33	21982.91
AUG	2743.2	4600.086	16484.13	23827.416	AUG	2743.2	4383.69	17065.64	24192.53
SEP	2592	4784.491	14163.5	21539.991	SEP	2592	4578.026	14703.18	21873.21
OCT	2635.2	5186.896	11862.7	19684.796	OCT	2635.2	4981.159	12378.87	19995.23
NOV	2028	5530.001	8437.086	15995.087	NOV	2028	5311.715	8904.349	16244.06
DEC	2592	5675.103	6838.941	15106.044	DEC	2592	5461.4	7243.29	15296.69
Sum	30842.4	58160.51	131141.945	220144.855	Sum	30842.4	55753.36	137041.1	223636.9

PDLC 80%					TA'IF BASE CASE				
MONTH	Room Electric	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling Electricity	Total
JAN	2635.2	5986.188	5625.22	14246.608	Jan	2635.20	7359.91	8303.89	18299.00
FEB	2419.2	4894.919	6571.273	13885.392	Feb	2419.20	6149.46	9124.18	17692.84
MAR	2743.2	4763.666	8072.427	15579.293	Mar	2743.20	6665.99	10802.67	20211.86
APR	2484	3993.631	11856.41	18334.041	Apr	2484.00	5257.76	14077.14	21818.90
MAY	2743.2	4223.787	15331.27	22298.257	May	2743.20	5572.82	17225.64	25541.66
JUN	2635.2	4013.482	17451.01	24099.692	Jun	2635.20	5285.63	19149.27	27070.10
JUL	2592	3872.002	16330.96	22794.962	Jul	2592.00	5091.71	18093.18	25776.89
AUG	2743.2	4510.752	17827.63	25081.582	Aug	2743.20	5904.43	19637.21	28284.84
SEP	2592	4713.964	15435.85	22741.814	Sep	2592.00	5955.05	17444.60	25991.65
OCT	2635.2	5093.293	13046.15	20774.643	Oct	2635.20	6476.39	15337.91	24449.50
NOV	2028	5425.807	9541.477	16995.284	Nov	2028.00	6902.27	12125.76	21056.03
DEC	2592	5572.351	7793.599	15957.95	Dec	2592.00	7077.52	10505.06	20174.58
Sum	30842.4	57063.84	144883.276	232789.52	SUM	30842.40	73698.95	171826.51	276367.86

W4: Polymer Dispersed Liquid Crystal (PDLC), RIYADH

PDLC 20%					PDLC 30%				
MONTH	Room Electric	Lighting	Cooling Electricity	TOTAL	Month	Room Electric	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	10438.62	3178.403	16252.223	JAN	2635.2	8681.432	2703.669	14020.3
FEB	2419.2	9289.98	4529.873	16239.053	FEB	2419.2	7632.062	4031.469	14082.73
MAR	2743.2	10548.2	7241.667	20533.067	MAR	2743.2	8577.847	6621.636	17942.68
APR	2484	8917.586	11183.38	22584.966	APR	2484	7009.471	10573.45	20066.92
MAY	2743.2	9057.584	16617.94	28418.724	MAY	2743.2	6897.232	16078.08	25718.51
JUN	2635.2	9084.751	18687.82	30407.771	JUN	2635.2	6667.114	18052.62	27354.93
JUL	2592	8512.713	18619.38	29724.093	JUL	2592	6391.916	18184.72	27168.64
AUG	2743.2	9501.005	20324.13	32568.335	AUG	2743.2	7266.291	19834.56	29844.05
SEP	2592	9751.696	17574.24	29917.936	SEP	2592	7629.265	17049.44	27270.71
OCT	2635.2	10338.81	12956.29	25930.3	OCT	2635.2	8300.754	12416.17	23352.12
NOV	2028	10419.71	8109.006	20556.716	NOV	2028	8670.457	7656.641	18355.1
DEC	2592	10827.62	4471.587	17891.207	DEC	2592	9276.314	3957.734	15826.05
Sum	30842.4	116688.28	143493.72	291024.391	Sum	30842.4	93000.16	137160.19	261002.7

PDLC 40%					PDLC 50%				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.2	7200.859	2429.862	12265.921	JAN	2635.2	6396.579	2488.363	11520.142
FEB	2419.2	6217.761	3727.305	12364.266	FEB	2419.2	5500.082	3802.319	11721.601
MAR	2743.2	6727.732	6122.333	15593.265	MAR	2743.2	5799.814	6130.821	14673.835
APR	2484	5488.454	10233.14	18205.594	APR	2484	4614.654	10291.2	17389.854
MAY	2743.2	5494.608	16026.91	24264.718	MAY	2743.2	4731.619	16345.49	23820.309
JUN	2635.2	5179.272	17988.44	25802.912	JUN	2635.2	4461.24	18379.66	25476.1
JUL	2592	5138.443	18277	26007.443	JUL	2592	4401.089	18669.28	25662.369
AUG	2743.2	5871.045	19848.79	28463.035	AUG	2743.2	4989.748	20164.23	27897.178
SEP	2592	5914.877	16796.37	25303.247	SEP	2592	4993.64	17011.56	24597.2
OCT	2635.2	6595.985	12133.13	21364.315	OCT	2635.2	5656.691	12291.61	20583.501
NOV	2028	7302.6	7478.549	16809.149	NOV	2028	6384.845	7558.189	15971.034
DEC	2592	7728.913	3505.374	13826.287	DEC	2592	6838.79	3402.168	12832.958
Sum	30842.4	74860.549	134567.203	240270.15	Sum	30842.4	64768.79	136534.89	232146.081

PDLC 60%					PDLC 70%				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONT H	Room Electric.	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	5847.596	2660.923	11143.719	JAN	2635.2	5600.992	2903.197	11139.39
FEB	2419.2	5065.912	4017.53	11502.642	FEB	2419.2	4837.617	4303.008	11559.83
MAR	2743.2	5320.037	6366.134	14429.371	MAR	2743.2	5013.73	6693.452	14450.38
APR	2484	4110.706	10557.18	17151.886	APR	2484	3823.896	10942	17249.9
MAY	2743.2	4284.901	16833.52	23861.621	MAY	2743.2	4028.19	17418.07	24189.46
JUN	2635.2	4069.691	18945.94	25650.831	JUN	2635.2	3770.226	19542.73	25948.16
JUL	2592	3950.247	19207.25	25749.497	JUL	2592	3717.478	19846.68	26156.16
AUG	2743.2	4439.602	20656.23	27839.032	AUG	2743.2	4087.858	21244.29	28075.35
SEP	2592	4555.23	17500.21	24647.44	SEP	2592	4246.128	18042.24	24880.37
OCT	2635.2	5188.427	12708.76	20532.387	OCT	2635.2	4845.557	13173.94	20654.7
NOV	2028	5902.814	7860.512	15791.326	NOV	2028	5604.664	8256.642	15889.31
DEC	2592	6214.453	3407.944	12214.397	DEC	2592	5885.961	3565.579	12043.54
Sum	30842.4	58949.616	140722.133	230514.15	Sum	30842.4	55462.3	145931.828	232236.5

PDLC 80%					RIYADH BASE CASE				
MONTH	Room Electric	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling Electricity	Total
JAN	2635.2	5719.881	3384.252	11739.333	Jan	2635.20	7400.03	6980.26	17015.49
FEB	2419.2	4950.813	4778.336	12148.349	Feb	2419.20	6431.58	7684.52	16535.30
MAR	2743.2	5177.54	7225.179	15145.919	Mar	2743.20	6720.20	11507.29	20970.69
APR	2484	3964.51	11565	18013.51	Apr	2484.00	5436.02	15149.01	23069.03
MAY	2743.2	4155.393	18199.47	25098.063	May	2743.20	5729.88	20583.49	29056.57
JUN	2635.2	3879.274	20354.56	26869.034	Jun	2635.20	5364.12	21329.69	29329.01
JUL	2592	3800.256	20646.9	27039.156	Jul	2592.00	5254.60	22112.80	29959.40
AUG	2743.2	4227.984	22098.46	29069.644	Aug	2743.20	5922.33	23334.60	32000.13
SEP	2592	4373.479	18827.98	25793.459	Sep	2592.00	6158.49	20728.87	29479.36
OCT	2635.2	5024.305	13915.81	21575.315	Oct	2635.20	6801.88	16964.71	26401.79
NOV	2028	5760.902	8881.409	16670.311	Nov	2028.00	7613.85	11257.89	20899.74
DEC	2592	6070.699	3996.403	12659.102	Dec	2592.00	7499.10	7947.56	18038.66
Sum	30842.4	57105.036	153873.759	241821.2	SUM	30842.40	76332.08	185580.68	292755.16

W5: Suspended Particle Devices (SPD), JEDDAH

SPD (20% WWR) JEDDAH					SPD (30% WWR) JEDDAH				
Month	Room Electric	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	12115.40	13470.30	28221.02	JAN	2635.20	11100.26	13145.26	26880.72
FEB	2419.20	10868.36	12969.11	26256.67	FEB	2419.20	9895.90	12659.00	24974.10
MAR	2743.20	11598.95	16645.89	30988.04	MAR	2743.20	10422.56	16242.23	29407.99
APR	2484.00	10214.97	20050.57	32749.54	APR	2484.00	9055.53	19625.98	31165.51
MAY	2743.20	10407.39	24737.87	37888.46	MAY	2743.20	8757.01	24112.77	35612.98
JUN	2635.20	9922.67	26021.31	38579.18	JUN	2635.20	8284.53	25429.51	36349.24
JUL	2592.00	9591.08	28287.88	40470.96	JUL	2592.00	7999.50	27780.93	38372.43
AUG	2743.20	10272.16	30554.21	43569.57	AUG	2743.20	8681.19	30013.43	41437.82
SEP	2592.00	10454.51	29029.97	42076.48	SEP	2592.00	9196.64	28666.01	40454.65
OCT	2635.20	11418.55	21647.30	35701.05	OCT	2635.20	10400.42	21463.09	34498.71
NOV	2028.00	11742.67	17464.81	31235.48	NOV	2028.00	10657.47	17140.90	29826.37
DEC	2592.00	11898.35	15799.07	30289.42	DEC	2592.00	10784.66	15432.04	28808.70
SUM	30842.40	130505.08	256678.37	418025.8	SUM	30842.40	115235.67	251711.15	397789.22

SPD (40% WWR) JEDDAH					SPD (50% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	9410.81	12441.82	24487.83	JAN	2635.20	8218.92	12013.26	22867.38
FEB	2419.20	8417.58	12053.15	22889.93	FEB	2419.20	7177.67	11548.50	21145.37
MAR	2743.20	8801.13	15584.25	27128.58	MAR	2743.20	7640.50	15178.81	25562.51
APR	2484.00	7081.75	18672.70	28238.45	APR	2484.00	6100.09	18346.73	26930.82
MAY	2743.20	6866.85	23315.23	32925.28	MAY	2743.20	5950.64	23125.64	31819.48
JUN	2635.20	6428.01	24684.63	33747.84	JUN	2635.20	5585.42	24560.31	32780.93
JUL	2592.00	6245.03	27201.94	36038.97	JUL	2592.00	5489.78	27069.69	35151.47
AUG	2743.20	7034.80	29510.19	39288.19	AUG	2743.20	6266.08	29400.39	38409.67
SEP	2592.00	7770.88	28269.99	38632.87	SEP	2592.00	6857.56	28017.11	37466.67
OCT	2635.20	8751.12	21033.35	32419.67	OCT	2635.20	7632.13	20669.59	30936.92
NOV	2028.00	9202.13	16578.72	27808.85	NOV	2028.00	7948.62	16127.31	26103.93
DEC	2592.00	9347.13	14884.37	26823.50	DEC	2592.00	7993.18	14352.09	24937.27
SUM	30842.40	95357.22	244230.34	370429	SUM	30842.40	82860.57	240409.43	354112.40

SPD (60% WWR) JEDDAH					SPD (70% WWR) JEDDAH				
Month	Room Electric	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	7444.55	11863.35	21943.10	JAN	2635.20	6971.63	11853.43	21460.26
FEB	2419.20	6475.61	11413.95	20308.76	FEB	2419.20	6023.34	11382.44	19824.98
MAR	2743.20	6815.07	15012.18	24570.45	MAR	2743.20	6321.85	15002.22	24067.27
APR	2484.00	5538.86	18301.48	26324.34	APR	2484.00	5156.29	18357.89	25998.18
MAY	2743.20	5457.85	23224.67	31425.72	MAY	2743.20	5124.00	23393.13	31260.33
JUN	2635.20	5125.87	24705.80	32466.87	JUN	2635.20	4818.46	24902.53	32356.19
JUL	2592.00	4988.47	27219.70	34800.17	JUL	2592.00	4711.30	27358.88	34662.18
AUG	2743.20	5714.00	29533.64	37990.84	AUG	2743.20	5328.41	29604.65	37676.26
SEP	2592.00	6259.00	28055.04	36906.04	SEP	2592.00	5821.40	28073.58	36486.98
OCT	2635.20	6820.51	20603.47	30059.18	OCT	2635.20	6279.34	20527.07	29441.61
NOV	2028.00	7079.20	15915.24	25022.44	NOV	2028.00	6476.20	15851.27	24355.47
DEC	2592.00	7163.17	14165.89	23921.06	DEC	2592.00	6647.80	14133.47	23373.27
SUM	30842.40	74882.16	240014.41	345738.97	SUM	30842.40	69680.02	240440.56	340962.98

SPD (80% WWR) JEDDAH					JEDDAH BASE CASE				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	7210.789	12272.88	22118.869	JAN	2635.20	7595.64	16276.65	26507.49
FEB	2419.2	6274.159	11801.29	20494.649	FEB	2419.20	6462.34	15342.09	24223.63
MAR	2743.2	6620.724	15497.2	24861.124	MAR	2743.20	6665.28	18857.68	28266.16
APR	2484	5380.226	18821.3	26685.526	APR	2484.00	5777.24	21771.66	30032.90
MAY	2743.2	5326.386	23931.13	32000.716	MAY	2743.20	5730.05	26976.97	35450.22
JUN	2635.2	4998.727	25433.81	33067.737	JUN	2635.20	5355.74	28185.87	36176.81
JUL	2592	4873.862	27921.81	35387.672	JUL	2592.00	5222.12	30450.98	38265.10
AUG	2743.2	5588.728	30216.57	38548.498	AUG	2743.20	5925.37	32925.66	41594.23
SEP	2592	6114.281	28669.36	37375.641	SEP	2592.00	6053.01	31220.66	39865.67
OCT	2635.2	6600.774	21065.47	30301.444	OCT	2635.20	6750.87	23598.32	32984.39
NOV	2028	6804.854	16382.04	25214.894	NOV	2028.00	7275.32	20037.99	29341.31
DEC	2592	6948.017	14628.48	24168.497	DEC	2592.00	7433.93	18466.53	28492.46
SUM	30842.4	72741.527	246641.3	350225.27	SUM	30842.40	76246.91	284111.06	391200.37

W5: Suspended Particle Devices (SPD), TA'IF

SPD (20% WWR) TA'IF					SPD (30% WWR) TA'IF				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	11898.97	5770.98	20305.15	JAN	2635.20	10818.75	5359.47	18813.42
FEB	2419.20	10654.09	6833.73	19907.02	FEB	2419.20	9539.75	6414.57	18373.51
MAR	2743.20	11724.34	8789.38	23256.92	MAR	2743.20	10650.72	8397.88	21791.80
APR	2484.00	9334.43	11788.40	23606.83	APR	2484.00	7859.08	11149.89	21492.97
MAY	2743.20	9980.75	14663.01	27386.96	MAY	2743.20	8244.20	13941.50	24928.90
JUN	2635.20	9594.11	16522.03	28751.34	JUN	2635.20	7889.52	15912.11	26436.83
JUL	2592.00	9477.93	15516.30	27586.23	JUL	2592.00	7778.91	14878.44	25249.35
AUG	2743.20	10333.49	17079.07	30155.76	AUG	2743.20	8688.47	16484.56	27916.23
SEP	2592.00	10653.53	15071.38	28316.91	SEP	2592.00	9355.74	14638.86	26586.60
OCT	2635.20	11054.53	12842.58	26532.31	OCT	2635.20	9908.38	12440.13	24983.71
NOV	2028.00	11392.14	9277.31	22697.45	NOV	2028.00	10195.96	8877.98	21101.94
DEC	2592.00	11600.43	7958.35	22150.78	DEC	2592.00	10472.50	7528.30	20592.80
SUM	30842.40	127698.74	142112.52	300653.7	SUM	30842.40	111401.9	136023.69	278268.1

SPD (40% WWR) TA'IF					SPD (50% WWR) TA'IF				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	9101.57	4634.43	16371.20	JAN	2635.2	7973.41	4262.539	14871.149
FEB	2419.20	8033.67	5800.15	16253.02	FEB	2419.2	6867.048	5324.341	14610.589
MAR	2743.20	8893.54	7653.24	19289.97	MAR	2743.2	7642.122	7216.367	17601.689
APR	2484.00	6421.28	10535.53	19440.81	APR	2484	5648.547	10345	18477.547
MAY	2743.20	6641.40	13326.85	22711.45	MAY	2743.2	5796.889	13175.01	21715.099
JUN	2635.20	6331.45	15394.83	24361.48	JUN	2635.2	5548.973	15340.64	23524.813
JUL	2592.00	6181.28	14305.15	23078.43	JUL	2592	5376.564	14204.74	22173.304
AUG	2743.20	7042.46	15888.89	25674.55	AUG	2743.2	6221.72	15799.11	24764.03
SEP	2592.00	7864.73	14088.35	24545.08	SEP	2592	6879.311	13843.36	23314.671
OCT	2635.20	8402.36	11826.72	22864.28	OCT	2635.2	7298.571	11480.26	21414.031
NOV	2028.00	8724.79	8346.40	19099.19	NOV	2028	7538.019	7957.935	17523.954
DEC	2592.00	8951.46	6946.30	18489.76	DEC	2592	7639.544	6498.828	16730.372
SUM	30842.40	92589.98	128746.84	252179.2	SUM	30842.4	80430.72	125448.13	236721.25

SPD (60% WWR) TA'IF					SPD (70% WWR) TA'IF				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	7187.95	4057.63	13880.78	JAN	2635.20	6780.99	4073.42	13489.61
FEB	2419.20	6155.09	5142.40	13716.69	FEB	2419.20	5738.95	5109.24	13267.39
MAR	2743.20	6777.14	6981.47	16501.81	MAR	2743.20	6231.46	6911.41	15886.07
APR	2484.00	5131.07	10308.77	17923.84	APR	2484.00	4818.20	10379.43	17681.63
MAY	2743.20	5317.52	13258.54	21319.26	MAY	2743.20	4971.82	13402.30	21117.32
JUN	2635.20	5068.21	15464.62	23168.03	JUN	2635.20	4771.70	15691.59	23098.49
JUL	2592.00	4909.31	14313.22	21814.53	JUL	2592.00	4604.35	14501.50	21697.85
AUG	2743.20	5694.74	15886.35	24324.29	AUG	2743.20	5292.24	16032.44	24067.88
SEP	2592.00	6282.39	13840.04	22714.43	SEP	2592.00	5828.69	13909.38	22330.07
OCT	2635.20	6559.80	11340.86	20535.86	OCT	2635.20	6039.37	11331.23	20005.80
NOV	2028.00	6644.55	7765.67	16438.22	NOV	2028.00	6228.50	7807.64	16064.13
DEC	2592.00	6768.79	6223.00	15583.79	DEC	2592.00	6369.49	6227.18	15188.67
SUM	30842.40	72496.55	124582.57	227921.51	SUM	30842.40	67675.75	125376.75	223894.9

SPD (80% WWR) TA'IF					TA'IF BASE CASE				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	7004.678	4408.479	14048.357	JAN	2635.20	7359.91	8303.89	18299.00
FEB	2419.2	5937.848	5416.93	13773.978	FEB	2419.20	6149.46	9124.18	17692.84
MAR	2743.2	6512.038	7292.643	16547.881	MAR	2743.20	6665.99	10802.67	20211.86
APR	2484	5077.676	10831.26	18392.936	APR	2484.00	5257.76	14077.14	21818.90
MAY	2743.2	5198.803	13913.3	21855.303	MAY	2743.20	5572.82	17225.64	25541.66
JUN	2635.2	4969.95	16211.02	23816.17	JUN	2635.20	5285.63	19149.27	27070.10
JUL	2592	4773.09	14970.92	22336.01	JUL	2592.00	5091.71	18093.18	25776.89
AUG	2743.2	5555.36	16585.54	24884.1	AUG	2743.20	5904.43	19637.21	28284.84
SEP	2592	6117.895	14433.95	23143.845	SEP	2592.00	5955.05	17444.60	25991.65
OCT	2635.2	6348.111	11833.29	20816.601	OCT	2635.20	6476.39	15337.91	24449.50
NOV	2028	6505.924	8237.357	16771.281	NOV	2028.00	6902.27	12125.76	21056.03
DEC	2592	6603.323	6573.4	15768.723	DEC	2592.00	7077.52	10505.06	20174.58
SUM	30842.4	70604.696	130708.1	232155.19	SUM	30842.40	73698.95	171826.51	276367.9

W5: Suspended Particle Devices (SPD), RIYADH

SPD (20% WWR) RIYADH					SPD (30% WWR) RIYADH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	12009.58	4607.05	19251.83	JAN	2635.20	10896.62	4231.92	17763.74
FEB	2419.20	10756.06	5343.17	18518.43	FEB	2419.20	9845.27	5048.13	17312.60
MAR	2743.20	11852.33	9275.22	23870.75	MAR	2743.20	10794.35	8919.80	22457.35
APR	2484.00	9900.27	13192.63	25576.90	APR	2484.00	8621.07	12720.42	23825.49
MAY	2743.20	10614.83	18415.42	31773.45	MAY	2743.20	9143.28	17981.22	29867.70
JUN	2635.20	10169.04	19220.42	32024.66	JUN	2635.20	8492.37	18711.54	29839.11
JUL	2592.00	9856.38	19993.29	32441.67	JUL	2592.00	8288.69	19572.00	30452.69
AUG	2743.20	10779.45	21124.20	34646.85	AUG	2743.20	9361.97	20806.46	32911.63
SEP	2592.00	11128.70	18479.46	32200.16	SEP	2592.00	10077.94	18301.70	30971.64
OCT	2635.20	11639.96	14211.11	28486.27	OCT	2635.20	10712.30	14064.46	27411.96
NOV	2028.00	12013.45	8538.73	22580.18	NOV	2028.00	11024.15	8267.85	21320.00
DEC	2592.00	12005.60	5451.67	20049.27	DEC	2592.00	10941.65	5063.96	18597.61
SUM	30842.40	132725.65	157852.37	321420.4	SUM	30842.40	118199.66	153689.5	302731.5

SPD (40% WWR) RIYADH					SPD (50% WWR) RIYADH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	9513.49	3760.67	15909.36	JAN	2635.20	7948.76	3212.69	13796.65
FEB	2419.20	8434.53	4508.97	15362.70	FEB	2419.20	7242.22	4109.29	13770.71
MAR	2743.20	8916.18	8144.21	19803.59	MAR	2743.20	7659.01	7726.73	18128.93
APR	2484.00	6988.18	12030.46	21502.64	APR	2484.00	6065.85	11751.62	20301.47
MAY	2743.20	6933.22	17094.47	26770.89	MAY	2743.20	6014.87	16984.99	25743.06
JUN	2635.20	6372.97	17908.84	26917.01	JUN	2635.20	5677.50	17962.49	26275.19
JUL	2592.00	6321.73	18880.94	27794.67	JUL	2592.00	5611.43	18937.88	27141.31
AUG	2743.20	7227.26	20024.31	29994.77	AUG	2743.20	6167.23	19889.35	28799.78
SEP	2592.00	8274.46	17647.56	28514.02	SEP	2592.00	7001.13	17295.39	26888.52
OCT	2635.20	9080.06	13493.85	25209.11	OCT	2635.20	7766.27	13118.35	23519.82
NOV	2028.00	9557.29	7722.18	19307.48	NOV	2028.00	8231.73	7278.86	17538.59
DEC	2592.00	9452.28	4500.23	16544.51	DEC	2592.00	8034.16	4034.76	14660.92
SUM	30842.40	97071.66	145716.70	273630.8	SUM	30842.40	83420.16	142302.39	256564.9

SPD (60% WWR) RIYADH					SPD (70% WWR) RIYADH				
Month	Room Electric	Lighting	Cooling Electricity	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6991.779	2981.586	12608.57	JAN	2635.20	6514.91	2962.93	12113.03
FEB	2419.2	6338.448	3866.739	12624.39	FEB	2419.20	5813.50	3790.55	12023.25
MAR	2743.2	6870.694	7535.514	17149.41	MAR	2743.20	6311.12	7487.42	16541.74
APR	2484	5476.871	11683.76	19644.63	APR	2484.00	5129.93	11759.72	19373.65
MAY	2743.2	5485.18	17096.03	25324.41	MAY	2743.20	5117.96	17294.13	25155.29
JUN	2635.2	5142.671	18093.72	25871.59	JUN	2635.20	4776.18	18318.20	25729.58
JUL	2592	5019.16	19050.69	26661.85	JUL	2592.00	4672.29	19298.48	26562.77
AUG	2743.2	5566.421	20009.1	28318.72	AUG	2743.20	5262.09	20284.92	28290.21
SEP	2592	6317.276	17298.96	26208.24	SEP	2592.00	5822.59	17404.61	25819.20
OCT	2635.2	6870.417	12962.14	22467.76	OCT	2635.20	6317.78	13004.30	21957.28
NOV	2028	7317.559	7035.429	16380.99	NOV	2028.00	6757.52	7006.48	15792.00
DEC	2592	7014.804	3746.024	13352.83	DEC	2592.00	6587.63	3748.09	12927.72
SUM	30842.4	74411.28	141359.7	246613.4	SUM	30842.40	69083.50	142359.83	242285.73
SPD (80% WWR) RIYADH					RIYADH BASE CASE				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	6794.00	3284.49	12713.70	JAN	2635.20	7400.03	6980.26	17015.49
FEB	2419.20	6132.57	4111.75	12663.52	FEB	2419.20	6431.58	7684.52	16535.30
MAR	2743.20	6633.41	7911.17	17287.78	MAR	2743.20	6720.20	11507.29	20970.69
APR	2484.00	5361.67	12192.90	20038.57	APR	2484.00	5436.02	15149.01	23069.03
MAY	2743.20	5322.21	17831.21	25896.62	MAY	2743.20	5729.88	20583.49	29056.57
JUN	2635.20	5025.06	18906.41	26566.67	JUN	2635.20	5364.12	21329.69	29329.01
JUL	2592.00	4936.78	19905.20	27433.98	JUL	2592.00	5254.60	22112.80	29959.40
AUG	2743.20	5506.72	20877.41	29127.33	AUG	2743.20	5922.33	23334.60	32000.13
SEP	2592.00	6071.90	17945.79	26609.69	SEP	2592.00	6158.49	20728.87	29479.36
OCT	2635.20	6569.33	13498.15	22702.68	OCT	2635.20	6801.88	16964.71	26401.79
NOV	2028.00	7042.22	7379.86	16450.08	NOV	2028.00	7613.85	11257.89	20899.74
DEC	2592.00	6847.25	4061.05	13500.30	DEC	2592.00	7499.10	7947.56	18038.66
SUM	30842.40	72243.12	147905.39	250990.91	SUM	30842.40	76332.08	185580.68	292755.16

W6: THERMOCHROMIC, JEDDAH

TC (20% WWR) JEDDAH					TC (30% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	10732.30	13430.90	26798.40	JAN	2635.2	9673.07	13722.63	26030.9
FEB	2419.20	9715.36	12915.31	25049.87	FEB	2419.2	8620.48	13055.6	24095.28
MAR	2743.20	11086.23	16840.25	30669.68	MAR	2743.2	9665.28	16785.75	29194.23
APR	2484.00	10562.07	20595.84	33641.91	APR	2484	9244.98	20462.26	32191.24
MAY	2743.20	11343.72	25484.86	39571.78	MAY	2743.2	9598.3	25157.63	37499.13
JUN	2635.20	10923.25	26677.40	40235.85	JUN	2635.2	9235.99	26372.56	38243.75
JUL	2592.00	10955.68	28949.89	42497.57	JUL	2592	9121.01	28524.7	40237.71
AUG	2743.20	11564.17	31217.15	45524.52	AUG	2743.2	9759.65	30822.65	43325.5
SEP	2592.00	11830.45	29662.21	44084.66	SEP	2592	10393.1	29380.27	42365.38
OCT	2635.20	12147.58	21950.25	36733.03	OCT	2635.2	10834.7	21814.56	35284.42
NOV	2028.00	10969.06	17467.31	30464.37	NOV	2028	9854.08	17631.42	29513.5
DEC	2592.00	10901.96	15789.23	29283.19	DEC	2592	9778.24	15967.83	28338.07
SUM	30842.40	132731.83	260980.60	424554.83	SUM	30842.4	115779	259697.9	406319.1
TC (40% WWR) JEDDAH					TC (50% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	8281.6	13884.79	24801.59	JAN	2635.2	7389.74	14343.34	24368.28
FEB	2419.2	7325.28	13165.17	22909.65	FEB	2419.2	6345.58	13468.63	22233.41
MAR	2743.2	7949.54	16645.44	27338.18	MAR	2743.2	6789.52	16848.96	26381.68
APR	2484	7124.78	19854.74	29463.52	APR	2484	5923.32	19827.28	28234.6
MAY	2743.2	7208.8	24442.5	34394.5	MAY	2743.2	5981.96	24451.55	33176.71
JUN	2635.2	6822.13	25611.66	35068.99	JUN	2635.2	5712.53	25645.28	33993.01
JUL	2592	6757.35	27746.47	37095.82	JUL	2592	5665.87	27605.87	35863.74
AUG	2743.2	7488.55	30148.76	40380.51	AUG	2743.2	6381.46	30072.81	39197.47
SEP	2592	8304.39	28719.35	39615.74	SEP	2592	6898.9	28369.36	37860.26
OCT	2635.2	8823.76	21392.63	32851.59	OCT	2635.2	7367.7	21104.37	31107.27
NOV	2028	8458.81	17689.89	28176.7	NOV	2028	7347.37	17849.74	27225.11
DEC	2592	8446.62	16091.38	27130	DEC	2592	7440.27	16357.32	26389.59
SUM	30842.4	92992	255392.8	379226.8	Sum	30842.4	79244	255944.5	366031.1

W6: THERMOCHROMIC, JEDDAH

TC (60% WWR) JEDDAH					TC (70% WWR) JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.20	6825.29	14935.34	24395.83	JAN	2635.20	6482.23	15614.27	24731.70
FEB	2419.20	5797.02	13994.89	22211.11	FEB	2419.20	5492.76	14601.79	22513.75
MAR	2743.20	6004.66	17299.11	26046.97	MAR	2743.20	5656.63	17882.02	26281.85
APR	2484.00	5077.49	20126.29	27687.78	APR	2484.00	4798.63	20568.33	27850.96
MAY	2743.20	5270.27	24878.53	32892.00	MAY	2743.20	4930.54	25380.80	33054.54
JUN	2635.20	4989.67	26048.76	33673.63	JUN	2635.20	4700.71	26526.94	33862.85
JUL	2592.00	4858.61	27872.92	35323.53	JUL	2592.00	4597.80	28229.92	35419.72
AUG	2743.20	5506.72	30382.22	38632.14	AUG	2743.20	5170.42	30676.38	38590.00
SEP	2592.00	5745.18	28558.13	36895.31	SEP	2592.00	5463.34	28622.21	36677.55
OCT	2635.20	6294.83	21185.98	30116.01	OCT	2635.20	5929.89	21437.05	30002.14
NOV	2028.00	6566.80	18179.49	26774.29	NOV	2028.00	6197.43	18627.12	26852.55
DEC	2592.00	6674.18	16735.10	26001.28	DEC	2592.00	6328.74	17279.78	26200.52
SUM	30842.40	69610.72	260196.76	360649.8	SUM	30842.4	65749.1	265446.6	362038.1

TC (80% WWR) JEDDAH					JEDDAH BASE JEDDAH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6727.5	16637.7	26000.41		2635.20	7595.64	16276.65	26507.49
FEB	2419.2	5694.1	15525.18	23638.47		2419.20	6462.34	15342.09	24223.63
MAR	2743.2	5935	18881.25	27559.46		2743.20	6665.28	18857.68	28266.16
APR	2484	5057.9	21445.81	28987.7		2484.00	5777.24	21771.66	30032.90
MAY	2743.2	5218.4	26356.42	34317.99		2743.20	5730.05	26976.97	35450.22
JUN	2635.2	4943.5	27439.06	35017.76		2635.20	5355.74	28185.87	36176.81
JUL	2592	4842.7	29081.4	36516.1		2592.00	5222.12	30450.98	38265.10
AUG	2743.2	5516.7	31606.01	39865.95		2743.20	5925.37	32925.66	41594.23
SEP	2592	5820.6	29492.08	37904.7		2592.00	6053.01	31220.66	39865.67
OCT	2635.2	6245.7	22211.38	31092.3		2635.20	6750.87	23598.32	32984.39
NOV	2028	6490.3	19535.78	28054.11		2028.00	7275.32	20037.99	29341.31
DEC	2592	6616.2	18244.69	27452.93		2592.00	7433.93	18466.53	28492.46
SUM	30842.4	69109	276456.8	376407.9	SUM	30842.40	76246.91	284111.06	391200.4

W6: THERMOCHROMIC, TA'IF

TC (20% WWR) TA'IF					TC (30% WWR) TA'IF				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	10492.66	5975.09	19102.95	JAN	2635.20	9444.08	6250.52	18329.80
FEB	2419.20	9123.66	6907.81	18450.67	FEB	2419.20	8098.63	7107.18	17625.01
MAR	2743.20	10676.70	8943.45	22363.35	MAR	2743.20	9161.48	8900.87	20805.55
APR	2484.00	9354.99	12333.44	24172.43	APR	2484.00	7680.79	12074.90	22239.69
MAY	2743.20	10589.81	15396.11	28729.12	MAY	2743.20	8643.78	15044.16	26431.14
JUN	2635.20	10525.18	17172.43	30332.81	JUN	2635.20	8564.54	16798.09	27997.83
JUL	2592.00	10304.96	16171.07	29068.03	JUL	2592.00	8347.69	15776.79	26716.48
AUG	2743.20	11216.50	17716.18	31675.88	AUG	2743.20	9348.54	17366.60	29458.34
SEP	2592.00	11011.24	15481.77	29085.01	SEP	2592.00	9590.79	15373.51	27556.30
OCT	2635.20	10048.99	12825.18	25509.37	OCT	2635.20	8928.20	13033.33	24596.73
NOV	2028.00	9926.15	9275.00	21229.15	NOV	2028.00	8849.86	9565.86	20443.72
DEC	2592.00	10151.86	8195.09	20938.95	DEC	2592.00	9022.09	8398.49	20012.57
SUM	30842.40	123422.70	146392.62	300657.7	SUM	30842.40	105680.46	145690.30	282213.16

TC (40% WWR) TA'IF					TC (50% WWR) TA'IF				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	8038.308	6433.207	17106.72	JAN	2635.20	7201.51	6845.68	16682.39
FEB	2419.2	6851.725	7300.509	16571.43	FEB	2419.20	6000.63	7667.88	16087.72
MAR	2743.2	7471.552	8771.877	18986.63	MAR	2743.20	6506.10	9092.15	18341.45
APR	2484	6045.303	11899.78	20429.08	APR	2484.00	5196.10	12233.72	19913.82
MAY	2743.2	6634.245	14704.01	24081.46	MAY	2743.20	5712.77	15060.16	23516.13
JUN	2635.2	6568.987	16423.8	25627.99	JUN	2635.20	5632.64	16724.30	24992.14
JUL	2592	6315.363	15367.55	24274.91	JUL	2592.00	5430.05	15668.28	23690.33
AUG	2743.2	7296.161	16937.67	26977.03	AUG	2743.20	6380.23	17180.87	26304.3
SEP	2592	7761.834	15057.66	25411.49	SEP	2592.00	6530.65	15109.23	24231.88
OCT	2635.2	7512.709	13104.24	23252.15	OCT	2635.20	6502.51	13397.51	22535.22
NOV	2028	7625.042	9842.801	19495.84	NOV	2028.00	6734.08	10299.60	19061.68
DEC	2592	7759.892	8602.585	18954.48	DEC	2592.00	6887.24	8977.91	18457.15
SUM	30842.4	85881	144445.7	261169.2	Sum	30842.4	74715	148257.3	253814.2

W6: THERMOCHROMIC, TA'IF

TC (60% WWR) TA'IF					TC (70% WWR) TA'IF				
Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	Month	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6678.958	7388.143	16702.301	JAN	2635.2	6363.038	8064.056	17062.294
FEB	2419.2	5520.844	8205.832	16145.876	FEB	2419.2	5253.638	8836.993	16509.831
MAR	2743.2	5753.178	9560.383	18056.761	MAR	2743.2	5362.01	10263.43	18368.64
APR	2484	4705.638	12781.45	19971.088	APR	2484	4386.692	13435.05	20305.742
MAY	2743.2	5144.659	15618.83	23506.689	MAY	2743.2	4755.549	16280.11	23778.859
JUN	2635.2	5030.015	17201.66	24866.875	JUN	2635.2	4633.752	17813.09	25082.042
JUL	2592	4838.526	16136.17	23566.696	JUL	2592	4448.744	16723.66	23764.404
AUG	2743.2	5712.695	17569.1	26024.995	AUG	2743.2	5231.726	18070.55	26045.476
SEP	2592	5818.591	15475.71	23886.301	SEP	2592	5343.932	15979.5	23915.432
OCT	2635.2	5930.854	13895.84	22461.894	OCT	2635.2	5569.91	14518.87	22723.98
NOV	2028	6208.309	10906.35	19142.659	NOV	2028	5879.22	11618.48	19525.7
DEC	2592	6310.445	9446.873	18349.318	DEC	2592	6003.168	10064.61	18659.778
SUM	30842.4	67652.71	154186.3	252681.45	SUM	30842.4	63231.379	161668.4	255742.18

TC (80% WWR) TA'IF					TA'IF BASE CASE				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.2	6589.6	8989.805	18214.65	JAN	2635.20	7359.91	8303.89	18299.00
FEB	2419.2	5428	9742.077	17589.24	FEB	2419.20	6149.46	9124.18	17692.84
MAR	2743.2	5612.8	11270.92	19626.9	MAR	2743.20	6665.99	10802.67	20211.86
APR	2484	4605.9	14416.98	21506.86	APR	2484.00	5257.76	14077.14	21818.90
MAY	2743.2	5011.7	17333.27	25088.16	MAY	2743.20	5572.82	17225.64	25541.66
JUN	2635.2	4869	18807.65	26311.85	JUN	2635.20	5285.63	19149.27	27070.10
JUL	2592	4684	17681.6	24957.59	JUL	2592.00	5091.71	18093.18	25776.89
AUG	2743.2	5562.4	19063.64	27369.23	AUG	2743.20	5904.43	19637.21	28284.84
SEP	2592	5660.1	16965.16	25217.23	SEP	2592.00	5955.05	17444.60	25991.65
OCT	2635.2	5800.4	15492.99	23928.6	OCT	2635.20	6476.39	15337.91	24449.50
NOV	2028	6104.2	12623.77	20755.96	NOV	2028.00	6902.27	12125.76	21056.03
DEC	2592	6223.3	11075.07	19890.41	DEC	2592.00	7077.52	10505.06	20174.58
SUM	30842.4	66151	173462.9	270456.7	SUM	30842.40	73698.95	171826.51	276367.86

W6: THERMOCHROMIC, RIYADH

TC (20% WWR) RIYADH					TC (30% WWR) RIYADH				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	10427.30	4629.87	17692.37	JAN	2635.20	9213.37	4883.78	16732.35
FEB	2419.20	9258.00	5402.35	17079.55	FEB	2419.20	8124.65	5562.18	16106.03
MAR	2743.20	10896.29	9412.16	23051.65	MAR	2743.20	9422.78	9388.21	21554.18
APR	2484.00	10348.41	13749.19	26581.60	APR	2484.00	8958.47	13604.93	25047.40
MAY	2743.20	11778.21	19016.50	33537.91	MAY	2743.20	10205.46	18837.65	31786.31
JUN	2635.20	11381.35	19656.01	33672.56	JUN	2635.20	9758.87	19418.49	31812.56
JUL	2592.00	11164.27	20368.53	34124.80	JUL	2592.00	9639.13	20167.89	32399.02
AUG	2743.20	12119.22	21495.96	36358.38	AUG	2743.20	10633.09	21318.10	34694.39
SEP	2592.00	11940.64	18732.73	33265.37	SEP	2592.00	10704.14	18668.85	31964.99
OCT	2635.20	11852.28	14462.84	28950.32	OCT	2635.20	10523.95	14445.00	27604.15
NOV	2028.00	10921.05	8639.64	21588.69	NOV	2028.00	9818.66	8850.81	20697.47
DEC	2592.00	10410.45	5503.51	18505.96	DEC	2592.00	9363.76	5803.89	17759.65
SUM	30842.40	132497.	161069.3	324409.2	SUM	30842.40	116366.3	160949.78	308158.5

TC (40% WWR) RIYADH					TC (50% WWR) RIYADH				
MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	8211.32	5211.70	16058.22	JAN	2635.20	7265.91	5546.13	15447.24
FEB	2419.20	7103.98	5829.85	15353.03	FEB	2419.20	6297.04	6210.08	14926.32
MAR	2743.20	7663.54	9283.45	19690.19	MAR	2743.20	6678.83	9664.27	19086.30
APR	2484.00	6901.46	13100.06	22485.52	APR	2484.00	5723.82	13142.55	21350.37
MAY	2743.20	7595.65	18051.04	28389.89	MAY	2743.20	6122.02	17948.48	26813.70
JUN	2635.20	7125.28	18574.64	28335.12	JUN	2635.20	5814.71	18543.72	26993.63
JUL	2592.00	7055.09	19330.85	28977.94	JUL	2592.00	5763.64	19269.33	27624.97
AUG	2743.20	8267.63	20585.67	31596.50	AUG	2743.20	6695.46	20342.04	29780.70
SEP	2592.00	8522.55	18046.24	29160.79	SEP	2592.00	7069.91	17876.81	27538.72
OCT	2635.20	8809.85	14260.86	25705.91	OCT	2635.20	7409.73	14236.58	24281.51
NOV	2028.00	8633.29	9079.64	19740.93	NOV	2028.00	7549.55	9399.76	18977.31
DEC	2592.00	8273.37	6048.45	16913.82	DEC	2592.00	7342.77	6436.87	16371.63
SUM	30842.40	94163.0	157402	282407.9	SUM	30842.40	79733.38	158616.62	269192.40

W6: THERMOCHROMIC, RIYADH

TC (60% WWR) RIYADH					TC (70% WWR) RIYADH				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling (Electricity)	TOTAL
JAN	2635.20	6654.38	6053.07	15342.65	JAN	2635.20	6238.01	6575.13	15448.34
FEB	2419.20	5697.07	6711.97	14828.24	FEB	2419.20	5343.04	7295.90	15058.15
MAR	2743.20	5904.32	10160.76	18808.28	MAR	2743.20	5543.25	10819.43	19105.88
APR	2484.00	4863.03	13518.07	20865.10	APR	2484.00	4623.33	13957.81	21065.14
MAY	2743.20	5384.42	18352.76	26480.38	MAY	2743.20	5032.35	18853.56	26629.11
JUN	2635.20	5019.81	18865.10	26520.11	JUN	2635.20	4710.93	19367.50	26713.63
JUL	2592.00	4912.63	19540.58	27045.21	JUL	2592.00	4618.06	20010.27	27220.33
AUG	2743.20	5461.52	20567.15	28771.87	AUG	2743.20	5304.55	20913.22	28960.97
SEP	2592.00	5771.08	17968.34	26331.42	SEP	2592.00	5396.62	18232.61	26221.23
OCT	2635.20	6262.73	14397.55	23295.48	OCT	2635.20	5856.54	14794.69	23286.43
NOV	2028.00	6861.58	9906.00	18795.58	NOV	2028.00	6433.53	10465.69	18927.22
DEC	2592.00	6794.73	6999.04	16385.77	DEC	2592.00	6348.26	7476.62	16416.88
SUM	30842.40	69587.28	163040.39	263470.1	SUM	30842.40	65448.46	168762.43	265053.3

TC (80% WWR) RIYADH					RIYADH BASE CASE				
MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL	MONTH	Room Electricity	Lighting	Cooling Electricity	TOTAL
JAN	2635.20	6508.82	7463.28	16607.30	JAN	2635.20	7400.03	6980.26	17015.49
FEB	2419.20	5572.75	8185.81	16177.76	FEB	2419.20	6431.58	7684.52	16535.30
MAR	2743.20	5784.55	11840.26	20368.01	MAR	2743.20	6720.20	11507.29	20970.69
APR	2484.00	4874.59	14850.74	22209.33	APR	2484.00	5436.02	15149.01	23069.03
MAY	2743.20	5266.53	19755.97	27765.70	MAY	2743.20	5729.88	20583.49	29056.57
JUN	2635.20	4937.42	20233.43	27806.05	JUN	2635.20	5364.12	21329.69	29329.01
JUL	2592.00	4842.64	20842.75	28277.39	JUL	2592.00	5254.60	22112.80	29959.40
AUG	2743.20	5645.07	21812.62	30200.89	AUG	2743.20	5922.33	23334.60	32000.13
SEP	2592.00	5688.19	19081.48	27361.67	SEP	2592.00	6158.49	20728.87	29479.36
OCT	2635.20	6156.73	15684.66	24476.59	OCT	2635.20	6801.88	16964.71	26401.79
NOV	2028.00	6721.14	11438.27	20187.41	NOV	2028.00	7613.85	11257.89	20899.74
DEC	2592.00	6630.54	8420.89	17643.43	DEC	2592.00	7499.10	7947.56	18038.66
SUM	30842.40	68628.96	179610.16	279081.5	SUM	30842.40	76332.08	185580.68	292755.2

APPENDIX II: Daylight Simulation Results

W1: Electrochromic Window at Jeddah

Daylight with EC at 70% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	22.44	36.93	37.37	61.50
Block	2	98.87	98.78	99.90	57.29	57.94	82.32	83.25
Block	3	60.76	60.76	100.00	14.45	23.79	36.23	59.62
Block	4	60.83	60.83	100.00	38.65	63.54	49.60	81.53
Block	5	98.98	98.89	99.90	98.70	99.71	98.98	100.00
Block	6	60.82	60.82	100.00	26.56	43.66	50.16	82.47
Block	7	86.24	52.75	61.17	56.56	65.59	82.89	96.12
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	51.16	59.33	40.18	46.60	82.42	95.58
Total		753.82	544.74	72.26	354.83	47.07	519.95	68.98

W1: Electrochromic Window at Taif

Daylight with EC at 70% WWR in Taif								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	20.06	33.02	32.71	53.83
Block	2	98.87	98.87	100.00	57.67	58.33	76.80	77.67
Block	3	60.76	60.76	100.00	12.27	20.19	32.23	53.05
Block	4	60.83	60.83	100.00	35.98	59.16	45.31	74.49
Block	5	98.98	98.98	100.00	96.03	97.02	98.79	99.81
Block	6	60.82	60.82	100.00	22.46	36.93	45.12	74.18
Block	7	86.24	55.54	64.40	51.63	59.87	79.17	91.80
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	54.14	62.78	36.09	41.86	79.16	91.80
Total		753.82	550.70	73.06	332.19	44.07	489.28	64.91

W1: Electrochromic Window at Riyadh

Daylight with EC at 70% WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	15.12	24.88	37.08	61.03
Block	2	98.87	98.87	100.00	50.72	51.30	82.32	83.25
Block	3	60.76	60.76	100.00	10.17	16.75	38.03	62.60
Block	4	60.83	60.83	100.00	31.89	52.43	52.17	85.76
Block	5	98.98	98.89	99.90	96.98	97.98	98.98	100.00
Block	6	60.82	60.82	100.00	22.46	36.93	54.07	88.89
Block	7	86.24	52.37	60.73	46.23	53.61	86.24	100.00
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	48.28	55.99	33.30	38.62	85.76	99.46
Total		753.82	541.58	71.85	306.89	40.71	534.64	70.93

W2: Gasochromic Window at Jeddah

Daylight Performance with GC window at 60% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	26.05	42.88	37.65	61.97
Block	2	98.87	98.68	99.81	63.38	64.10	81.08	82.00
Block	3	60.76	60.76	100.00	18.64	30.67	36.99	60.88
Block	4	60.83	60.83	100.00	42.17	69.33	48.45	79.66
Block	5	98.98	97.75	98.75	98.98	100.00	98.98	100.00
Block	6	60.82	60.82	100.00	31.32	51.49	48.74	80.13
Block	7	86.24	50.33	58.36	60.56	70.23	80.10	92.88
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	49.77	57.71	46.04	53.40	79.35	92.02
Total		753.82	539.69	71.59	387.14	51.36	511.33	67.83

W2: Gasochromic Window at Taif

Daylight Performance with GC window at 60% WWR in Taif								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	24.06	39.59	34.23	56.34
Block	2	98.87	98.78	99.90	62.81	63.52	76.80	77.67
Block	3	60.76	60.76	100.00	15.02	24.73	33.75	55.56
Block	4	60.83	60.83	100.00	38.17	62.75	44.36	72.93
Block	5	98.98	97.84	98.85	98.70	99.71	95.94	96.92
Block	6	60.82	60.82	100.00	26.46	43.51	44.83	73.71
Block	7	86.24	52.56	60.95	56.09	65.05	77.49	89.86
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	52.00	60.30	40.09	46.49	76.83	89.11
Total		753.82	544.34	72.21	361.40	47.94	484.23	64.24

W2: Gasochromic Window at Riyadh

Daylight Performance with GC window at 60% WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	18.16	29.89	37.94	62.44
Block	2	98.87	98.78	99.90	56.05	56.69	81.46	82.39
Block	3	60.76	60.76	100.00	14.17	23.32	38.22	62.91
Block	4	60.83	60.83	100.00	33.32	54.77	51.59	84.82
Block	5	98.98	97.65	98.65	98.89	99.90	98.98	100.00
Block	6	60.82	60.82	100.00	26.37	43.35	52.64	86.54
Block	7	86.24	50.61	58.68	48.47	56.20	83.54	96.87
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	46.98	54.48	38.23	44.34	82.51	95.69
Total		753.82	537.18	71.26	333.65	44.26	526.88	69.90

W3: Photochromic Window in Jeddah

Daylight with PC at 60% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	24.63	40.53	30.81	50.70
Block	2	98.87	98.87	100.00	62.33	63.04	73.85	74.69
Block	3	60.76	60.76	100.00	17.30	28.48	30.05	49.45
Block	4	60.83	60.83	100.00	39.22	64.48	40.55	66.67
Block	5	98.98	98.89	99.90	98.70	99.71	90.22	91.15
Block	6	60.82	60.82	100.00	29.51	48.51	40.64	66.82
Block	7	86.24	60.93	70.66	56.65	65.70	76.10	88.24
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	58.14	67.42	44.28	51.35	76.00	88.13
Total		753.82	560.00	74.29	372.62	49.43	458.21	60.79

W3: Photochromic Window in Taif

Daylight with PC 60% WWR in Taif								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	22.63	37.25	27.86	45.85
Block	2	98.87	98.87	100.00	62.05	62.75	69.75	70.55
Block	3	60.76	60.76	100.00	14.83	24.41	26.91	44.29
Block	4	60.83	60.83	100.00	35.89	59.00	36.55	60.09
Block	5	98.98	98.98	100.00	96.22	97.21	86.69	87.58
Block	6	60.82	60.82	100.00	25.80	42.41	36.74	60.41
Block	7	86.24	63.16	73.25	53.96	62.57	73.77	85.55
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	60.74	70.44	39.35	45.63	73.39	85.11
Total		753.82	564.93	74.94	350.71	46.53	431.67	57.27

W3: Photochromic Window in Riyadh

Daylight with PC at 60 WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	17.21	28.33	30.43	50.08
Block	2	98.87	98.87	100.00	55.48	56.11	74.04	74.88
Block	3	60.76	60.76	100.00	14.17	23.32	31.00	51.02
Block	4	60.83	60.83	100.00	31.60	51.96	42.27	69.48
Block	5	98.98	98.89	99.90	98.89	99.90	95.84	96.82
Block	6	60.82	60.82	100.00	26.37	43.35	43.60	71.67
Block	7	86.24	61.03	70.77	45.49	52.75	78.79	91.37
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	56.74	65.80	38.23	44.34	79.07	91.69
Total		753.82	558.70	74.12	327.44	43.44	475.02	63.02

W4: PDL Window in Jeddah

Daylight e with PDL window at 60% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	25.01	41.16	33.09	54.46
Block	2	98.87	98.87	100.00	62.90	63.62	75.84	76.71
Block	3	60.76	60.76	100.00	17.59	28.95	32.33	53.21
Block	4	60.83	60.83	100.00	39.89	65.57	42.93	70.58
Block	5	98.98	98.89	99.90	98.70	99.71	93.36	94.32
Block	6	60.82	60.82	100.00	29.60	48.67	43.02	70.74
Block	7	86.24	57.40	66.56	57.40	66.56	77.40	89.75
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	55.63	64.51	44.28	51.35	77.30	89.64
Total		753.82	553.95	73.49	375.36	49.80	475.28	63.05

W4: PDL Window in Taif

Daylight Performance with PDL window at 50% WWR in Ta'if								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	22.92	37.72	29.86	49.14
Block	2	98.87	98.87	100.00	62.24	62.95	71.75	72.57
Block	3	60.76	60.76	100.00	14.83	24.41	29.19	48.04
Block	4	60.83	60.83	100.00	36.36	59.78	39.41	64.79
Block	5	98.98	98.89	99.90	96.22	97.21	89.46	90.38
Block	6	60.82	60.82	100.00	25.89	42.57	38.93	64.01
Block	7	86.24	59.82	69.36	54.14	62.78	74.89	86.84
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	58.04	67.31	39.35	45.63	75.07	87.06
Total		753.82	558.79	74.13	351.95	46.69	448.55	59.50

W4: PDL Window in Riyadh

Daylight Performance with PDL at 60% WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	20.06	33.02	34.14	56.18
Block	2	98.87	98.87	100.00	58.81	59.48	76.70	77.58
Block	3	60.76	60.76	100.00	19.78	32.55	35.37	58.22
Block	4	60.83	60.83	100.00	35.13	57.75	45.98	75.59
Block	5	98.98	98.79	99.81	98.98	100.00	98.22	99.23
Block	6	60.82	60.82	100.00	34.46	56.65	47.02	77.31
Block	7	86.24	56.19	65.16	50.61	58.68	79.44	92.13
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	52.37	60.73	49.58	57.50	81.21	94.18
Total		753.82	549.39	72.88	367.40	48.74	498.08	66.07

W5: SPD Windows at Jeddah

Daylight Performance with SPD at 70% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	27.86	45.85	41.08	67.61
Block	2	98.87	98.30	99.42	65.19	65.93	84.50	85.47
Block	3	60.76	60.76	100.00	20.44	33.65	40.31	66.35
Block	4	60.83	60.73	99.84	44.74	73.55	51.98	85.45
Block	5	98.98	96.41	97.40	98.98	100.00	98.98	100.00
Block	6	60.82	60.82	100.00	33.60	55.24	52.83	86.85
Block	7	86.24	46.98	54.48	63.44	73.57	81.77	94.82
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	46.42	53.83	48.46	56.20	82.04	95.15
Total		753.82	531.18	70.47	402.72	53.42	533.49	70.77

W5: SPD Windows at Taif

Daylight Performance with SPD at 70% WWR in Taif								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100	28.526	46.948	38.985	64.163
Block	2	98.87	98.778	99.904	68.136	68.912	80.697	81.617
Block	3	60.76	60.756	100	20.822	34.272	39.078	64.319
Block	4	60.83	60.828	100	42.932	70.579	49.976	82.16
Block	5	98.98	97.745	98.749	98.984	100	98.984	100
Block	6	60.82	60.824	100	33.696	55.399	50.353	82.786
Block	7	86.24	48.931	56.742	62.42	72.384	80.188	92.988
Block	8	140.33	0	0	0	0	0	0
Block	9	86.23	47.533	55.124	49.672	57.605	80.741	93.635
Total		753.82	536.155	71.126	405.188	53.752	519.002	68.85

W5: SPD Windows at Riyadh

Daylight Performance with SPD at 70% WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100	23.486	38.654	43.074	70.892
Block	2	98.87	98.683	99.808	61.76	62.464	85.455	86.429
Block	3	60.76	60.756	100	17.97	29.577	43.832	72.144
Block	4	60.83	60.828	100	39.124	64.319	56.164	92.332
Block	5	98.98	96.793	97.786	98.984	100	98.984	100
Block	6	60.82	60.824	100	32.173	52.895	56.826	93.427
Block	7	86.24	46.327	53.722	58.42	67.745	85.397	99.029
Block	8	140.33	0	0	0	0	0	0
Block	9	86.23	42.603	49.407	45.207	52.427	85.764	99.461
Total		753.82	527.573	69.987	377.125	50.029	555.496	73.691

W6: Thermochromic (TC) Windows at Jeddah

Daylight with TC at 60% WWR in Jeddah								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	28.15	46.32	44.79	73.71
Block	2	98.87	97.16	98.27	65.19	65.93	87.45	88.45
Block	3	60.76	60.76	100.00	20.82	34.27	43.55	71.67
Block	4	60.83	60.83	100.00	44.74	73.55	54.93	90.30
Block	5	98.98	92.89	93.84	98.98	100.00	98.98	100.00
Block	6	60.82	60.73	99.84	33.89	55.71	55.87	91.86
Block	7	86.24	43.07	49.95	63.63	73.79	84.00	97.41
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	42.60	49.41	48.74	56.53	82.97	96.22
Total		753.82	518.79	68.82	404.14	53.61	552.55	73.30

W6: Thermochromic (TC) Windows at Taif

Daylight with TC at 60% WWR in Taif								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100.00	26.91	44.29	40.98	67.45
Block	2	98.87	98.30	99.42	65.19	65.93	82.98	83.93
Block	3	60.76	60.76	100.00	19.40	31.93	40.12	66.04
Block	4	60.83	60.83	100.00	42.74	70.27	51.98	85.45
Block	5	98.98	94.89	95.86	98.98	100.00	98.98	100.00
Block	6	60.82	60.73	99.84	32.27	53.05	51.97	85.45
Block	7	86.24	46.23	53.61	61.58	71.41	80.47	93.31
Block	8	140.33	0.00	0.00	0.00	0.00	0.00	0.00
Block	9	86.23	44.74	51.89	47.16	54.69	80.74	93.64
Total		753.82	527.24	69.94	394.23	52.298	528.225	70.07

W6: Thermochromic (TC) Windows at Riyadh

Daylight with TC at 60% WWR in Riyadh								
Building			sDA Area in Range		ASE Area in Range		UDI Area in Range	
Block	Zone	Floor Area (m2)	Area (m2)	(%)	Area (m2)	(%)	Area (m2)	(%)
Block	1	60.76	60.76	100	22.73	37.4	45.36	74.65
Block	2	98.87	97.92	99.04	59.29	59.96	87.64	88.64
Block	3	60.76	60.76	100	16.35	26.92	45.26	74.49
Block	4	60.83	60.83	100	38.55	63.38	58.07	95.46
Block	5	98.98	92.6	93.55	98.98	100	98.98	100
Block	6	60.82	60.73	99.84	30.46	50.08	58.64	96.4
Block	7	86.24	42.42	49.19	56.19	65.16	84.28	97.74
Block	8	140.33	0	0	0	0	0	0
Block	9	86.23	40.46	46.93	43.07	49.95	82.51	95.69
Total		753.82	516.48	68.52	365.62	48.5	560.73	74.39

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