Fixed Shading Scenarios to Optimize Lighting Performance and Energy Efficiency in Office Buildings
Case Study of Dubai Design District

سيناريوهات التظليل الثابتة لتحسين أداء الإضاءة وكفاءة الطاقة في مباني المكاتب

دراسة حالة منطقة دبي للتصميم

by

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Abstract

As the global movement is moving towards reducing the leading causes of global warming, the United Arab Emirates is one of the striving countries that is moving towards tackling this phenomenon by launching initiatives that help reduce and control these emissions. In the UAE, the building's cooling loads account for 60% of the electricity load during the summer in Dubai. Therefore, buildings need a profound and practical solution to reduce the energy consumption caused by the building facades. As the primary façade materials used in Dubai are fully glazed facades, this paper aims to illustrate the potential reduction in energy consumption and daylight for a fully glazed building in the Dubai Design District. Although this case study already includes a shading device, the aesthetic importance for architects impacted the real benefits of the fixed shading device on this building. Therefore, the study aims to quantify the absolute energy consumption reduction caused by applying different, more beneficial shading designs for that particular building.

An office building was selected as the case study for this paper in Dubai Design District, specifically building six. An extensive literature review was performed in this paper to highlight relevant information to incorporate into the research methodology and simulation strategy. The existing building was modeled on the simulation tool IES VE Software and was used as the base case scenario. Six different fixed shading devices were simulated and texted on the building against the base case. These scenarios were in this order: Overhang Louvers in three dimensions 1200mm, 1500mm and 1800mm, 90 Vertical Fins, 45 Vertical fins as scenario two, Egg-crate, Horizontal Louvers, Vertical Louvers and a double skin façade in scenario six.

The energy consumption test was carried on every month of a year with a total energy consumption result for each scenario. The daylight analysis was conducted on one typical office space during

three timings, 9:00 am, 12:30, and 17:00, on two dates, 21st of December and 21st of June, to check variations.

The results proved that fixed shading devices on a fully glazed office improved energy consumption by using all the scenarios. Therefore, it is always beneficial to use external shading devices. The results in chapter 5 show that the Egg-crate scheme performed most effectively on the office building case study achieving a reduction in energy consumption of 8.2% from the base case result in a year. Also, in Daylighting analysis, the most effective was the egg-crate scenario, where it achieves a reduction in average illuminance level of 60% in both December and June. The second-best method was the Horizontal Louvers, where it achieved a reduction in energy consumption by 7.7% compared to the base case, and in daylight, it achieved a decrease of 50% in Both selected months. Horizontal louvers were generally more effective than vertical louvers. Although this study tests the vertical louvers in two degrees yet the horizontal proves to be more effective.

The annual energy consumption of the optimal scenario is reduced from 1670 MWh to 1532MWh in the Egg-crate scenario three, which is a high reduction of 138MWh per year. Moreover, daylighting analysis shows decreased average illuminance levels from 407.8 to 154.97 Lux, equivalent to a 60% reduction in December and June. The results show that external fixed shading devices on the office building façade reduce energy consumption dramatically, increasing building efficiency and performance. It is recommended that external shading devices be applied at the early stages of design phases, especially in fully glazed building facades that are very common in office buildings in Dubai. It is also essential to consider that shading device calculations should be done according to the latitudes and longitude of the city of the case study, in this case, Dubai city, to get the optimum energy-saving results possible.

الملخص

في الوقت الذي يتجه العالم نحو الحد من الأسباب المؤدية للاحتباس الحراري، تعدّ دولة الإمارات العربية المتحدة من الدول الرائدة في معالجة هذه الظاهرة من خلال إطلاق مبادرات تساعد في التقليل من الانبعاثات الحرارية والسيطرة عليها. في دولة الإمارات، تمثل أحمال تبريد المبنى 60٪ من حمل الكهرباء خلال فصل الصيف في دبي. لذا هناك حاجة لإيجاد حلول عميقة وعملية لتقليل استهلاك الطاقة الناتجة عن واجهات المباني. نظرًا لأن المواد الأولية للواجهات المستخدمة في دبي هي واجهات زجاجية بالكامل، تهدف هذه الرسالة إلى توضيح الانخفاض المحتمل في استهلاك الطاقة وضوء النهار لمبنى زجاجي معيّن في منطقة دبي للتصميم. على الرغم من أن المبنى يتضمن جهاز تظليل، إلا أن الأهمية الجمالية للمهندسين المعماريين أثرت على الفوائد الحقيقية لجهاز التظليل الثابت في المبنى. لذا تهدف الدراسة إلى تحديد مقدار الانخفاض المطلق في استهلاك الطاقة الناتج عن تطبيق حلول تظليل مختلفة وأكثر فائدة لذلك المبنى على وجه التحديد.

تم اختيار مبنى إداري ليكون محط تركيز البحث لهذه الورقة، وتحديداً المبنى السادس في منطقة دبي للتصميم. تم إجراء مراجعة واسعة للدراسات السابقة لتسليط الضوء على المعلومات ذات الصلة لدمجها في منهجية البحث واستراتيجية المحاكاة. تم نقل تصميم المبنى الحالي باستخدام IES VE Software برنامج واستخدم كسيناريو الحالة الأساسية. تم تصميم ومحاكاة ستة أجهزة تظليل ثابتة مختلفة تركيبها على المبنى مقابل الغلاف الأساسي. وجاءت السيناريوهات وفق الترتيب التالي: أولاً أعمدة التظليل المعلقة Overhang Louvers بثلاثة مقاسات ((1200مم، و1500 مم، و1800مم. ثانياً 90 زعنفة رأسية، و45 زعنفة عمودية Vertical Fins، ثالثاً، مقترح (Egg crate)، رابعاً، أعمدة التظليل الأفقية (Horizontal Louvers، خامساً، أعمدة التظليل العمودية(Louvers Vertical) وسادساً واجهة مزدوجة.

أثبتت النتائج أن أجهزة التظليل الثابتة في مكتب زجاجي بالكامل أدت إلى تحسين استهلاك الطاقة في جميع السيناريوهات. لذلك، من المفيد دائمًا استخدام أجهزة تظليل خارجية. توضح النتائج الواردة في الفصل الخامس أن مخطط Egg-crate تم تنفيذه بشكل أكثر فاعلية في حالة المبنى حيث حقق انخفاضًا في استهلاك الطاقة بنسبة 8.2٪ من نتيجة الحالة الأساسية خلال عام. كما يتبيّن في تحليل ضوء النهار، أن السيناريو الأكثر فاعلية هو سيناريو صندوق البيض(Egg-crate) ، حيث حقق انخفاضًا في متوسط مستوى الإضاءة بنسبة 60٪ في كل من ديسمبر ويونيو. وكان ثاني أفضل مقترح هو الأعمدة الأفقية (Horizontal Louvers)،

حيث حققت انخفاضًا في استهلاك الطاقة بنسبة 7.7٪ مقارنة بالحالة الأساسية، وفي ضوء النهار، حققت انخفاضًا بنسبة 50٪ في كلا الشهرين المختارين. كانت الأعمدة الأفقية بشكل عام أكثر فعالية من العمودية بعد حتى عند اختبار الأعمدة العمودية بدرجتين مختلفتين، إلا أن الأفقية أثبتت فاعليتها بشكل أكبر.

يتم تقليل استهلاك الطاقة السنوي للسيناريو الأمثل من 1670 ميجاوات في الساعة إلى 1532 ميجاوات في الساعة في السيناريو الثالث (صندوق البيض)، وهو انخفاض كبير يبلغ 138 ميجاوات في الساعة سنويًا. إضافة لذلك، يُظهر تحليل ضوء النهار انخفاضًا متوسط مستويات الإضاءة من 407.8 إلى 154.97 لوكس، وهو ما يعادل انخفاضًا بنسبة 60٪ في ديسمبر ويونيو. تظهر النتائج أن أجهزة التظليل الخارجية الثابتة على واجهة مباني المكاتب تقلل من استهلاك الطاقة بشكل كبير، مما يزيد من كفاءة المبنى وأدائه. يوصى بتطبيق أجهزة التظليل الخارجية في المراحل الأولى من مراحل التصميم، خاصة في واجهات المباني المزججة بالكامل والتي تعتبر شائعة جدًا في مباني المكاتب في دبي. من الضروري أيضًا مراعاة أن حسابات جهاز التظليل يجب أن تتم وفقًا لخطوط العرض وخط الطول للمدينة، في هذه الحالة، مدينة دبي، للحصول على أفضل النتائج الممكنة لتوفير الطاقة.

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Table of Contents

List of Figures

List of Tables

CHAPTER ONE

INTRODUCTION

1. Introduction

1.1. Background Information

Many recent studies have shown that buildings around the world require a large amount of energy for the lighting, heating, and cooling of the indoor spaces. Lighting alone in an office building typically takes about 20%–40% of the building's energy consumption (Yang and Nam, 2010; Jenkins and Newborough, 2007; Li, 2010). Nowadays, there is a trend toward an excessive use of glazing in office buildings to maximize daylight lighting and to increase the connection of the building users to the outside environment. However, this increase in the use of glazing is a highly critical design consideration that has an impact on the building's cooling, heating, and lighting demands; not to mention the possible visual discomfort caused by the abundance of direct sunlight.

A building's façade is the main element of the building's architecture, helping to define its value and its effect on the urban fabric of the building's setting. Therefore, architects tend to work hard to achieve the most appropriate façade since the visual aesthetics might also impact the indoor environment drastically in a given climatic condition. The building's orientation, climate, and façade materials are all part of the consideration in defining the ideal building façade treatment. However, until recently, most office buildings tended to be mainly glass boxes, which is perceived as the most aesthetically pleasing material. Unfortunately, glass' thermal properties are not very strong, whereby it conducts five times heat more than a well-insulated solid wall, and transmits 30%–70% more solar radiation that a solid wall would do for the building's interior spaces (Ashrae, 20013).

The best solution to tackling the effect of glazing is the application of shading systems on the façade, which until recently was part of the design stage of the façade treatment but has now become integrated within the façade design to achieve the best aesthetic results. Fixed external shading was originally used for promoting greater privacy, natural ventilation, and as a shelter from the outside environment. However, over time, external fixed shading has become essential and is now an important part of the building envelope and helps to optimize the lighting performance, visual comfort, and reduce energy consumption, especially in office buildings.

This research involves a case study of an office building in Dubai Design District, Dubai, UAE. These office buildings are designed with an external fixed shading system. However, the research will study these buildings and simulate the existing shading effect on the energy consumption as a base case scenario. Later, the research will depict the potential energy savings achievable through applying different external fixed shading scenarios, which should have a better impact on the energy consumption from a lighting and visual comfort perspective. Computer simulation tools will be used to simulate the potential energy savings achieved by applying different external shading design options. The shading options to be investigated are as follows: perpendicular vertical fins, angular vertical fins, egg-crate and horizontal fins. These external shadings systems will be tested on the southern, western, and eastern facades in summer and winter seasons in Dubai. The report will first depict information gathered from relevant research found in the existing literature, which helped in directing the aims and objectives of this research. Methodologies will be explained followed by a full analysis of the outcomes achieved along with their discussion. Finally, the conclusion of the research study will be presented along with some recommendations for future studies to address any outstanding issues identified during the literature research stage.

1.2. UAE and Dubai

This research involves a case study performed in the city of Dubai in the United Arab Emirates (UAE), which is a country with a hot climate. In such climatic conditions, it is important to manage the solar radiation entering the indoor spaces. The need for controlling the heat is to reduce the effect it has on the thermal and visual comfort of the building users, especially in areas close to the glazed windows. Negative health effects can be caused by exposure to excessive sunlight, which can cause fatigue and insomnia (Aboulnaga, 2005).

Due to the increasing economic and population growth in Dubai, energy consumption is increasing drastically. Therefore, sustainable strategies related to energy efficiency, regulatory frameworks, and sustainable events are being embraced in Dubai to help reduce this increase in energy consumption. Studies have shown that energy consumption grew by around 4% over the six years from 2009 to 2014, with a projected further 5% increase anticipated by 2020, as presented in Figure

1.1. In order to slow down this growth, green building design methodology has been implemented in governmental building regulations, such as in the Estidama in Abu Dhabi and Sa'fat in Dubai, through rating systems (Karlsson, Decker, & Moussalli, 2015).

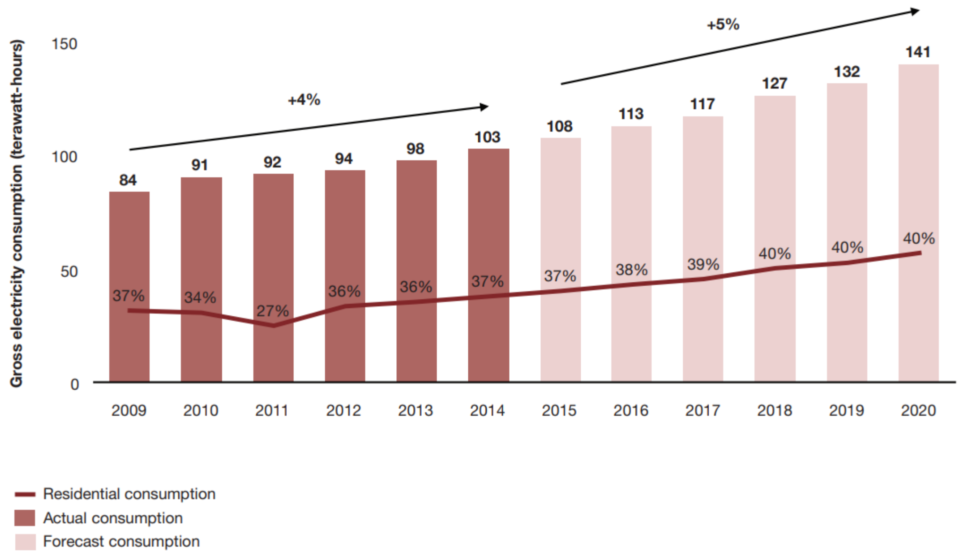


Figure 1. 1UAE energy consumption over the last decade (Karlsson, Decker, & Moussalli, 2015)

As a strong initiative to resolve the energy consumption issue in Dubai, the Dubai government developed a new version of its green building evaluation system, Al Sa'fat, which consists of four categories: Bronze, Silver, Golden, and Platinum. The Silver Sa'fa is required for private villas and industrial buildings, whereas the Silver Sa'fa is obligatory for all types of buildings, and the rest of the categories are optional. A simulation study was conducted to check the impact of Al Sa'fact regulations on buildings. The results showed increases in the energy savings of buildings through implementing Sa'fat categories of 7%–32% according to the category followed. (Zid 2016).

As a hot and humid country, Dubai's temperature can reach up to 49 °C during the summer season with a high humidity of 100% (Attia, 2017). However, most commercial buildings in Dubai have fully glazed facades that result in discomfort due to the undesired heat gain for the users. Reduced daylight in an office space and solar gains can affect the performances of the workers in a building, but can be tackled by enhancing the glazing system, such as by using shading systems that eliminate the solar exposure and reduce the discomfort (Bach & Bourbia, 2016).

1.3. Research Motivation

The main motivation for this research is the abundant use of external shading devices on fully glazed facades purely for aesthetic purposes. According to a study in 2017, around 40% of the world's total energy was consumed by buildings, with around 40%–60% of the total heat loss/gain occurring through the building (Cuce and Cuce, 2019). Therefore, the motivation behind this research paper to encourage designers and developers to apply fixed external shading devices rationally in order to improve the indoor environment and the energy consumption of buildings. In particular, this study aims to appraise the performances of external fixed shading devices on office buildings in hot climates that are fully glazed. The main motive was also to improve and assess the effects of these fixed external shading devices on the indoor climate comfort and on the performances of the employees in the work place.

Having to work in a fully glazed building with a shading device that barely has any impact on the indoors environment encouraged me to carry out this study to emphasize the importance of analyzing the best case scenario for the applied shading devices in the early design stages.

1.4. Problem Statement

Designing shading devices on a building's envelope to reduce the sunlight and heat and to impact the energy consumption of the building should be properly contemplated. Several research studies have proven the impact of shading devices on saving energy in a hot and humid climate. However, most designers tend to design external shading devices as an aesthetic feature rather than as a tool for energy conservation. Delays in performing a proper energy analysis of the shading system design can result in the designers and builders ignoring the findings and therefore the impact of the designed shading system is not as efficient as it should be.

Therefore, shading devices require careful consideration at an early stage of the design process, especially in an office building's façade, which commonly has a high window to wall ratio

(Shahdan, 2018). This paper aims to analyze the benefit of external fixed shading for achieving better energy conservation in a hot-humid climate like Dubai.

1.5. Research Aims & Objectives

The main aim of this research is to measure the impact of different fixed shading typologies on the energy consumption of an existing office building in Dubai Design District. As most office buildings in Dubai are fully glazed to achieve the desired aesthetic value, this research will highlight the importance of selecting the correct fixed shading devices for an office building to ensure they have the desired impact on the overall thermal and visual comfort of the employees. In addition, the research will focus on external fixed shading devices since they have been proven to be more effective than internal shading systems in reducing heat gain and solar radiation. Fixed shading devices will thus be investigated in this research since they have been proven to be more practical in the UAE than movable kinetic shading devices. The design scenarios for the fixed external shading will be: horizontal louvers, vertical find, vertical louvers, and an improved design alternative to the exiting shading design currently applied on the façade of Dubai Design District office buildings.

The main objectives of this research are listed below:

1- Observe the energy performance of each fixed shading typology as tested in the design scenarios.
2- Identify potential savings by the use of these fixed shading devices through using energy modeling simulation software, such as IES VE.
3- Discover the impact of the façade on the indoor environment after applying the shading devices on the building envelope.
4- Evaluate and compare the outcomes with other research papers relevant to this research as identified in the literature review.
5- Highlight any limitations and knowledge gaps relevant to this research and propose research recommendations for future researchers.

6- Test the impact of the external fixed shading on the indoor lighting levels to reduce the solar gain and glare on screen monitors to improve workers' visual comfort.

1.6. Research Focus and Limitation

This research focuses on optimizing the external fixed shading system strategy to improve the indoor climate as well as the visual comfort of a fully glazed office building. The research will study several scenarios involving different external shading device typologies, which will be validated on an existing case study of an office building located in Dubai. The study aims to improve the performance and increase the benefits of external shading devices on office buildings since the case study selected already includes fixed external shading devices. However, this thesis is aimed at bridging the gap between designing shading deices for aesthetic purposes and actually taking full advantage of these devices applied on the façade of the building.

In addition, buildings located in sites with similar climatic conditions to Dubai will be able to use and benefit from the outcomes of the research to help them select and apply the most beneficial fixed shading device for the building. Furthermore, different research papers with different shading systems will be studied to find the best tools to measure the performance of the building indoor environment and visual comfort.

One of the research limitations is the extent of data collection and analysis, as it is not possible to get all the required information from each and every tenant. Therefore, data will be collected for one typical floor and multiplied by the floor numbers to get an estimate, which can then be validated with the IES VE base case model.

1.7. Dissertation Content and Structure

The paper includes six chapters that are listed below as follows:

- Chapter 1: Introduction. This discusses the information on fixed shading devices as well as provides an overview of the importance of providing it in the UAE. Also, this chapter includes the list of the research aims and objectives as well as the problem statement in addition to outlining the focus of the study and its limitations.

- Chapter 2: Literature review. This includes discussions on the shading devices, their impact, and their history. The importance of external fixed shading devices will be highlighted to explain the motivation behind this research topic. In this chapter, the shading typologies will be mentioned to explain why the fixed shading device was selected for this study. Also, different fixed shading device applications will be investigated and mentioned in this chapter.
- Chapter 3: Methodology. This covers the different methodologies used to study and implement fixed shading devices to investigate their impact on the building performance and energy conservation. It will also describe the types of software used to do the simulations for this research and the methodological framework for this research.
- Chapter 4: Case Study of Dubai Design District. This chapter talks about the building selected for this research and introduces the building features, location, and conditions. The climatic conditions are also explained in order to conduct the base case and validate the use of IES VE software as the main tool for this research.
- Chapter 5: Results and Analysis. This includes all the results and analysis of the different design scenarios conducted on the case study. This chapter will also include a comparison between the different scenarios for the fixed shading device behavior on the indoor environment of an office space. The results will be compared with the base case generated from the data collection and therefore any energy savings and lighting performance will be detected and analyzed carefully.
- Chapter 6: Conclusion. A summary overview of the research paper is given here, where the results are discussed and the findings are stated. The research limitations and the contributions to the field will be acknowledged in this chapter along with the future recommendations for any future studies.

CHAPTER TWO

LITERATURE REVIEW

2. Literature Review

2.1. Shading devices

The building sector consumed around 40% of worldwide energy production and generated 1/3 of greenhouse gas emissions. The building consumption of the energy varies through its life cycle stages, mainly through the operating location, where around 35% to 60% is consumed for cooling, ventilation, heating, and artificial lighting. Designing and constructing energy-efficient buildings can enhance the energy performance of the construction through their life cycle.

Some newspapers appear to be testing automatic louvers with lighting controls. For example, Hammad and Abu-Hizleh (2010) examined the annual energy savings achieved by adding functional external louvers on the office building in Abu Dhabi. The method used is IES-VR software as a simulation tool. Their results showed no substantial difference in savings between the two forms (at an appropriate angle), where the difference was only about 3%. Therefore, the use of a dynamic louver system in the climate of the United Arab Emirates is not needed due to the extra cost and effort (Hammad and Abu-Hizleh, 2010). Therefore, a fixed louver system is more practical and cost-effective. For this reason, this study has focused on static dinghy systems.

A study by Bellia et al. (2013) was done on an office building in Italy. The study was done on the effect of shading devices on energy demands. IT was based on three different climates, where the results showed that adding shading devices on building in hotter climates is more practical than in cold climates. The results showed that the savings in Milan (cold weather) were simulated to be 8% as critical 20% in Palmero (Bellia et al., 2013).

Various strategies and methods are developed for each stage of the project lifespan to minimize the building energy consumption, divided into three main phases: prebuilding, operation, and post building. The essential methods selected in the prebuilding phase include setting an appropriate site, building configuration and envelope, proper space organization, suitable building material, and landscape design. At the same time, the operation phase consists of both construction strategies and the building usages process. In the last phase, the energy-efficient process covers building demolishing and recycling (Yüksek and Karadayi, 2017).

As mentioned before, various energy-efficient methods could be used through the building lifespan; however, only building envelop enhancement will be studied in this paper.

The most crucial elements of any building functionally are the exterior shell, which considers the first defense line against physical, environmental, and excessive climatic conditions exposure based on its unique location and design (Sandak, Sandak, Marcin, and Kutnar, 2020). The envelope of the building is separation barriers between the exterior and interior environments of the construction, which includes the floors, walls, doors, glazing elements, roof, and all the connection joints. In addition, it must meet the economic, aesthetic, and security factors because the design and construction of the building skin is a complex process that integrates science, art, and craft to attain an efficient economic and operational building performance. (Kassem and Mitchell, 2015).

De Oliveira Neves and Marques (2017) mentioned that the building envelope has a tremendous effect on Indoor environmental quality and air quality energy efficiency, and the total project budget. According to several studies, around 70% of energy-conserving occurred through appropriate identification of the building's configuration and materials selection regarding project local climate. The skin of the building responsible for controlling and filtering the natural light, intake air, heat, and cold, therefore in summer, it decreases the heat gain while winter minimizes the heat loss (Yüksek and Karadayi, 2017).

The selection for appropriate and energy-efficient building skin strategies varies based on the project's climatic conditions and location, where the envelope enhancement adopts both active and passive design processes. The active design strategies utilize mechanical energy systems, but the passive design methods harness the environment's energy resources such as sun heat, daylighting, and natural ventilation (Zou, Zhan and Xiang, 2021). Passive design strategies contribute to preserving thermal comfort by utilizing the natural and climate parameters to achieve the maximum and appropriate benefits and minimize heating, cooling, and lighting mechanical systems.

Passive design methods vary based on the climatic and microclimatic conditions, project location, and targets. As in cold climate regions, a building is designed and constructed to absorb solar heat, achieve proper daylighting and avoid winter wind (Tendulkar, 2017). While in hot and dry climate regions like UAE, cooling is the main concern; therefore, the envelope of the building employed strategies that decrease the daytime heat gain, increase heat loss through the night-time and enhance cool ventilation accessibility. The passive cooling design used various technologies and methods which improve the adaption of the building envelope in the hot and dry climate, such as building orientation and configuration, shading devices, insulation material, thermal mass, glazing elements, and cool roof (Altan and Aoul, 2016) & (Keeler and Burke, 2016). The author of this research will concentrate on shading devices.

2.2. Importance of Shading Device

Shading Devices might be one of the primary architectural elements that impact the city's urban fabric. However, they also are essential in our communities for several reasons. First, these shading devices sometimes help design our urban fabric and define the building's façade aesthetics. Not to mention the effect on our daylight, lighting energy, and cooling /heating consumption depending on the building orientation and climate. Therefore, a well-designed shading device system is essential for a more energy-efficient building design and a better lifestyle and human performance.

2.2.1. Energy Consumption

In a Cold climate, sunlight entering the space will provide passive solar heat gain, which will reduce energy consumption for the use of the heater. On the other hand, in Hot climates, the lousy design of sun control will result in excess solar gain, which will require high energy consumption to cool the space.

2.2.2. Lighting

Another important use of controlled sunlight gain is receiving good daylight instead of the discomforting direct sunlight, which will again directly impact the lighting energy consumption and affect human performance due to the discomforting glare that will be caused.

A well-designed building will reduce the heat gain in a building or space, reducing the energy consumption and cooling requirements and improving the quality of the light received into the spaces. Energy efficiency increase is reported to be reduced significantly between 5% to 15% depending on the shading devices' location and quantity.

2.2.3. Design of the building

In addition to all the energy conservation and improved lighting in the building, it is essential to notice the impact of the shading design on the building façade. A well-designed shading system will achieve a better energy performance and act as an essential aesthetic component in the building design. Which can either be either well-integrated or unappealing within an urban context. (Prowler, 2016)

All these impacts are achievable only when the design is done correctly and well-studied regarding the sun study, building orientation, and climate conditions. This report will further explain the correct steps to achieve the optimum design for shading devices in an office building.

2.2.4. Visual Comfort

Shading devices have a tremendous impact on the visual comfort of a given space, especially in an office space occupied with computer screens and requires a particular lighting system. Therefore, achieving the best amount of daylight into the entire space will help reduce the need for artificial lighting and eliminate the glare caused by the direct sunlight hitting the computer screen. Unlike thermal comfort, which is related to the air quality and temperature of the space, visual comfort is related to the light quality, glare, and brightness. Visual comfort is determined by few factors such as the spatial geometry and orientation, size and glazing openings, and surface materiality and color specifications. (Steane & Steemers, 2004) All these factors can be tackled by a successful external fixed shading system provision.

2.3. History of Shading Devices

Throughout history, architecture's primary task and purpose are to create a suitable human shelter despite the change in time, culture, and energetic parameters. The building skin is considered the main element that is contemplated to help prevent any external discomfort from temperature, wind, radiation, and climate conditions as it is considered the load-bearing mechanism of a building. The building envelope is an important design factor and a curtail factor in the energy usage of the building. Therefore, shading devices have gone through profound changes through time to reach today an advanced design mechanism that helps in improving the visual comfort of the users and improve the energy performance of the building. (Nady, 2017)

2.3.1. External Shading Devices Through History

Throughout history, architecture's primary task and purpose are to create a suitable human shelter despite the change in time, culture, and energetic parameters. The building skin is considered the main element that is contemplated to help prevent any external discomfort from temperature, wind, radiation, and climate conditions as it is considered the load-bearing mechanism of a building. The building envelope is an important design factor and a curtail factor in the energy usage of the building. (Nady, 2017)

The most common uses for shading devices are to regulate in-light and enhance privacy. In hot climates, the most significant purpose is to inhibit the advancement of the heat during sunny hours

(Langston, 2008). The expected outcomes in reduced requirements for AC systems permit households and organizations to save money and contribute to saving the planet, such as reducing carbon emissions.

Since prehistoric times individuals employed different means to block the sun from contact with their homes. In tropical environments, ancient designers used to keep solar radiation off the building's cover's impervious solid components where conceivable. Special care was to be taken to shade the windows to minimize the incoming heat and prevent the risk of high temperatures. The following are examples of external shading devices used in ancient times.

2.3.2. Iwans

The material used to make these external shading devices consist of stone, bricks, and concrete. Iwan is an external shading structure used in conventional Islamic architecture; however, it is also prevalent in modern architecture. It first materialized during the Parthian Empire (247 BC – 224 AD), and after the 11th century, it was extensively employed within monumental Islamic architecture. Consistent with recent studies, a south-facing iwan can decrease a structure's energy utility by 32%. However, Iwans cannot be executed if the building is already constructed (Mumovic and Santamouris, 2013).

2.3.3. Shutters

These external shading devices are made of wood. Initial sandstone shutters with fixed boards were completed in ancient Greece between 800 BC and 500 BC. Afterward, the notion was rented by Mediterranean designers, and shutters made of wood with movable louvers emerged. In medieval Europe, solid shutters were utilized for safeguarding the household inhabitants, both from the creepy-crawlies and the thieves. Today, people denote the word shutters to either slotted or solid window cover fixed outside.

2.3.4. Venetian Blinds

Although many people have believed that the Venetian blinds originated from Venice, yet it is still unknown. It was also known that Egyptians used a reed to create a similar blind and the Chinese with bamboo. Nonetheless, the Venetian Blinds were made out of wooden horizontal stats with a cord to control the openings of the blinds. They become popular in the 20th century as they were made of aluminum or plastic and were mainly used in office spaces.

2.3.5. Mashrabiya

According to history, the Mashrabiya, a window overlooking the street in Islamic architecture, was a name given to a space enclosed with a wooden perforated screen where drinking water jars were kept cool. The origin of the work Mashrabiya comes from the Arabic word "yashrab," which means "drinking." (Fathy,1986).

The Mashrabiya dates back to Egypt as it was flourishing during the Tulunid era (868-905); most buildings were made of wood.

The industry of Mashrabiya construction has gone through all different eras and times, from the Ayyubid (1171-1250) to the Mamluk era (1250- 1517). Since the Mashrabiya was offering great privacy, it was prevalent in the time of the Islamic Ottoman era (1517-c1805) as it also was using in various Arab regions as a unique artistic feature that beautified the streets (Maspero,1974). The Mashrabiya is commonly used on the façade of vernacular buildings and an interior feature acting as a privacy partition that would allow air circulation from one space to the other. (Feeny,1974)

However, the popularity of the Mashrabiya started to decline due to modernization and the abandonment of vernacular architecture. The decline in the use of the Mashrabiya was summarized into two aspects: one is due to the cultural abandonment of the vernacular architecture and the second aspect is due to the impracticality of manufacturing the Mashrabiya structures.

Later, the name Mashrabiya was given to any wooden lattice screen with a circular perforation that provided air ventilation for space. The screens were all handmade with a baluster that varied in design—old Mashrabiya in Cairo, Egypt 1640s (Özsavaş Akçay and Alotman, 2017).

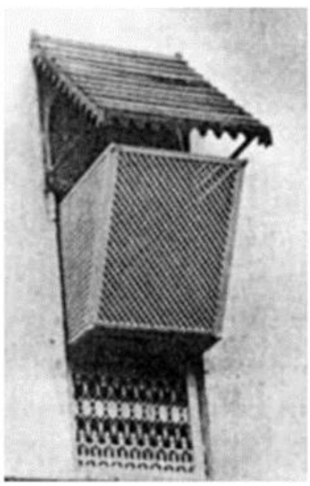


Figure 2.2: Old Mashrabiya design in Cario source: Özsavaş Akçay and Alotman, 2017

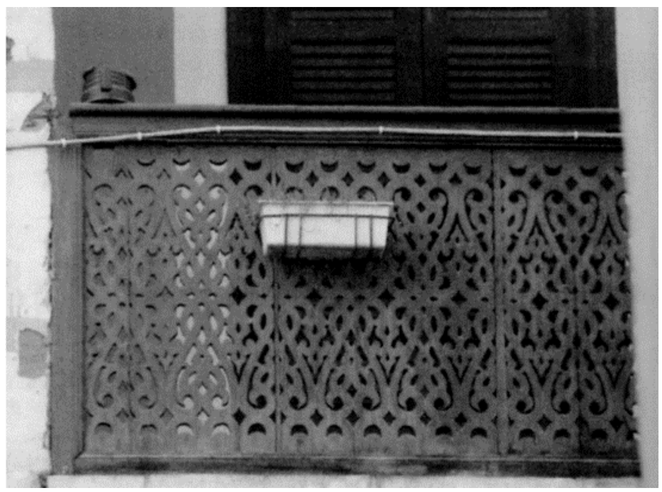


Figure 2.1: Mashrabiya with wooden perforations in one panel source: Ashour, 2018

One of the fundamental architectural monuments of Islamic Architecture, the Mashrabiya, was used vastly in most Islamic nations throughout history. The main impact the Mashrabiya has on the building is sunlight, airflow, and temperature. The Mashrabiya consists of an upper part made of perforated wood and a lower solid wooden base. The lower base has a height between 30-50 cm, while the upper part is between 60 to 80 cm. The Mashrabiya comes wither in one panel or divided into several panels, as illustrated in Figure 2.4 below.

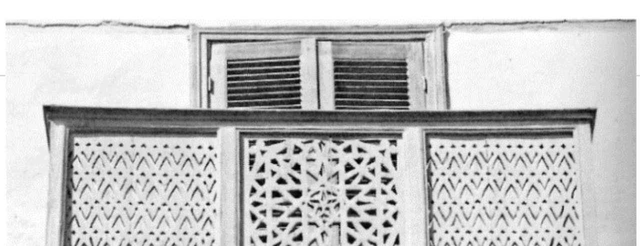


Figure 2.3: Divided panels of wooden screens source: Ashour, 2018

2.4. Types of shading devices

The selection of appropriate shading devices varies according to various factors, for example, building configuration and function, location, orientation, sky conditions, climatic conditions, and more. Therefore, shading devices are varied. Solar shading elements are categorized based on their application into external and internal shading devices (Faisal and Aldy, 2016).

2.4.1. Internal shading devices

Curtains, roller, or blinds considers used in the building as an internal shading device, where they are installed inside windows. They specifically promote reflected and diffuse light, where blinds and curtains control daylight brightness while louvers changed light direction. In General, internal shading devices efficiently control natural lighting and glare since they block sunlight after it crosses glazed elements. However, they are thermally ineffectual because most of the sunlight short wave heat absorbed by the interior air, which requires a cooling system to be removed from the internal spaces. In addition, they can be adjusted, retracted, and maintained easily, as well as available in various forms and prices. (Stack, Goulding, and Lewis, 2013).

2.4.2. External shading devices

External shading elements are installed within the building façade to hinder sun radiations before they pass through glazed features to the interior environment. Therefore, they are considered to be the most efficient in minimizing the heat gains. Further, they affect the building performance in terms of daylighting and natural ventilation. From the daylighting aspect, external shading contributes to everting glare and decreasing the intensity of light. Moreover, they could be utilized as wind capture in terms of natural ventilation. External shading also impacts the project envelope aesthetic characteristic.

Consequently, they require crucial consideration and deep thoughts for designing and construction. Otherwise, they may negatively influence the building energy performance, thermal and visual comfort (Wong and Istiadji, 2003) & (Stack, Goulding, and Lewis, 2013). According to Carletti, Sciurpi, and Pierangioli (2014), external shading systems are mostly more expensive and require more maintenance than internal shading devices since they are constantly exposed to various atmospheric factors.

Solar external shading devices are either fixed, moveable, or combined could be implemented in building skin. Static (fixed) shading devices are an outstanding characteristic in vernacular architecture, predominantly used in the building concerning various environmental conditions. Several typologies and materials of fixed shading elements were used, such as horizontal overhangs and vertical fins shading, which could have been made of wood, concrete, tree branches, bamboo, and fabric. They have been known widely as efficient monitoring glare and solar heat gain and minimizing cooling energy consumption in various climatic conditions (Al Dakheel and Tabet Aoul, 2017).

While the moveable (Dynamic) shading elements can enhance the shading performance by altering their positions and orientations, properties according to interior needs, and exterior climate. The implementation of dynamic shading systems minimizes unpleasant and excessive solar heat gain, improves natural light, increases natural ventilation utilization, may in some systems generate energy, and enables the building occupants to adjust the shading elements according to their thermal and visual comfort and requirements. Further, they can be located either within the openings glazing or erected overbuilding envelope. The implantation and maintenance of the active shading system are complicated, expensive, and require extensive study and careful analysis. (Al Dakheel and Tabet Soul, 2017 & Stack, Goulding and Lewis, 2013).

Moreover, vegetation such as evergreen trees, vines, and shrubs consider as one of the external shading devices; if they are placed in appropriate locations beside the building could provide sufficient shading, which enhances building energy performance and thermal comfort. (Stack, Goulding, and Lewis, 2013). Despite having various features, the primary usage of shading devices is to reduce the solar radiation angle which hits the glazed building elements.

Figure 2.5: static shading devices in Aqua Tower Hedrich Blessing envelpe, source: Aqua Tower de Studio Gang | Edificio de Oficinas, 2020.

Figure 2.4: kinitec shading elements of Al Bahr Towers source: Ltd., Glass, KG and Corporation, 2020.

Figure 2.6: Vegetation façade in Parkroyal Collection Pickering hotel
source: Dense and Green Building Typologies, 2020

As mentioned above, solar external shading devices are fixed, moveable, or vegetation. The author to conduct this research will concentrate only on fixed external shading device types and their impact on the proposed building energy and daylighting performances.

2.5. Static external shading device

Static shading elements are used for a long time in various building types, especially in recent decades when the designers developed their commercial, health care, offices, residential and institutional buildings based on curtain wall systems. Nevertheless, controlling daylight and heat gain in curtain walls with the conventional shading system is complicated. Therefore, static shading systems have developed over time in configuration, size, material, and function to attain an adequate and appropriate interior visual and thermal comfort with an eye on the building's architectural aesthetic, function, and requirements (Shrestha, 2016).

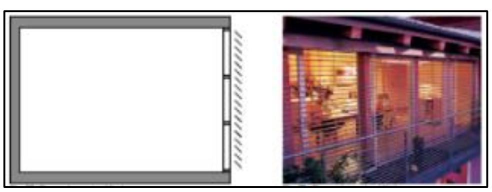
As presented in Hans's (2006) research, fixed shading devices implemented in the building in their primary orientation either horizontally or vertically or could be integrated. They are installed concerning the sun path of the building location and the consequence solar angles. They are also building roof projections and balconies considered as fixed shading elements. Orientation, location of the building, and solar angles are significant factors in selecting the optimum type of static shading system. Therefore, it is crucial to study the main typologies of fixed shading components.

2.6. Static shading devices typologies

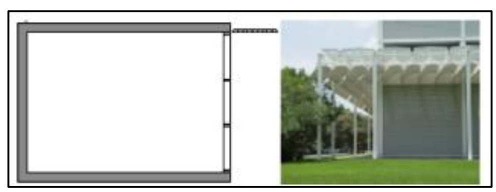
As mentioned before, fixed shading devices' main classifications are separated into vertical, horizontal (overhangs), and egg-crate, a combination of horizontal and vertical.

2.6.1. Horizontal shading elements

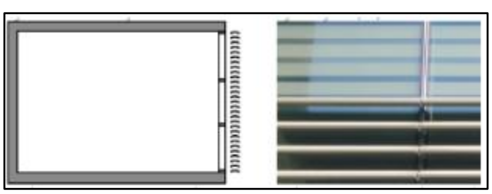
A horizontal fixed shading device is the most common shading element used to minimize sunlight at high altitudes. Several forms of horizontal shading can be introduced in the building design to achieve the maximum benefits, such as overhangs, ventilation blinds, fixed sunscreens, fixed blades, horizontal louvers, lamella structure, etc. (Ardekani, 2014).



External fixed horizontal venetian blinds



Horizontal fixed blinds works as overhang



Horizontal fixed blinds

Horizontal fixed overhang

Horizontal fixed louver

Horizontal fixed shading in cavity

Figure 2.7: Various typologies of horizontal shading devices source: Ardekani, 2014

Horizontal shading elements are the most appropriate and effective for the building south façade in comparison with the other fixed shading device typologies, but sometimes when the sun position is getting lower, the façade requires a broader shading device to attain enough shades for the area (Ardekani, 2014). Horizontal shading overhangs are the most popular configuration and the simplest devices placed in the construction for dominating direct sun radiation at a high angle. Further, they are preferable in the northern hemisphere to be implemented on the south building elevation, while in lower latitudes, they shade east and west faces. Moreover, in Mediterranean regions where the warm climate is dominated, designers placed louvered overhangs over the building envelope to freely let the cold breezes flow. Generally, to obtain the most effective performance of overhangs devices, they should expand on both sides of the glazed elements sufficiently where the length of the overhangs is specified by the window width while the depth defined by the height of aperture, latitude, and the distance between the overhang shading device and glazed panes (Stack, Goulding and Lewis, 2013). In some regions where the wind velocity is high, it is helpful to install shading elements in the gaps between glass panes in contrast with internal shading elements. Nevertheless, it is better to ventilate the cavity to dismiss solar heat to the outside (Ardekani, 2014).

2.6.2. Vertical shading elements

In comparison to horizontal shading devices, vertical shading devices are very efficient for solar daylight at a low angle, especially in the morning, afternoon, and evening time. They are beneficial for both west and east facades. Moreover, these devices enhance envelope insulation during the winter seasons. Also, vertical shading elements according to the sun's locations and angles can be designed and installed in various angles such as vertical fins, slanted vertical fins, vertical louvers, and pilasters. Implementing vertical shading components on the south (east and west) is not efficient due to the high sun angle in hot months (Faisal and Aldy, 2016) & (Ardekani, 2014).

External fixed vertical fins External fixed slanted vertical fins

Figure 2.8: Various typologies of vertical shading devices source: Faisal and Aldy, 2016

2.6.3. Egg-crate shading elements

Egg-crate components incorporate vertical and horizontal shading devices, as shown in the figure below (1.6). They are very efficient in blocking the sun's radiation at both high and low angles. Therefore, they are preferably implemented in hot and dry regions (Ardekani, 2014) & (Ejroushi, Smeda, and Bannani, 2013).

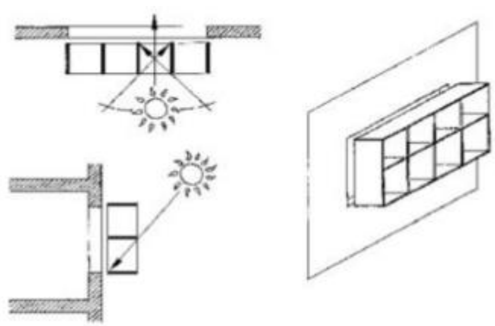


Figure 2.9: Egg-crate shading devices source: (Sahu, 2020)

Generally, louver in horizontal and vertical external shading devices can be designed with different section profiles such as ellipsoidal, gull wings, rectangular, diamond, curved. Further, the louver orientation and angle can either settle to sun position in summer or be adjusted by solar light sensors, which provide several orientations following sun path (Carletti, Sciurpi, and Pierangioli, 2014) & (Ardekani, 2014).

Figure 2.10: Louvers shading components with various directions to enhance shading source: tago architects: sur yapi offices, turkey, 2020

2.7. Factors that Affect Fixed External Devices

External shading and sun control devices are a significant facet of many energy-efficient building design approaches. Significantly, buildings that use passive daylighting or solar heating frequently rely on ingenious external shading and sun control devices. Some factors influence the efficiency of these devices, which consist of;

2.7.1. Climate

It is a datum that the weather changes daily, and the earth's position towards the Sun changes through the year. For example, external window shading is an outstanding technique to inhibit undesirable solar heat gain from accessing a habituated space during freezing seasons. Shading can be delivered by natural redesigning or constructing components such as canopies, outcroppings, and grills. Some shading devices can also work as reverberators, known as light shelves that bounce natural light for daylighting deeper into building centers (Robinson et al., 2015).

The design of active shading devices will be determined by the solar orientation of a specific structure front. For instance, simple fixed projections are very operational, covering south-facing windows during the summer when sun angles are high. The same horizontal device is unproductive at filibustering low afternoon sun from accessing west-facing windows during the summer's ultimate heat gain days.

2.7.2. Type of Glazing

Exterior shading devices are mainly operational, along with transparent glass facades. However, high-performance glazing is now accessible that has very squat shading coefficients (SC). When computed, these new glass products decrease the necessity for external shading devices. A distinctive exterior shading device such as a window with one or two layers of glazing permits approximately 75 to 85 percent of the solar energy to access a structure that has an undesirable influence on cooling bills and summer luxury, particularly in hot climates (Dixon, Connaughton, and Green, 2018).

2.7.3. Position of the Sun

To correctly design external shading devices, it is essential to comprehend the Sun's position in the sky during the cooling season. The site of the Sun is articulated in terms of azimuth and altitude angles. The altitude angle is the Sun's direction above the horizon, attaining its outer scope on a particular day at solar noon. On the other hand, the azimuth angle, also called the bearing angle, is the Sun's prognosis's approach onto the ground plane comparative to the south (Yao, 2013). External shading devices can have a vivid influence on a building's exterior. This influence can be for the better or, the worse, the earlier within the design procedure that shading devices are reflected. They are more likely to be gorgeous and effectively incorporated into the general structural design of a project.

2.7.4. Materials

An extensive assortment of adaptable shading products is commercially obtainable, from canvas canopies to solar screens, vertical louvers, shutters, and roll-down blinds. While they frequently perform well, their practicality is restricted by the necessity for physical or power-driven operation. Permanency and preservation matters are also critical concerns. When planning shading devices, it is essential to carefully assess all operations and maintenance (O&M) and safety insinuations (Dixon, Connaughton, and Green, 2018). In some places, risks such as earthquakes and nesting birds may decrease integrating external shading devices in the design. The prerequisite to uphold and clean shading devices, mainly treatable ones, should be factored into any life-cycle budget scrutiny of their utility.

2.8. Advantages and Disadvantages:

shading devices are considered integrated components of the overall building skeleton; they are also designed to reduce and control excessive direct sunlight from internal spaces. As well and avoid any discomfort of the glare caused by the light entering a glazed building since shading devices have been going through a historical change and improvements. There are many types of shading devices with different advantages and disadvantages. However, since this research considers Fixed Shading Devices, this section will state the advantages and disadvantages of this specific shading type.

2.8.1. Advantages

1. The impact of shading devices on a glazed building could be drastic in terms of the construction cost, energy consumption level, and the climate comfort of the building, depending on the building use and the climate condition of the building location.

2. Fixed shading devices can reduce the direct solar radiation, which is directly related to the unwanted buildup of solar heat gain inside the building, resulting in reducing the heat gain by 40%.
3. Fixed Shading Devices have a significant impact on the direct sunlight radiation, which is the most influential radiation which has the most immediate impact on the cooling load of a commercial office when it reaches windows and other apertures since it is instantly directed into the open-plan space interior. Therefore, using Shading devices will have an incredible impact on reducing air conditioning cooling load in the building located in a hot climate. Hence, saving energy and improving the thermal performance, especially in high cooling load and high glazing percentage buildings.
4. Providing the proper shading device on a building allows the daylight to enter and reduces lighting indoors, which reduces energy consumption, especially within open-plan offices.
5. Not to mention the significant impact on the Visual Comfort of the internal space by muting and scattering intense lighting that causes glare, especially in office buildings that are usually fully glazed no a day. Shading devices are considered anti-glare systems that help achieve glare-free workplaces, which mainly rely on monitoring workstations that require visual comfort.
6. Another advantage for shading devices used over history is the provision of privacy and protecting the inside of the building from the external environment Datta (, 2001).
7. Unlike movable shading devices, fixed shading systems do not require as much maintenance as movable parts (Bahr,2009).

2.8.2. Disadvantages

1. Providing shading devices on a building façade might block the users' view and contact with the employees with the surrounding environment.
2. In addition, using external shading devices might minimize the natural daylight intake entering the building, which increases the need for artificial lighting usage and hence increasing the energy consumption from the lighting aspect. External devices cannot e uniformity of lighting within the space, which is done through usually using advanced glazing systems that can redistribute the radiation room the façade area into space evenly.
3. The use of fixed stationary shading systems does not allow flexibility to adapt the shading aspect to the sun's direction, resulting in technical drawbacks in terms of shading, clarity, and use of daylight.
4. In addition, external shading devices act as barriers between the building's internal environment and the external noise level within a loud environment, which helps control indoor acoustic comfort. (Aksamija, 2013)
5. Unlike indoor shading systems mounted behind the building, external fixed shading devices might be more challenging to install and install. In addition, the maintenance and cleaning of these shading devices are more problematic.
6. Reflected and diffused light radiations are not controlled by eternal shading systems due to the radiation's wider angles of incidence, and therefore, it is more effectively controlled by internal shading systems.
7. Another significant advantage is the building envelope aesthetics, in which the fixed external shading could be a great addition to the building envelope design, making it iconic and recognizable within the urban fabric (Paul, 2019).

2.9. Solar shading devices selection considerations

Several factors affect the selection of solar shading devices, as presented below:

1. Façade orientation: The angle between the solar radiation and the façade window needs to be considered to select the optimum shading components. As mentioned before, horizontal shading elements are appropriate for the south façade where the sun's angle is high. In contrast, vertical shading devices are more suitable for east and west faces.
2. Windows type: Materials and types of windows require to be taken into account. Also, if the building needs to cool down through natural ventilation, especially in summer, the designer should consider that the solar shading devices do not minimize wind flow capacity.
3. Solar shading devices color: It is better to install shading components with light colors to reflect the sun's radiation.
4. Shading component durability: Exterior shading elements raise the cost of the building budget. Therefore, it is essential to select durable shading elements, and they are well installed in building skin without neglecting the maintenance methods and cost. Moreover, they need to be compatible with the location weather, that solid shading components light shelves usually used to reflect solar radiation in hot and moderate climates. However, they are not preferable in the regions with snowy weather because they will gather snows and ice (Hotel Energy Solutions (HES) | UNWTO, 2020).

2.10. Fixed façade Application

Many buildings are recognizable and distinctive due to the fixed shading system used. The application of these fixed shading devices is not primarily aesthetical but mainly practical. The need for applying external fixed shading on a building's envelope varies. There are many factors to consider, like the orientation of the building, the climate conditions, and the building's function.

Recognizing the need for external shading devices on an early stage helps integrate the external fixed shading in the façade design, resulting in an iconic feature that also provides a better climate and visual comfort. This section will discuss case studies of fixed external shading applications in different buildings by highlighting the main strategy features to indicate the impact of these applications on energy consumption. The following case studies are listed in table 1.1.

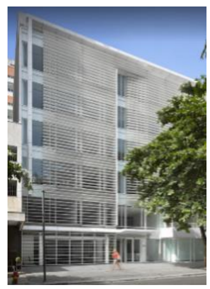
Typology	Vertical		Horizontal		Egg-crate
Case Study					
	Jackman Law Building – Canada	Cruzen-murray Academic Library- USA	Leblon Offices– Brazil	Public Service Office Building- Spain	Pam Centre Bangsar- Malaysia

Table 2. 1kinetic façade applications and typologies, edited source: Elzeyadi 2017

Jackman Law Building is an example of a vertical fixed shading system integrated into the building's façade design. It is an addition to the University of Toronto Campus. North America is more likely to integrate the shading systems into their building envelope; the Jackman Law building was designed with a simple rhythm of vertical shade fins. Vertical stone fins run the height of the crescent façade to shade from the south and west sun. After conducting daylight studies, the architects have spaced the fins to avoid blocking day

light coming into the building. The 2-foot depth and 5-foot center spacing of the fins helped mitigate the glare and improved the daylight intake into the deep spaces within the building.

Figure 2.11: Jackman Law building utilized external fixed vertical shading devices source: Hariri Pontarini Architects, 2020

Cruzen-Mur e of perforated metal spiraling around the round glazed building. This building was awarded an AIA Arizona Design Award in 2018 and is designed to follow several sustainable design solutions, both passive and active design measures to reduce energy consumption. Some of these sustainable measures are the geothermal heat pump system, insulated glass curtain wall, and the vertical fins that shade the building façade. The perforated metal vertical fins are carefully placed to accept natural light into the spaces at the appropriate times of the year.

Figure 2.12: Cruzen-murray Academic Library source: (Cruzen-Murray Academic Library, College of Idaho | Richärd Kennedy Architects | Archinect, 2020)

Leblon Office building in Rio de Janeiro is the leading alternative investment management firm in Brazil. The building consists of office spaces and private courtyards that include hidden vertical courtyards. The G+7 floors building was designed carefully to reflect the distinct building orientation, tackle the sustainable issues, and maximize its efficiency. To achieve maximum sun shading and privacy in the office building, the architect has introduced horizontal louvers along the western frontage, as shown in figure 2.14. This treatment maintained the visual connection with the outer environment while providing the desired protection and privacy needed.

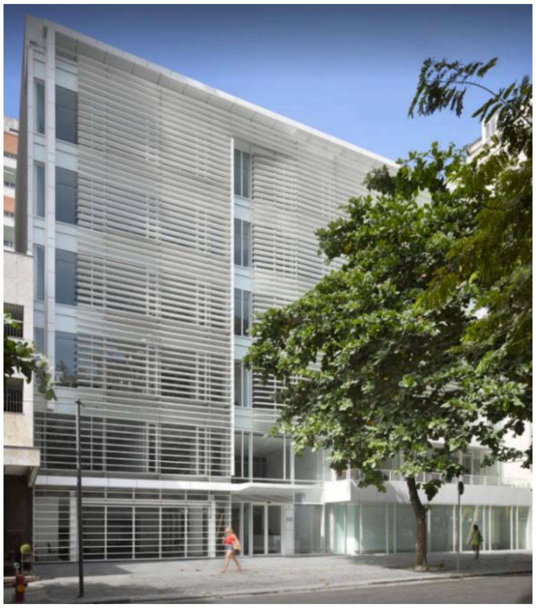


Figure 2.13: Leblon Office building implemented horizontal shading devices source: Leblon Offices / Richard Meier & Partners, 2020

The institutional building in Spain is an administrative public service office building. The building form consists of three volumes that overlap with rotations. The rotations of each volume are which is suggested by the building's plot. The first volume (ground floor) follows the geometry of the plot connecting the ground floor with the public realm. The second volume (first to the fourth floor) rotates to align to the streets, which projects as shown in figure 2.15.

Moreover, the third volume (fifth to the Sixth floor) is guided by a turn between the other volumes. The building's office space requires natural daylight. Therefore, the main façade consists of large windows that are carefully wrapped with translucent metal filters. These continuous horizontal louvers provide solar shading and privacy and a unique identity to the building envelope.

Figure 2.14: Public Service Office Building- Spain source: Offices in the Historic Centre of Barcelona BCQ arquitectura barcelona, 2020

The Pam Centre in Bangsar is the current headquarters of the Association of Architects of Malaysia. The design provides a distinct ventilation approach to the Malaysian Climate conditions. Box louvers, an important shading system in hot climates such as Malaysia, are the main facades of the building as shown in figure 2.16. In order to decrease solar coefficients, the egg-crate louvers are directed towards the North Westside. These box louvers are made of horizontal and vertical aluminum frames to provide adequate daylight. In addition to the solar shading system offered by this egg crate louver system, the architecture also provides stack ventilation that exists in the shape of the building by a vertical void and the other through the diagonally stacked stepped atriums that allow the air to flow directly from the lowest to the highest level.

Figure 2.15: The Pam Centre used egg-crate shading elements source: (The New Architecture Icon in Malaysia // The New PAM Centre, 2020

2.11. Study factor

As mentioned in the previous chapter, the study goals are to enhance the energy performance of the building and provide a sufficient amount of daylight during the working hours of the occupants after implementing various types of shading devices at the office building envelope.

2.12. Energy performance

Most people spend time inside the building either in their houses or offices. Therefore, in some countries building sector used more energy than another sector as transportation and industrialization. As presented in International Energy Agency, buildings consume around 42% of the global electricity production as shown below figure; in the UAE, where the dissertation case study location, the residential and commercial buildings consume around 60% of the total energy production (Alkhateeb and Abu-Hijleh, 2019).

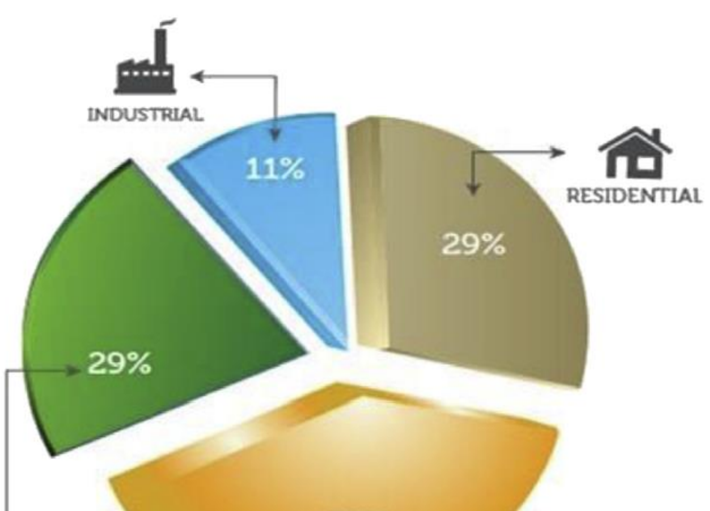


Figure 2.16: UAE energy consumption by different sector
source: Alkhateeb and Abu-Hijleh, 2019

Designing and constructing an energy-efficient building is preferable for several reasons, for example, minimizing electricity consumption used for heating, cooling, water heating, lighting, etc. Also, building-integrated energy efficiency technology can enhance the indoor level of comfort, reduce maintenance demands and cost, and improve the property's value. Furthermore, they contribute to reducing greenhouse gas emissions and the utilization of fossil fuels.

2.13. Daylighting

Generally, daylight incorporates all of direct, reflected, and diffused solar light, which can change indoor rooms from a dreary atmosphere to a joyful and comfortable place. Therefore, architects try to provide daylighting wherever in the building as much as possible. Office employees' surveys presented that workers prefer areas with sufficient sunlight with some artificial lighting. Moreover, previous studies indicated that spaces with enough daylights could provide several benefits related to the building users' health and productivity (Day)Lighting the way to a greener and healthier buildings | World Green Building Council, 2020).

Department of Energy (DOE) presented that lighting systems in all building types use around 25% electricity and 40% by commercial constructions. Around half of this consumption could be conserved by the efficient utilization of daylight. Offices, schools, museums, and libraries can reduce electricity consumption since lighting plays a vital role in these buildings. Therefore, the proper utilization of daylighting within the building minimizes the consumption of energy. Also, it can decrease the heating and cooling consumption of electricity because daylighting cooler in summer than other electrical systems, and in winter, it can heat the indoor spaces passively (Lechner, 2015).

Furthermore, in terms of building occupants' health, exposure to daylighting impacts circadian rhythm positively, which seeks to enhance people's work productivity and satisfaction with their surroundings. The surrounding exterior environment immeasurably influence humane health, that the uses of window and sunlight provide access to ecological information, links building users with the exterior world and recuperate and recovers their psychical health (Shrestha, 2016).

CHAPTER THREE

METHODOLOGY

3. Methodology

3.1. Overview

The methodology chapter introduces an examination of the study stages and steps. Each step of the study requires specific methods and tools to ensure the research validity, which later all of them will be defined and justified. Also, this chapter will show a review of similar research methods related to the study topic. The literature review presents that researchers used various methodologies to evaluate the impact of fixed shading devices in terms of thermal and visual comfort. Specifically, they mostly used the computer simulation method to conduct their studies. Moreover, it will introduce the study software used to evaluate proposed statics shading design models' energy and daylighting performance.

3.2. Similar studies methodologies

The daylighting and electricity performance evaluation for the fixed shading elements was conducted either by single or mixed methodologies; however, by reviewing the previous research, the most used methods recognized were simulation and field measurements methods, and a few were carried out based on the literature review methodologies.

3.2.1. Literature review methodology

The literature review is an essential part of conducting any research that introduces an extensive background and information that leads the authors to establish their studies; as presented in Bellia properly, Marino, Minichiello, and Pedace (2014) reviewed various papers related to solar shading devices. They concluded with several considerations that guide future researchers to conduct their investigations to build shading elements. Also, Kirimtat, Koyunbaba, Chatzikonstantinou, and Sariyildiz (2016) presented several types of shading devices that could be used on building facades. Also, they provided a list of previous studies that evaluated the impact of shading elements in different climatic regions to highlight the simulation models' significance for various shading element types.

3.2.2. Computer Simulation methodology

Researchers carried out various studies regarding shading devices' influences regarding thermal performance and visual comfort based on the computer simulation method. Simulation is an essential process to conduct different study types were the actual parameters and conditions are imitated and developed through computer software to evaluate and analyze them. It assists the researchers in prophesying the study outcomes for both simple and complex projects. Moreover, simulation gives an idea of the project performance without building it in the real world, which reduces the cost and time consumption, and risk. Further, it expands the investigation circle and provides several alternative solutions and concepts for the study. Meresi, in 2016, used Radiance software to evaluate the daylight performance for the classroom in Athens after integrated both light shelf and semi-transparent movable external blinds shading elements at the class façades in different models to select the optimum shading height, reflection, inclination, and reflection. Also, Alhuwayil, Abdul Mujeebu, and Algarny (2019) utilized DesignBuilder software to assess a multi-story hotel in KSA's energy behavior. Several scenarios were developed to consist of a specific type of shading devices such as vertical fins, overhangs, and louvers. Also, the author evaluated the payback period for the models. The study presented that the consumption of energy-reduced by 20.5% yearly compared to the base case after the utilization of shading devices, and the additional cost returned in two years. In kharga Oasis, Egypt, a study was conducted to investigate the influence of wooden solar screens on residential buildings through EnergyPlus software. The authors developed several models based on the changing for screens perforation percentage and depth to achieve the best energy performance. The study presented an enhancement in energy consumption that reduced around 20% in both West and south façade (Sherif, El-Zafarany and Arafa, 2012). Moreover, Shahdan, Ahmad, and Hussin in 2018 used Revit computer software to evaluate different configurations of shading device's effectiveness on a school building in Shah Alam, Malaysia. The study outcomes introduced a tremendous improvement in the reduction of energy, particularly egg-crate shading elements.

3.2.3. Qualitative methodology

Some of the shading devices papers were conducted based on qualitative methodology where the researcher was gathering data through observation, documentation, interviews, videos, questionnaires, etc. Faisal and Aldy (2016) observed around 172 building on Jalan Sudirman-Pekanbaru in their study. The research aimed to determine and study the shading devices utilization regarding form and function. The observation findings presented that there were two shading device categories in Jalan Sudirman, which were based on quantity and forms.

3.2.4. Mixed methodology

Furthermore, the study was carried out in Seoul, South Korea, by Cho, Yoo, and Kim (2014) to assess exterior fixed solar shading devices' efficiency. The research was conducted in three stages. In the 1st stage, the author used Ecotect and Daysim to evaluate sun shading and daylighting performance for 16 types of shading elements to select the most effective two devices. In the 2nd stage, the simulation was developed based on DOE-2.1E software to evaluate the energy performance of the selected devices combined with the economic analysis. In the last stage, a mock-up test model was created to check the applicability of installing these devices at high-rise residential buildings, particularly wind-pressure tests and vibration tests. The findings introduced that the horizontal overhangs and vertical panels were the most appropriate shading devices for a high-rise building. Also, the consumption of cooling energy was reduced by 20%. The combination of simulation and field experiments provides more reliable, accurate, and applicable results, but the study needs a long period and the control of variables more complicated, and it is more expensive than other research methodologies.

3.3. Methodology selection and justification

As presented before, it is quite evident that different methodologies are used to evaluate and investigate the efficiency of static shading devices. The main concern of this study is to assess different types of solar shading elements on a multi-story office building in terms of energy and daylighting performance.

The primary method of this study is computer simulation support with literature review and personal interview methodologies. The research starts with an extensive study of the main topics related to fixed shading elements such as factors, importance, types, etc. Personal interviews contributed to collecting information, drawings, and electricity bills. Software simulation is used to investigate the validity of the case study and evaluate the proposed fixed shading scenarios. Simulation procedures and modeling will conduct through IES-VE software.

Computer simulation is the preferred methodology for this study for several factors related to efficiency, time, and cost. Simulation can expand the investigation area where different factors can be evaluated under a controlled environment and climate conditions. Further, this methodology can develop digital models that imitate reality and its potential conditions quickly. Thus, enhance the study efficiency and provide more accurate and effective findings. Also, computer software available for students either at a free or low price so that students can attain the objectives of their studies with reasonable expenses.

3.4. Software selection and justification

The simulation process will conduct by Integrated Environmental Solutions- Virtual Environment (IES-VE) software version 2019. The study targeted to measure the case study daylighting and energy performance before and after implemented several types and configurations of shading devices. It was chosen as the simulation tool for reasons of its validity, capability, and accuracy. Moreover, IES-VE provides several different environmental investigation variables and produces graphical forms for the simulated models.

Various studies have examined the IES-VE software validity by comparing its results with actual and field measurements. Freewan (2014), as mentioned before, used IES-VE software in his study to measure the annual daylight and solar distribution for offices in Jordan. The radiance simulation results of the scenarios and base case compared to the field experiments assessments. The findings comparison presented a slight variation between the results of less than 10%. Another study used

IES-VE software to simulate the effectiveness of shading devices over a high-rise building in Malaysia. The paper showed a slight difference between the measured and examination outcomes (Lau, Salleh, Lim, and Sulaiman, 2016).

Moreover, Daaboul, Ghali, and Ghaddar (2017) assessed in their studies the impact of a mixed-mode ventilation system that combined natural ventilation and HVAC system instead of the current system for an office building in Lebanon. The investigation of the system occurred via IES-VE software. The calibration process presented a high agreement between the building electricity consumption bills and IES-VE software outcomes, where the average discrepancy around 6%.

3.5. Research methodology steps

The research steps of using simulation tools by IES-VE software as the followings:

1- The office building computational model will be created through IES-VE software concerning the building architectural and engineering data, location, and climatic conditions.

2- The base case model validity and accuracy will be tested by comparing simulation results with building actual electricity bills.

3- Various scenarios will be developed based on different types of shading devices.

4- The proposed models will be evaluated in terms of their energy and daylighting performances.

5- The assessment findings will be compared between them to extract the most effective scenario.

3.6. Methodological framework

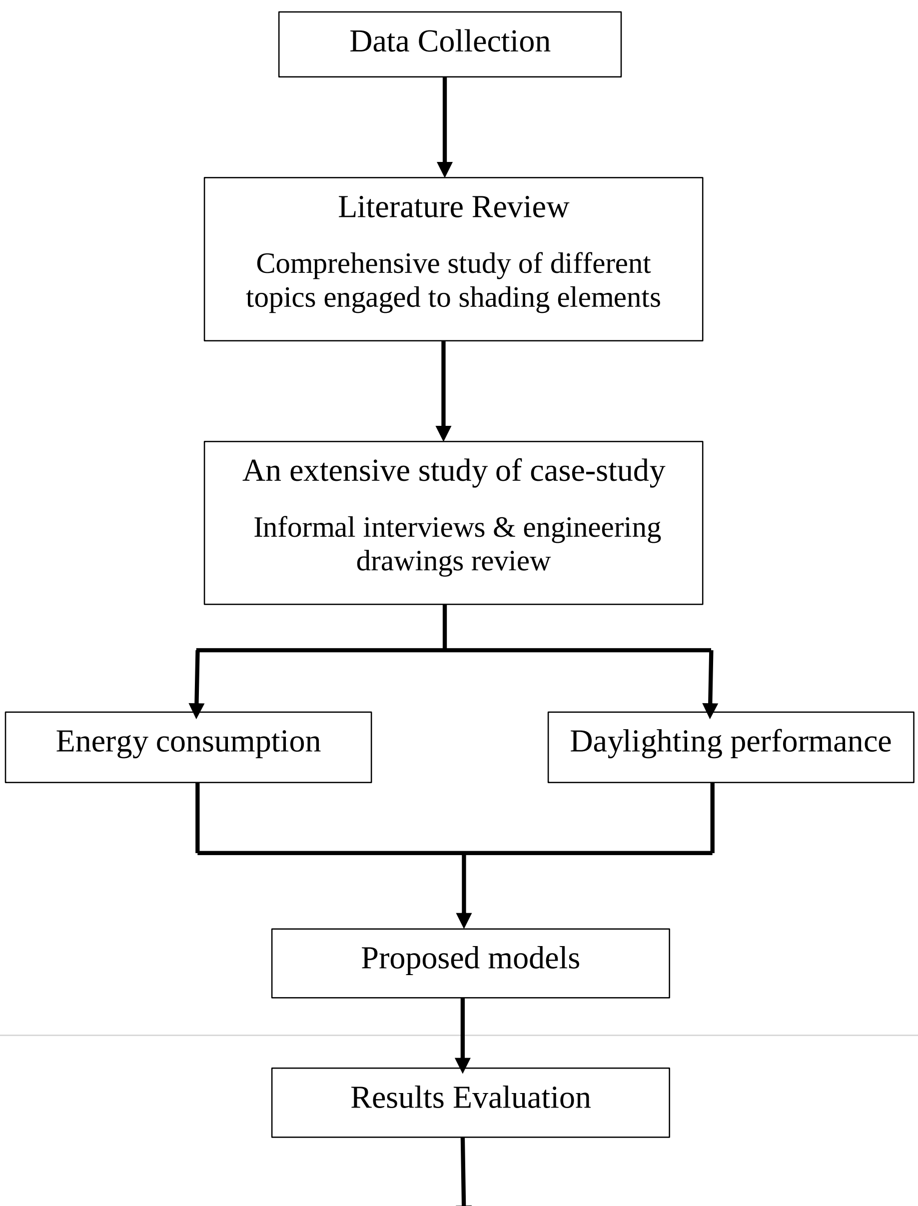


Figure 3.1: Study methodological framework

CHAPTER FOUR

COMPUTER SETUP

4. Computer Set-up

4.1. Introduction

As presented in previous chapters, constructing an energy-efficient building with an adequate comfort level for building occupants requires various considerations, especially in the building envelope.

This dissertation concerns upgrading an existing office building façade located in Dubai by providing different shading elements to be more energy-efficient and create a comfortable indoor environment for the workers.

After conducted the literature review and selected the suitable methodology of the analysis, this chapter will present the study implementation details. In addition, this study will illustrate the analysis of various variables of computer simulation that impact the final research findings and results.

The chapter will initiate with the case-study's physical and operational features description (D3 office building). Followed by carrying out a validation procedure of the IES-VE. Several shading devices will develop for the case study, which later will be analyzed in terms of building energy performance and daylighting level through the software.

The case study is located in Dubai; as mentioned before, it is essential to study the site's climatic conditions.

4.2. Climatic conditions analysis

The geographical location of the UAE made it characterized by a desert climate, which means a very hot and humid summer, and in the winter months, the climate is warm and mild. The below sections will show climatic conditions details.

4.3. Temperature and Humidity

The temperature in summer months between April to 1st of November is considerably high, where the maximum average between 31°C to 42°C while the minimum average between 21°C to 31°C. In the winter season, the minimum temperature reaches below 15°C, and the maximum average winter temperature range between 24°C and 29°C (The climate of Dubai, 2020).

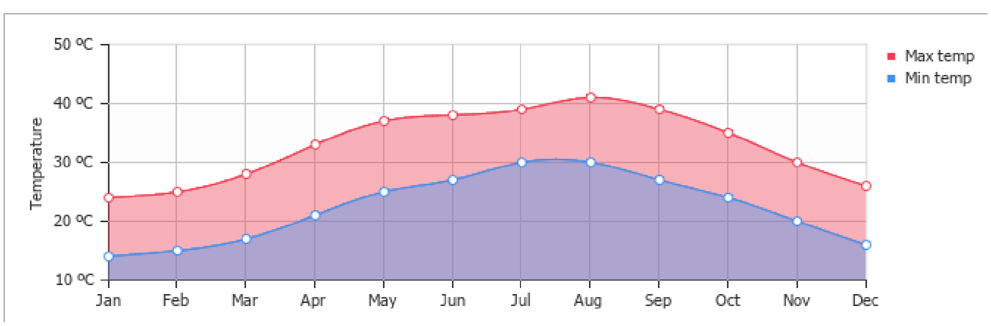


Figure 4.1: Dubai average minimum and maximum temperatures from Jan. to Dec. source: (Climate in Dubai, United Arab Emirates, 2020)

As presented in the above figure, the coolest month is January, where the lowest temperature is recorded at around 15°C at night and above 20°C at daytime. While the hottest month of the year is August, the highest temperature exceeded 40°C, the temperature decreased by around 10 degrees. Most of the year, the humidity level in Dubai is high, which ranges between 50% to 65%, as illustrated in the below figure 4.2. In February, humidity is the highest, while the lowest level is recorded in May.

Figure 4.2: Average level of humidity source: (Climate in Dubai, United Arab Emirates, 2020)

4.4. Rainfall

The rain percentage in Dubai is deficient, where more than half of the year, the rainfall is rare. As shown in figure 4.3, the highest precipitation percentage occurred in February, while the driest month is August.

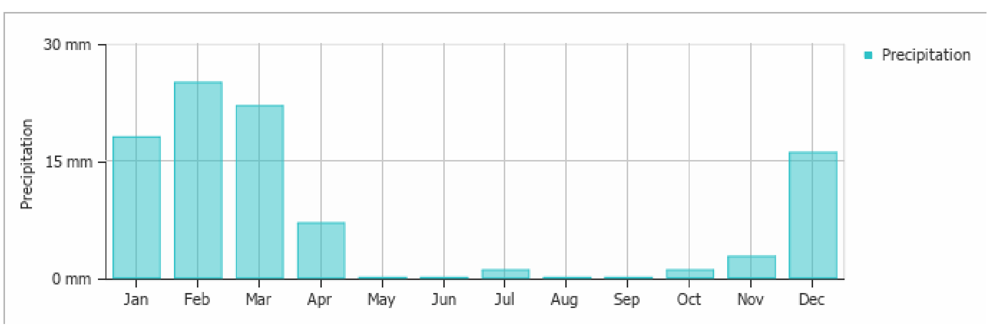


Figure 4.3: Dubai average precipitation over the year, source: (Climate in Dubai, United Arab Emirates, 2020)

4.5. Wind

Dubai city has an average wind speed extend from 5 km/h to 38 km/h, and from January to May, the average wind speed could be stronger. Further, as presented in the below figure, from June to December, the wind velocity becomes calmer with less than 20 km/h.

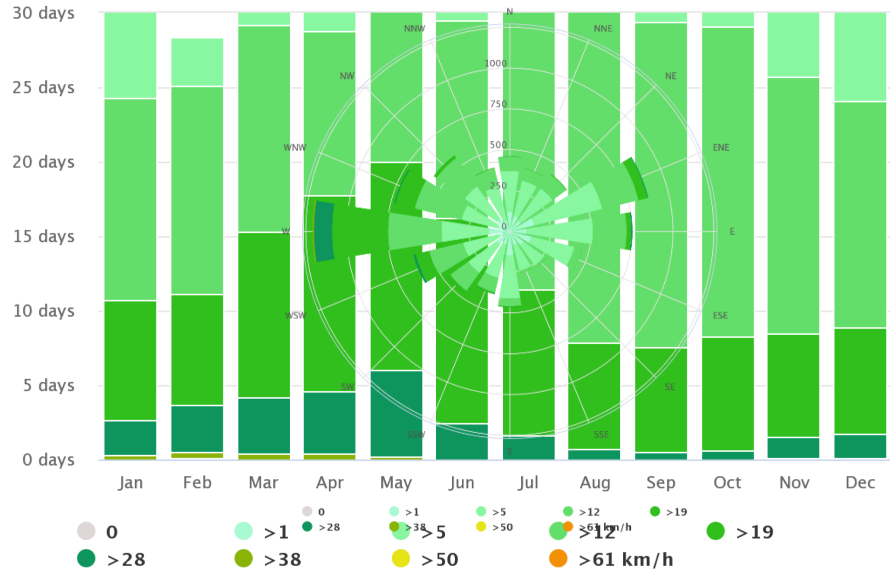


Figure 4.4: Dubai Average wind speed over a year
source: (weather et al., 2020)

Moreover, as indicate flows from different directions, but most of the wind flows from the west direction.

Figure 4.5: Wind rose of Dubai city
source: (weather et al., 2020)

4.6. Sun path

As identified in the solar path Figure 4.6, the total number of natural light hours in summer is around 14 hours, while in winter, the sun shined around 10 hours.

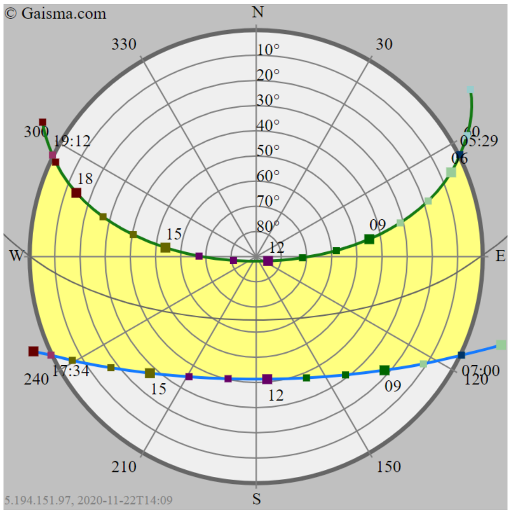


Figure 4.6: Dubai solar path diagram source: (Dubai, United Arab Emirates - Sunrise, sunset, dawn and dusk times for the whole year, 2020)

4.7. Case study selection

The Dubai Design District is selected as the case study to assess the best scenario for an external fixed shading device system. Dubai Design District (D3) is a mixed-use master plan dedicated to cultivating the growth of the design community in UAE, such as startups, entrepreneurs, and established international luxury design and fashion industries. The master plan consists of three phases within the free zone business parks, where the selected study is considered part of Phase one of the D3 masterplan, including 11 office buildings with an estimated 100 retail units and 1,000 office units. It is the most connected design, fashion, and luxury destination in the United Arab Emirates and the world. It is characterized by distinct public areas, unique shaded walkways, including millennial retail, f&b, and galleries for the public on the ground floor level. D3 hosts events throughout the year that attract designers and fashion brands worldwide to participate and visit, such as D3 Fashion Showcase, Dubai Design Week, and D3 Architectural Festival.

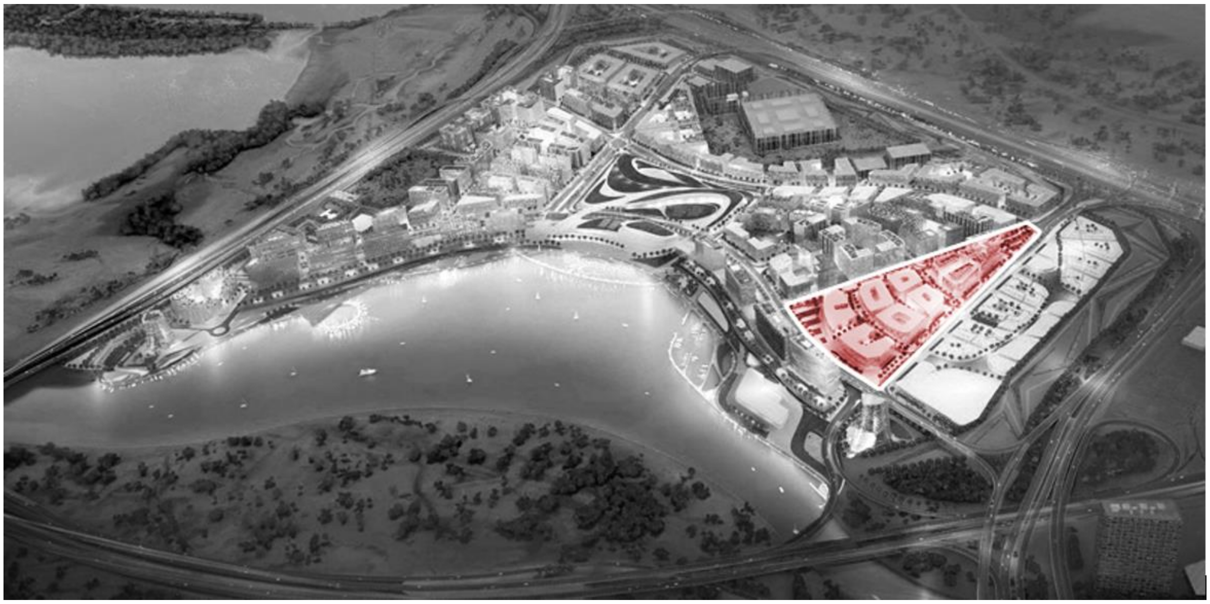
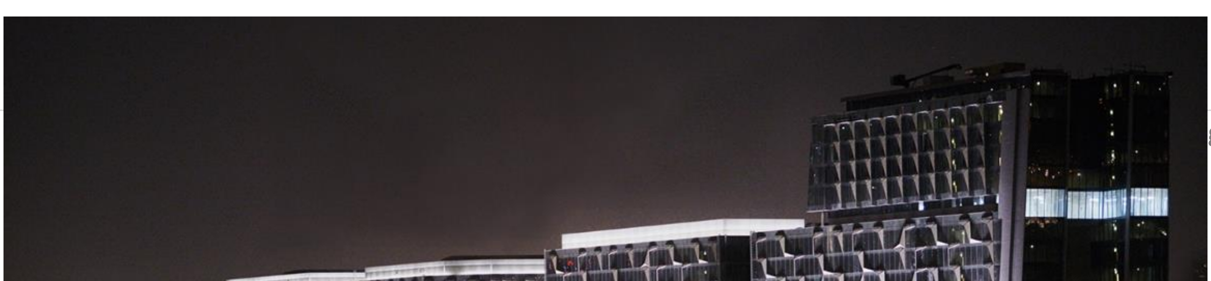


Figure 4.7: Design District masterplan highlighting completed Phase One of the vision

Phase one of the vision master plan was completed and opened for the public and tenants in 2015. The creative district consists of three main blocks: The North block, which includes four buildings towards the north direction overlooking the Dubai Creek. The Core Block is located in the center consisting of 4 buildings, two towards the east and two towards the west; the South Block consists of 4 buildings, two of which are the highest in the masterplan reaching 12 stories, unlike the rest of the buildings which reaches six stories only.

All buildings include a large ground floor level which includes the building lobby, retails, Restaurants and cafes, and galleries and event spaces that help activate the public realm and allow for all the events to happen successfully. Since this research addresses the external fixed shading device impact on office buildings, the design district building façade is unique and iconic due to its external fixed shading devices that are triangulated and applied in different orientations in the building envelope.



These shading elements were intended to improve the indoor climate comfort and the visual comfort for the offices of the D3. However, according to the surveys conveyed and filled out by the tenants and users of D3 offices, it has been stated that the indoor environment of the current shading design application is not convenient as the shading devices are intended to be. Therefore, one building has been selected to prove this theory and to apply different shading scenarios to improve the climate comfort as well as the visual comfort of the office spaces in one of the selected buildings in D3. This study has selected building six, which is located in the Core Block facing the west sunlight direction, for the analysis. Building 6 is shown in Figure 4.9 below.

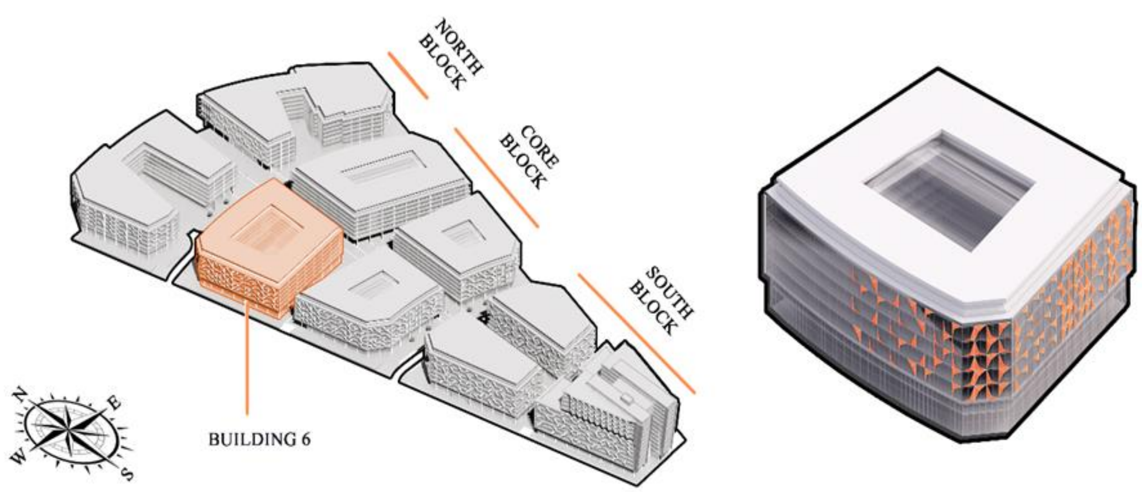


Figure 4. 9 Isometic Diagram Highlighting buidling Six of the Dubai Design District

4.8. Site analysis

Dubai Design District Phase one is located close to Mohammed Bin Rashid City and adjacent to Business Bay Dubai. Situated in a very geographical location near the city's major highways and is roughly 16 minutes away from Dubai International Airport and roughly 44 minutes away from the new Al Maktoum International Airport. D3 can be accessed from Sheikh Zayed Road E11 from the west or Al Khail Road E44 from the East and Al Ain Road E66 from the South, as shown in Figure 4.10. The Dubai Creek is located towards the North of the site, a walking distance away from the buildings. Public Transport is also convenient where the visitors can either take the public Bus route to D3 from either the Emirates Tower metro station or Dubai Mall Metro Station to reach D3, which is roughly eight minutes away.

Buildings Six is located to the west of the phase one buildings facing Al Khail Road. It is accessed from the same roads as the rest of the buildings, and the parking lots are all located on one side for all the phase one buildings. However, Buildings six is one of the few buildings with basement parking, as shown in Figure 4.11 below.

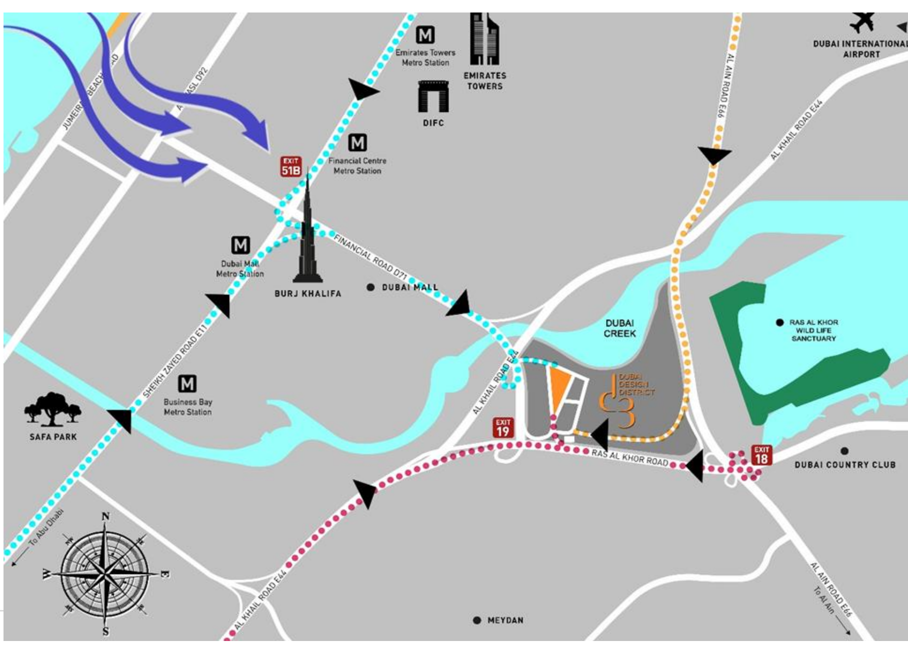


Figure 4. 10 Site Analysis Diagram

Figure 4.11: Site context of D3 and site accessibility

4.9. Case study construction materials

The construction materials of the D3 building have been installed in IES-VE software as mentioned in the architectural drawings and interviewed with the engineer. The main system used in the building envelope is curtain walls and combo roof, presented below in Table 4.1 in details.

Envelope elements	Material layers	Thickness (mm)	Total U-value (W/m².K)	Thermal conductivity (W/m.k)
Roof (combo roof)	Waterproof coating	8	0.134	0.5
	SBR bonding agent	-		-
	Screed	100		0.19
	Filter layer	-		-
	Liquid coating	6		0.5
	Insulation (Polyurethane foam)	170		0.0242
	Concrete	320		1.85
	Plaster layer	15		0.72
External wall (curtain wall)	Outer pane	6	1.91	1.06
	Cavity	18		-
	Inner pane	6		1.06

Table 4. 1Building envelope construction material

4.10. 4.9 Software validation

It is essential to conduct a validation process to ensure the investigation outcome's accuracy and capability. Therefore, the software results will be in the next stage compared with another source. The D3 office building will be constructed in the IES-VE software as identified in the architectural drawings concerning the building location, configuration, and construction materials.

Due to difficulties in collecting the energy consumption bills, only the author collected electricity bills of one floor for three months and the total consumption of one year, which was gathered from the landlord.

4.11. Model set-up

Building six offices consist of the ground floor, mezzanine used as commercial and five floors divided into offices. Only the office's floors are inserted in the software, including offices apartments, corridors, and services area, as shown in figure 4.12.

Furthermore, building the ground floor will be neglected in the simulation, which is used as a commercial area.

Figure 4.12: Typical floor plan

As illustrated below figure 4.13, all the architectural features of the building were considered, especially the shading elements. The construction materials of the façade were assigned as mentioned in the previous table. Moreover, the author defined other parameters to achieve more accurate results of building energy performance, such as infiltration, internal loads, thermal and lighting loads, orientation, and the surrounding buildings.

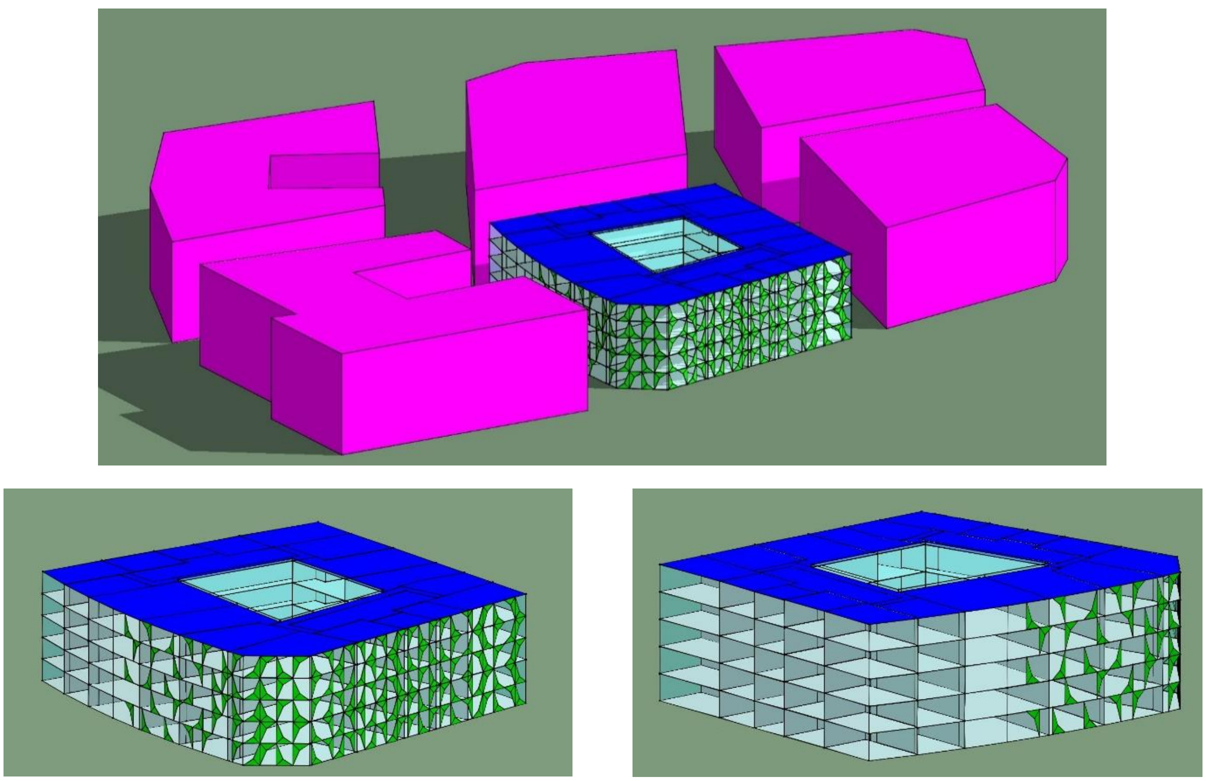


Figure 4.13: Perspectives of the base case simulation model, source: IES-VE software, 2019

The location of the selected case study and climate play a crucial role in achieving reliable findings. Therefore, the Dubai location and the nearest climate data were assigned, the Abu Dhabi weather file. These data consist of temperature ranges, wind velocity, latitude, and longitude.

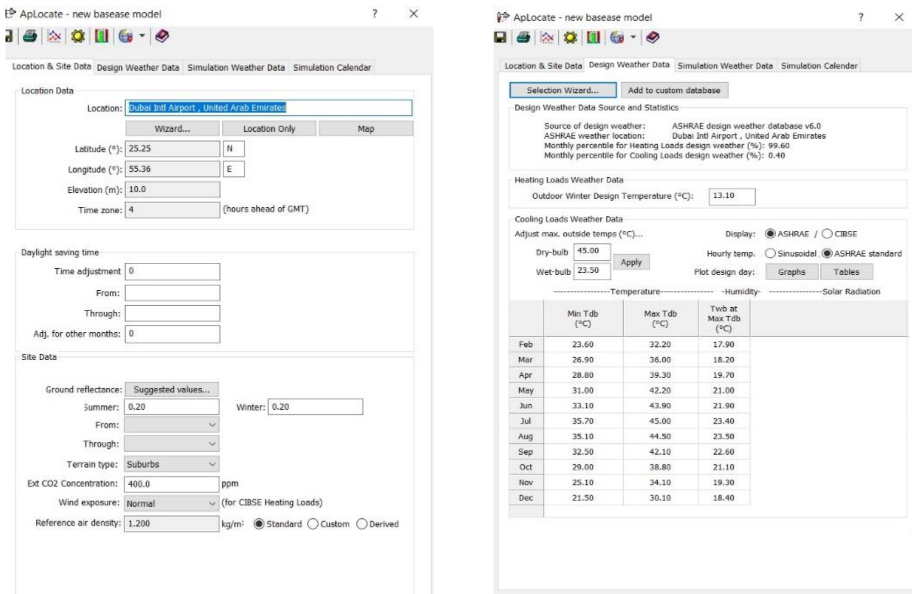


Figure 4.14: Base case weather data, source: IES-VE software, 2019

Generally, heat enters the building from exterior sources like solar radiation, which transfers through walls and glazing elements convection, radiation, and conduction. Also, the ambient air transfers heat to the building through ventilation and infiltration. For this research, only the infiltration rate value will be considered, which is equal to 0.25 ach.

The internal heat gains are both latent and sensible heat released within the building's interior spaces, which increase the temperature degree and humidity of the area. The main sources of heat in any building are occupants, lighting systems, and equipment (Wang, Hong, and Piette, 2019). The lighting system that used in the building is fluorescent lighting. Also, the number of building employee vary among the floors. Therefore, it will be estimated that range of workers on each floor from 50 to 75. The internal heat gains sources in the building defined in the software presented below in table 4.2.

Internal heat gain sources	Equipment	Lighting	People
Maximum consumption (W/m²)	8.7	10.6	-
Max. sensible gain (W/person)	-	-	90
Max. latent gain (W/person)	-	-	60

Table 4.2: Internal heat gains inserted in the IES-VE software, source: ASHRAE handbook, 2017 & IES-VE software, 2019

Furthermore, author create offices HVAC and lighting profiles to improve the efficiency of the simulation model results.

- HVAC profile

One profile developed for the building base case during weekdays. As shown in figure 4.15, during weekdays profile, author estimated that employees will start working from 8:00 am to 19:00. Further, it was assumed that during weekends the offices will be closed.

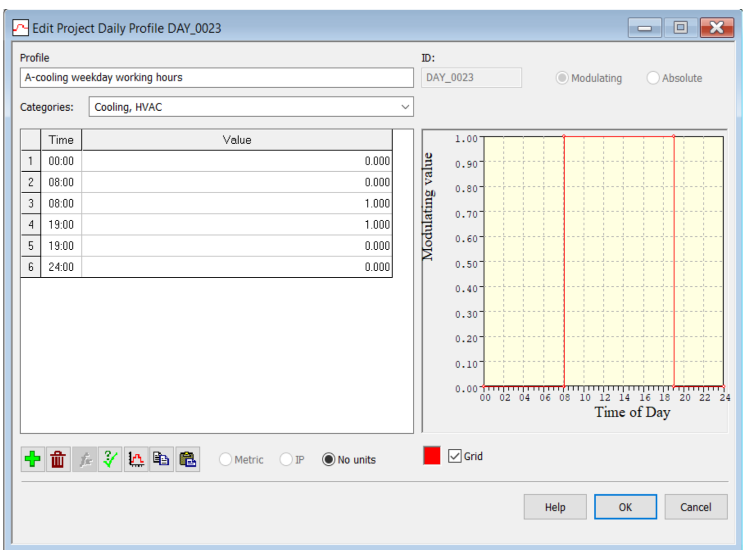
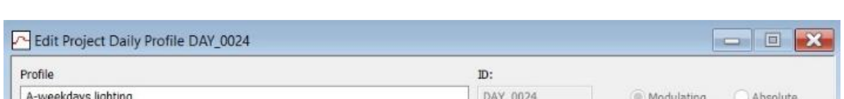


Figure 4.15: Weekdays HVAC profile, source: IES-VE software, 2019

- Lighting profile

Same of the HVAC profile, the author developed two profiles for the lighting system, which will be switched from 8:00 am to 19:00. Even during daytime, the offices depend on artificial lighting



system because most of the time employees prefer to close the curtains due to the sun glare. While in the weekends lighting system will be switched off.

Figure 4.16: weekdays lighting profile, source: IES-VE software, 2019

Corridors, services, part of energy simulation; therefore, their lighting, HVAC systems, and equipment electricity consumption will be avoided. However, they should be built in the computer model regarding their construction materials because they impact heat transfer.

4.12. Simulation model validity

After installing UAE climate conditions, internal heat gains, and HVAC systems setting of the office building as mentioned before, an investigation was conducted through IES-VE software for the base case model. Further, building construction material and envelope shading elements were modeled as the existing building.

A comparison between actual energy bills and the simulation model results is presented in table 4.3. As shown, the discrepancy between simulated model findings and actual energy consumption ranges between 3.26% and 8.5%.

Month	Energy bills (MWH)	IES-VE energy consumption (MWH)	Validation discrepancy %
April	30.3	27.7	8.5
October	33.14	31.42	5.2
November	28.86	27.44	5.1
Total consumption	362.63	374.45	3.26

Table 4.3: Validation of energy consumption between simulation model and actual consumption

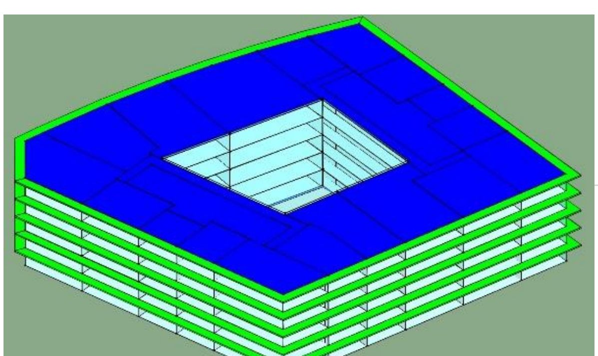
Unfortunately, actual electricity for all months is not available to support the accuracy of the simulation model, but based on this investigation, IES-VE software confirms its ability to conduct the rest of the study analysis properly.

In the next part of this chapter, several scenarios will be created on IES-VE software to improve building energy performance concerning building construction parameters.

According to the literature review, the most effective statistic shading devices implemented in building façade are horizontal overhangs, vertical fins, horizontal and vertical louvers, and egg-crate, which all of them proposed in the simulation models.

4.11.1 First scenario

Due to the complicity of specifying the depth of the horizontal shading device, the author assumes three dimensions for depth 1200, 1500, and 1800 mm located at the top of each floor with 50mm depth. Therefore, three simulation models were developed based on the horizontal overhangs shading elements, as shown below figure 4.17.



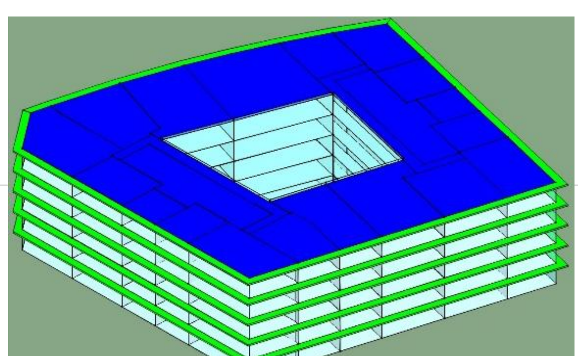


Figure 4.17: 1^{st} scenario simulation models horizontal overhangs shading elements
source: IES-VE software, 2019

4.11.2 S

In the second scenario, the author used vertical shading fins. Usually, the vertical fins are inserted at the window corners, but in the case study, the office building façade from fully curtains walls; therefore, the vertical fins dimensions used in the simulation model are 750 mm depth, 50 mm width and it extended along the building height equal 19,250 mm. Also, the distance between each fins 1000 mm. Moreover, the author proposed two scenarios of vertical fins. The first one is the vertical fins, placed perpendicularly in the building envelope, while the second one is designed at an angle of 45°.

a- Option “1”, perpendicular vertical fins placed in front of all building façades

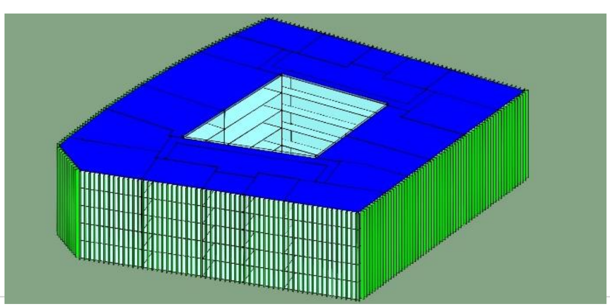


Figure 4.18: 90° vertical fins simulation model source: IES-VE software, 2019

b- Option “2”, the angular vertical fins, the rotation direction of the fins specified according to the sun path

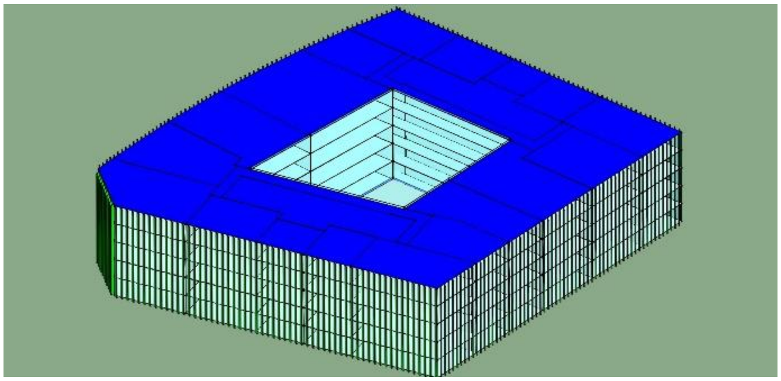


Figure 4.19: computational model of the 45° degree vertical fins source: IES-VE software, 2019

4.11.3 Third scenario

The third developed scenario was designed based on compensation between vertical fins and horizontal overhangs “egg-crate.” The proposed design took the identical measurements and rotation of 45° vertical fins for the vertical elements, while the horizontal devices will be repeated several times among the building with 750 mm depth and the space between them equal to 500 mm as presented in the below figure.

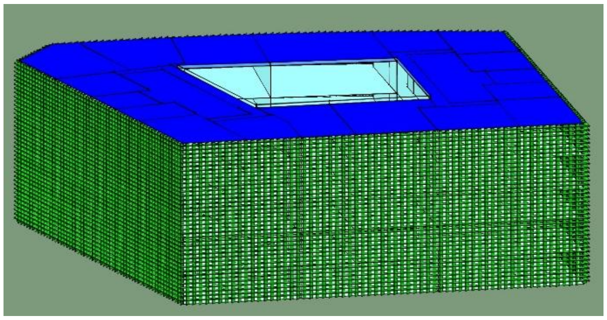
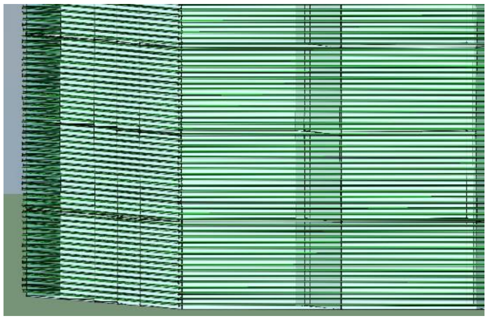


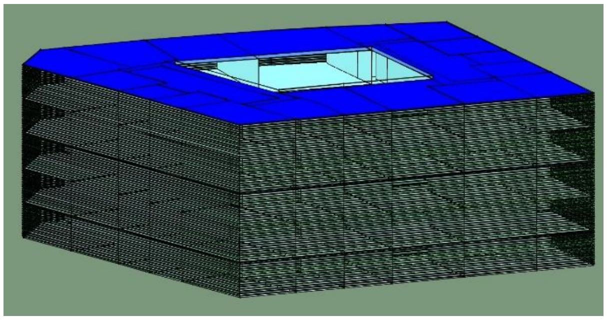
Figure 4.20: Egg-crate shading elements IES-VE model source: IES-VE software, 2019

4.11.4 Fourth scenario

In this scenario model, the author used the horizontal louvers concept; according to previous chapters, horizontal louvers are designed in different sizes and forms; therefore, the slats measurements implemented in the model 50 mm thick, 200 mm depth, and the length of the slats will be equal to the building perimeter. Also, the distance between each slat is 200 mm.



Side view



Perspective view

Figure 4.21: Horizontal louvers shading devices proposed model, source: IES-VE software, 2019

4.11.5 Fifth scenario

Vertical louvers are the shading elements used in this simulation model where the vertical slats are distributed surrounding building façades. The dimensions used for the same as the previous scenario, but the height will be 19,250 mm, and the depth is 200 mm, as shown in figure 4.22.

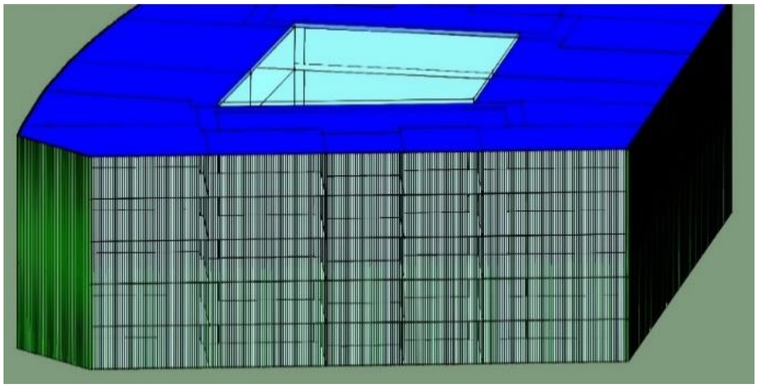


Figure 4.22: 5th scenario simulation model, source: IES-VE software, 2019

4.11.6 Sixth scenario

The author in this scenario created a unique design of shading elements used to cover the building, as illustrated in figure 4.23.

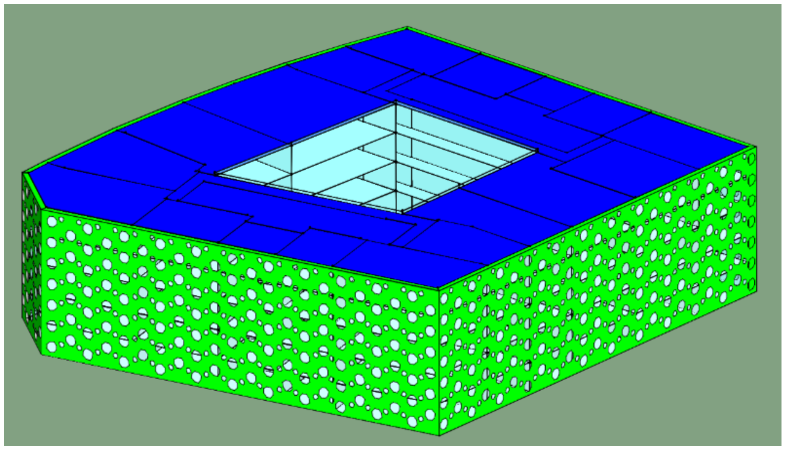


Figure 4.23: Sixth scenario computational model perspective, source: IES-VE software, 2019

After developing all ted before, the six scenarios were simulated on IES to conduct a study on energy consumption and daylighting analysis.

- Energy consumption simulation

The energy analysis will be concentrated on the whole building office apartments for one full year.

- Daylighting simulation

In the daylighting simulation, the author specifies one office on the fifth floor for all scenarios where the office will be simulated at two periods of time on 21 December and 21 of June at the most critical timing of the day, 9:00 am, 12:30 pm and 17:00 pm.

The findings of these scenarios investigation will be used in the next chapter to figure out their influences and find the optimum shading elements.

CHAPTER FIVE

RESULTS AND DISCUSSION

5. Results and discussion

5.1. Introduction

This chapter analyzes the results from the simulations conducted through IES VE software to investigate the impact of external fixed shading devices on the office building in the Dubai Design District, particularly building six. The simulation shows the impact of six different scenarios on energy consumption and daylight.

Cooling and electricity loads were analyzed on the existing building façade design to compare with the six proposed shading devices. These scenarios are: horizontal overhangs, vertical fins, horizontal and vertical louvers, and egg-crate. These results will be compared in later in this chapter against the base case and put in a chart to get the highest energy consumption result. Daylighting analysis is conducted in one office space on the fifth floor of building six due to the typical spaces the office building has. The investigation is done in December and June at noon to analyze the daylighting illuminance levels achieved by the different scenarios proposed at the harshest time of the day.

5.2. Energy consumption results

The following conditions were used in comparing energy consumption results:

1- Base Case: Existing Building Shading Devices

2- Six Shading Scenarios: All the scenarios were modeled on IES-VE software, and the energy analysis will be concentrated on the entire office building for one entire year. The daylighting study was conducted on two offices on the fifth floor for all scenarios during two periods; one 21st of December and the 21st of June during three different times; 9:00 am, 12:30, and 17:00.

These results will be compared on charts to figure out the most effective shading device on the energy consumption and daylighting of the case study.

5.2.1. Base Case Results

Based on the current condition of the existing building six described in the fourth chapter, the actual electricity bills were compared to the base case with a discrepancy between 3.26% and 8.5%. The results of the Design District Building 6 energy consumption per month are shown in Table 5.1.

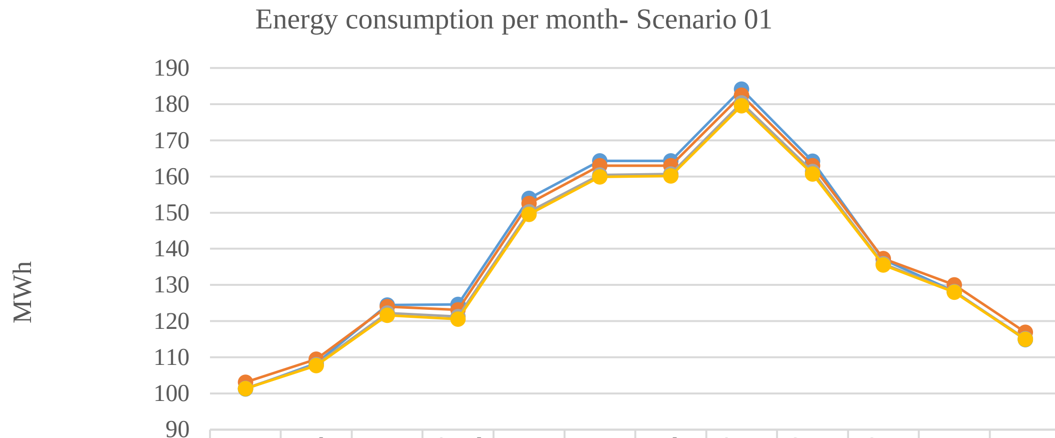
Month	Electricity consumption (MWh)
January	101.25
February	108.33
March	124.43
April	124.60
May	153.95
June	164.31
July	164.30

August	184.20
September	164.21
October	136.99
November	128.26
December	114.86
Total	1669.67

Table 5. 1Base Case Energy Consumption

5.2.2. First Scenario Results

Based on the literature review, the first enhanced scenario for the fixed shading device is the horizontal overhangs. Since it was not decided which dimension is the most optimum, three dimensions were tested 1200,1500, and 1800mm placed at the top of each floor. The three dimensions' results are compared with the base-case below in figure 5.1 as an outcome for scenario one. The results show that the electricity consumption of the three dimensions is better than the base case performance, especially Summer season, where the best-recorded reduction is in May by around 5MWh, while in winter, the energy consumption is almost the same. Comparing the three dimensions, the most efficient dimension in a horizontal overhang design is 1800, which achieves a total of 1639.4 MWh a year and is less by 30.3 MWh.

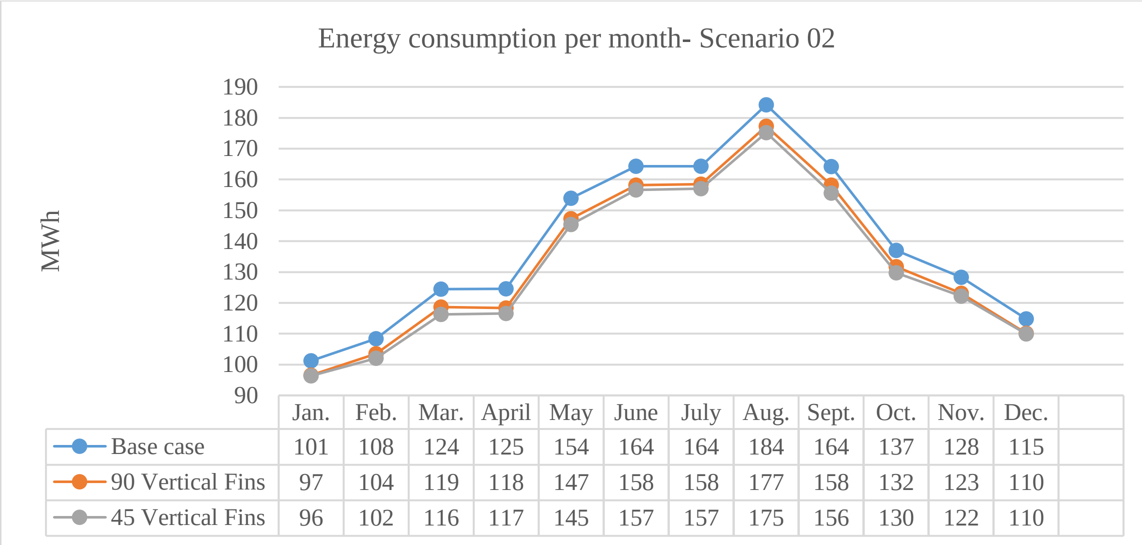


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
1200 Overhang	103	109	124	123	153	163	163	182	163	137	130	117
1500 Overhang	101	108	122	121	150	160	161	180	161	136	128	115
1800 Overhang	101	108	122	121	149	160	160	180	161	136	128	115

Figure 5.1: The energy consumption of the 1st scenario compared to the base case

5.2.3. Second Scenario Results

The second scenario strategy focused on using vertical fins as the enhanced solution to the façade treatment inserted at the window corners. Since the building is fully glazed, the scenario modeled is 750mm depth and 50mm width and extends throughout the full façade height. Two options were modeled; at 45° and 90°. Figure 5.2 illustrates the results of the two options within the second scenario against the base case. In general, the results are more effective than the first scenario, where the reduced energy consumption is very significant in both angles however the 45° shows better results, especially in Summer, which shows a reduction by 9MWh compared to the base case and 7 MWh for the 90° vertical fins option.

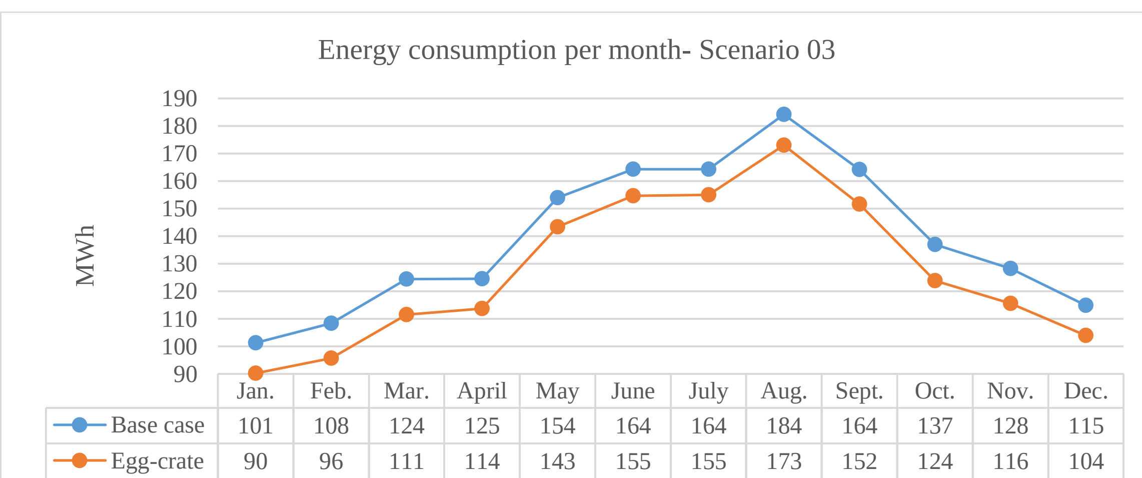


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
90 Vertical Fins	97	104	119	118	147	158	158	177	158	132	123	110
45 Vertical Fins	96	102	116	117	145	157	157	175	156	130	122	110

Figure 5. 1The energy consumption of the 2nd scenario compared to the base case

5.2.4. Third Scenario Results

The third scenario uses a combination of vertical fins and horizontal overhangs, an egg-crate external shading device. The simulation was modeled using the 45 vertical fins and horizontal devices, as shown in chapter four. The simulation results are presented in figure 5.3 below, with an apparent reduction throughout the year. A reduction of 11 MWh is detected in the Summer and Winter seasons, particularly in January and August. The total energy consumption for this scenario is 1532.04MWh which is less than the base case by 137.6 MWh.

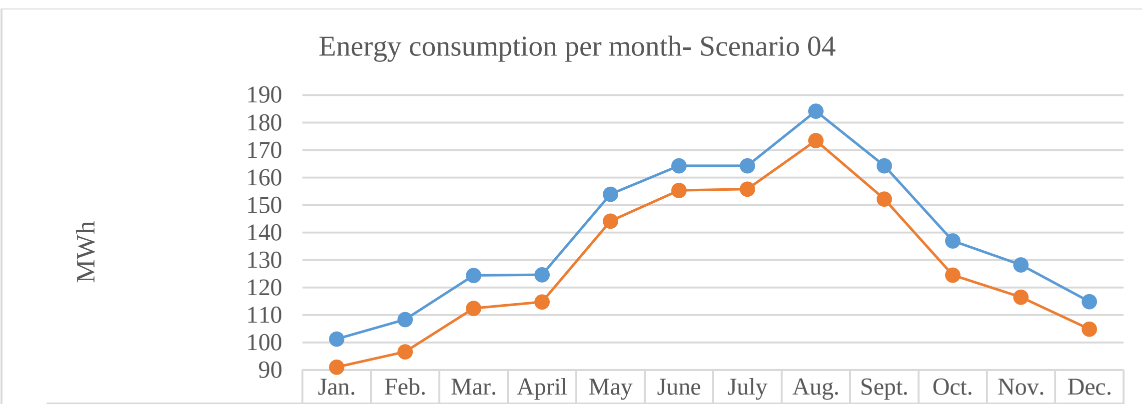


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
Egg-crate	90	96	111	114	143	155	155	173	152	124	116	104

Figure 5. 2The energy consumption of the 3rd scenario compared to the base case

5.2.5. Fourth Scenario Results

This scenario uses horizontal louvers as the fixed external shading device for the office building façade. The horizontal louvers are spaced on the façade by 200mm and 50mm thick, 200mm depth across the building perimeter. Figure 5.4 illustrates the energy consumption achieved in this scenario against the base case readings. This scenario achieves a similar reading as the egg-crate scenario. The energy efficiency increases in both the Summer and Winter seasons with total electricity consumption of 1541.64 MWh. The total energy reduction is equal to 128.0 MWh from the base case result.

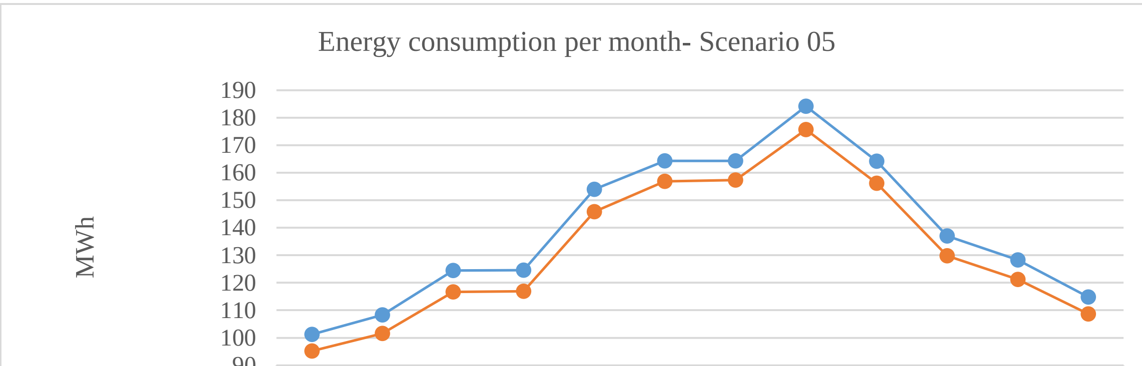


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
Horizontal Louver	91	97	112	115	144	155	156	173	152	125	117	105

Figure 5. 3The energy consumption of the 4th scenario compared to the base case

5.2.6. Fifth Scenario Results

This simulation model for this scenario was done using vertical louvers extending along the entire building façade with a depth of200mm as illustrated in figure 4.22. The results show an evident reduction in energy consumptions throughout the year, especially in the summer season, with a reduction of around 8 MWh in August. The total energy consumption for this scenario is 1582.45 MWh which is less than the base case by 87.22MWh in a year.

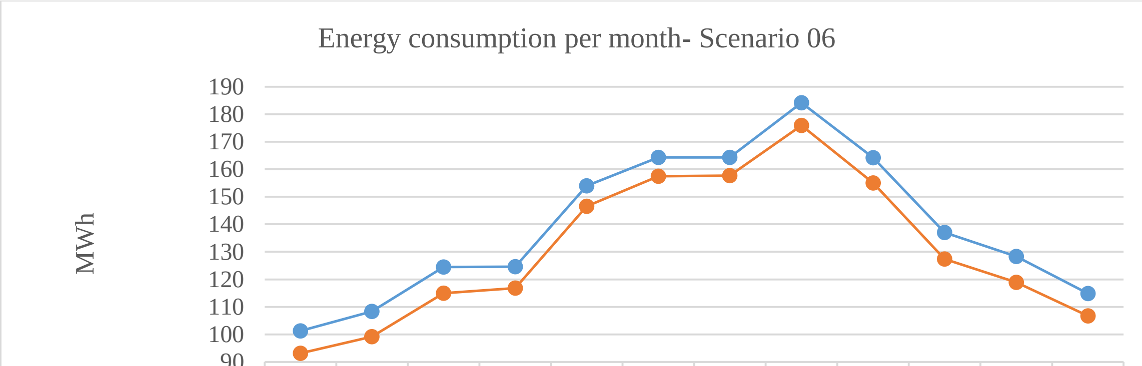


	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
Vertical Louver	95	102	117	117	146	157	157	176	156	130	121	109

Figure 5. 4The energy consumption of the 5th scenario compared to the base case

5.2.7. Sixth Scenario Results

The Sixth scenario was intended to be a unique fixed shading design covering the building envelope creating a double skin as illustrated in 4.23. The energy consumption per month is shown in figure 5.6; the figure illustrates an apparent reduction throughout the year but mainly in February and March, reducing 9 MWh. The total consumption of the sixth scenario is 1569.90MWh in a year, with around 100MWh of reduced energy consumption compared to the base case.



	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Base case	101	108	124	125	154	164	164	184	164	137	128	115
Sixth Scenario	93	99	115	117	147	158	158	176	155	127	119	107

Figure 5. 5The energy consumption of the 6th scenario compared to the base case

5.3. Energy Consumption Results Comparison

In order to assess the developed models' efficacy, a yearlong comparison is conducted regarding energy consumption. As can be seen from Figure 5.7, the enhancement scenarios provide an evidently improved energy performance against the base case scenario except for the horizontal overhangs presented in the first scenario, which show a minor impact on the energy consumption as the rest of the proposed designs. The most efficient scenario is the Egg-crate scenario (third scenario), where the total energy consumption is reduced by 138MWh from the base case scenario, as shown in the figure below. The Horizontal Louvers show promising results and improvement almost as good as the Egg-crate scenario with a reduction of 128.07MWh in a year. In order to select the most optimum strategy, it is essential to analyze the daylighting results conducted and compare them with the energy consumption to figure out the best solution that provides enough daylight and at the same time reduces the energy consumption of an office building.

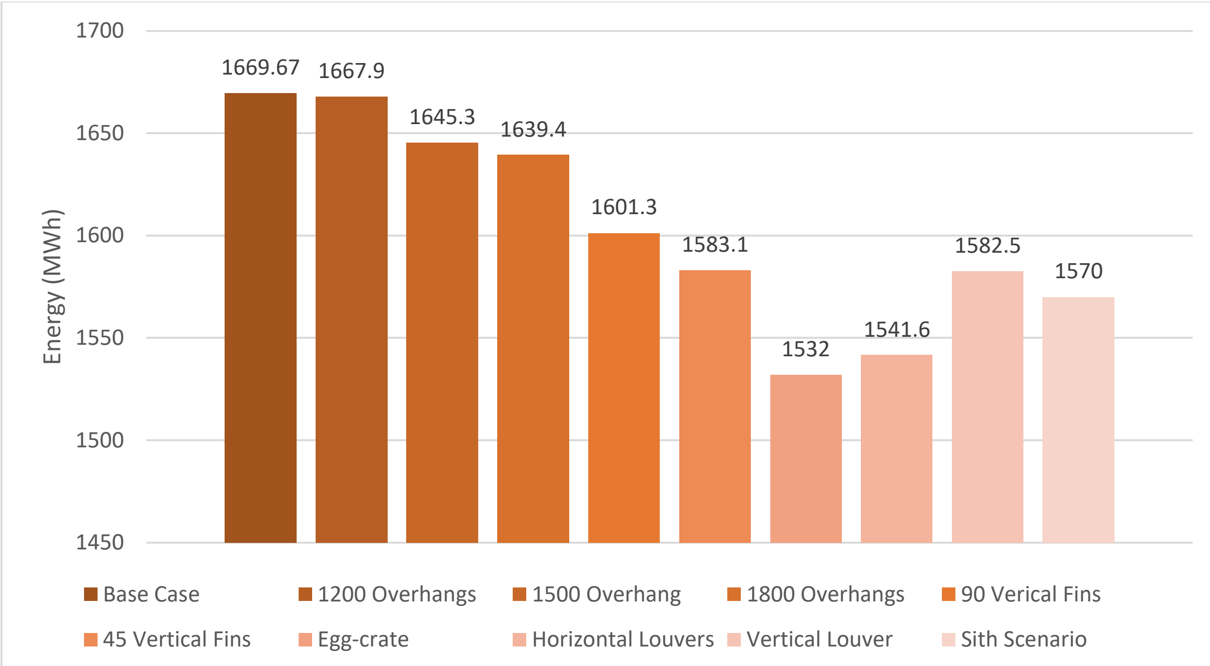


Figure 5. 6 Total Electrical of the base case and the developed scenarios for one year

Month	Base case	Scenario 1		Scenario 1		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
		MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%
Jan	101.25	101.32	0.07	96.38	4.81	90.21	10.9	91.08	10.04	95.19	5.99	93.07	8.08
Feb	108.33	107.68	0.60	102.05	5.80	95.69	11.67	96.63	10.80	101.63	6.18	99.14	8.48
Mar	124.42	121.61	2.26	116.29	6.53	111.47	10.41	112.39	9.67	116.7	6.20	114.92	7.64
April	124.59	120.58	3.22	116.52	6.48	113.78	8.68	114.7	7.94	116.93	6.15	116.78	6.27
May	153.94	149.48	2.90	145.46	5.51	143.41	6.84	144.11	6.39	145.86	5.25	146.5	4.83
June	164.31	159.89	2.69	156.61	4.69	154.64	5.89	155.32	5.47	156.91	4.50	157.51	4.14
July	164.29	160.16	2.51	157.07	4.39	154.97	5.67	155.82	5.16	157.41	4.19	157.77	3.97
Aug	184.18	179.53	2.52	175.16	4.90	172.97	6.09	173.43	5.84	175.75	4.58	175.97	4.46
Sep	164.21	160.66	2.16	155.61	5.24	151.45	7.77	152.16	7.34	156.23	4.86	155.09	5.55
Oct	136.99	135.54	1.06	129.79	5.26	123.86	9.58	124.55	9.08	129.83	5.23	127.42	6.99
Nov	128.26	127.94	0.25	122.16	4.76	115.62	9.85	116.54	9.14	121.26	5.46	118.94	7.27
Dec	114.85	114.97	-0.10	109.96	4.26	103.93	9.51	104.87	8.69	108.69	5.36	106.74	7.06
Total	**1669.67**	**1639**	**1.81**	**1583**	**5.18**	**1532**	**8.2**	**1541.6**	**7.67**	**1582.5**	**5.22**	**1570**	**5.98**

Table 5. 2 Energy Consumption results and reduction percentage per month

5.4. Daylight Results

In this section, indoor illuminance levels will be evaluated to measure the effectiveness of the proposed Fixed Shading devices. The results will be compared to the base case illuminance levels using simulation tools, IES VE using the RADIANCE plugin.

An illuminance level is a measure of the amount of daylight that falls upon surfaces. Table 5.3 lists the standards of daylight illuminance level that are to be used for evaluating the implications of the fixed shading devices (Nabil & Mardaljevic 2006).

Average Daylight Illuminance	**Energy implications**
100 lux	Insufficient either to be the sole source of illumination or to contribute significantly to artificial lighting.
100–500 lux	Effective either as the sole source of illumination or in conjunction with artificial lighting.
500–2000 lux	It is perceived either as desirable or at least tolerable.
> 2000 lux	Visual and thermal discomfort

Table 5. 3 Daylight Illuminance Standards, (Nabil & Mardaljevic 2006)

The Illuminance levels is measured in one office on the fifth floor for all scenarios where the office will be simulated on 21 of December and 21 of June at three different hours, 9:00 am, 12:30 pm, and 17:00. Table 5.6 shows all the results of the average illuminance levels in December and June and the three timings. Although the simulation was conducted for the three timings however the highest outcomes are at 12:30 pm. Therefore, the result analysis for each simulation model is completed later in this section only at one time in two months.

Date/Time		IED VE – Luminance Levels (Lux)						
		Base Case	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
DECEMBER 21st	09:00 AM	235.70	452.32	164.53	89.42	117.24	150.75	192.14
	12:30 PM	407.80	781.37	284.05	154.97	201.74	260.22	330.59
	17:00 PM	69.09	133.03	48.36	26.32	34.47	44.39	56.23

Date/Time		IED VE – Luminance Levels (Lux)						
		Base Case	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
JUNE 21st	09:00 AM	554.74	833.37	303.38	165.12	214.97	278.07	353.37
	12:30 PM	613.49	1176.54	428.10	235.24	305.10	392.61	498.67
	17:00 PM	283.42	542.60	197.61	107.54	140.15	180.90	229.66

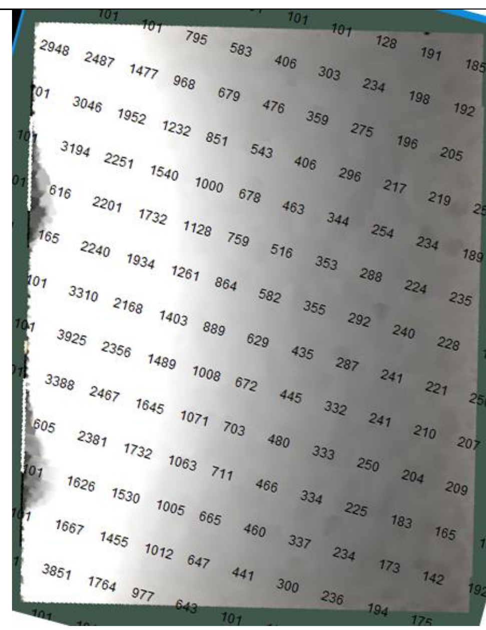
Table 5. 4 Illuminance Levels for Two Dates and Three timings source: IES VE

5.4.1. Base Case Daylighting Results

The following tables shows a comparison between the base case and the optimum shading device scenarios for one office on the fifth floor of building six in Dubai Design District. Radiance contour levels and average illuminance lux levels are indicated.

Illuminance plans indicate areas with daylight illuminance above 500lux in light green. With a threshold of 500 Lux, radiance contour images demonstrate the glare caused by sunlight reflection.

Table 5.4 shows the base case daylighting analysis for the current façade treatment. The radiance contour plan indicates that the illuminance levels are above 900 Lux in a large section of the space. The current conditions allow for much direct sunlight into space, causing overheating and glare, discomforting in an office space. However, the average illuminance results on 21st December is around 407.80 Lux, and on 21st of June with an average of 613.50 Lux.

	Base case **21st December**	**Base Case** **21st June**
Illuminance Plan		

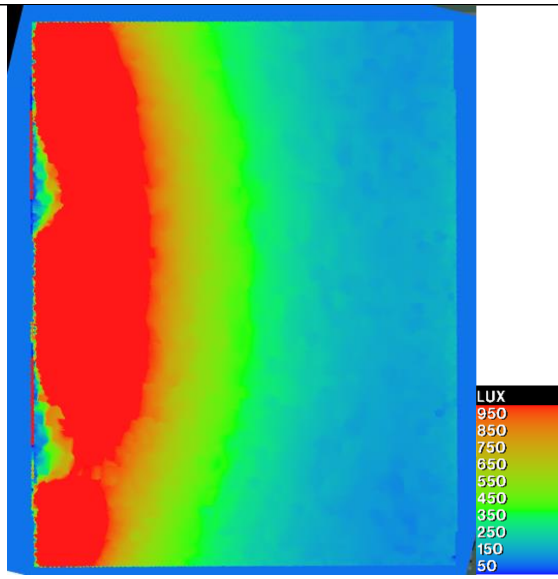
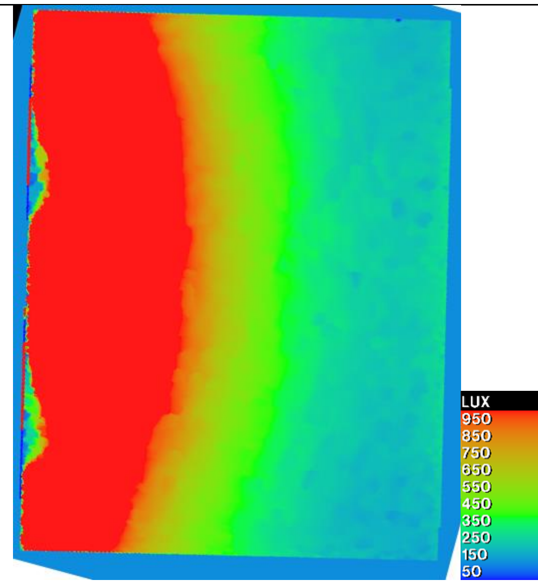
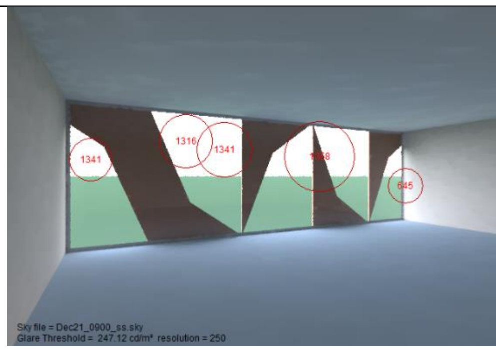
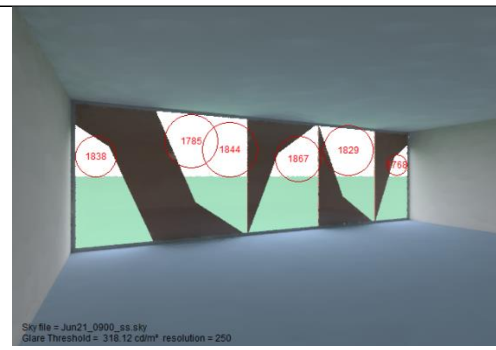
Radiance Contour Plan		
Luminance Image		
	Average Illuminance Level 407.80 Lux	**Average Illuminance Level 613.49 Lux**

Table 5. 5Base Case Illuminance and Radiance contour plans

5.4.2. Scenario One Daylighting Results

The first scenario has three options in three dimensions:1200, 1500, 1800mm, but according to the energy consumption analysis, the 1800mm option gave the best results in terms of energy consumption; therefore, the daylighting analysis was conducted on this option only as part of the first scenario. Table 5.5 below shows the daylight analysis for fixed shading design proposal of horizontal overhands. The results show a slight increase in the average illuminance levels compared to the base case. In December, the illuminance levels had reached 781.37 Lux and in June, 1176.54, which is not a promising result for the office climate comfort.

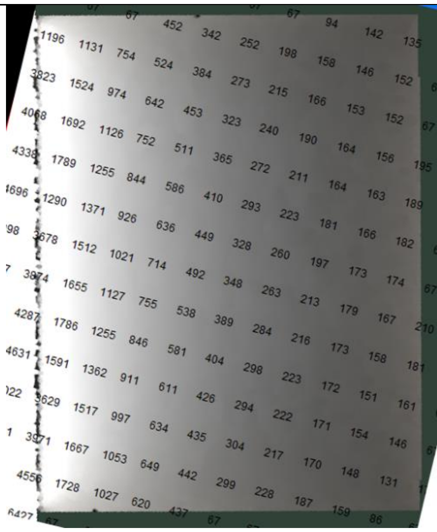
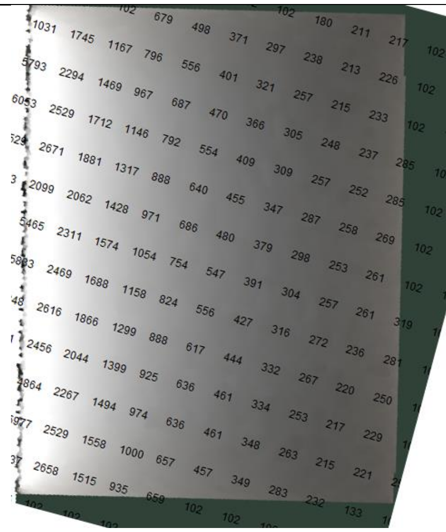
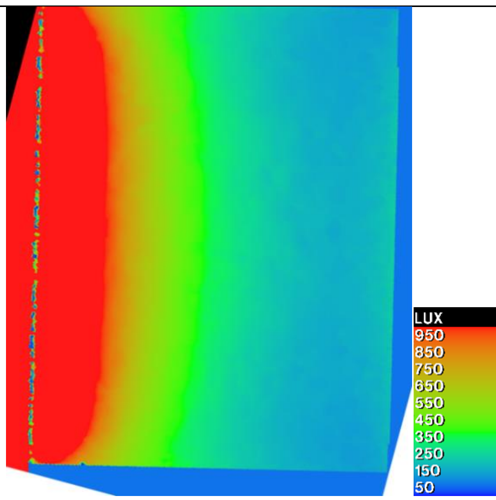
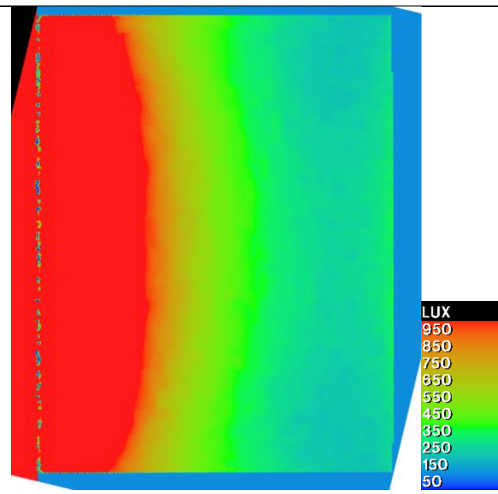
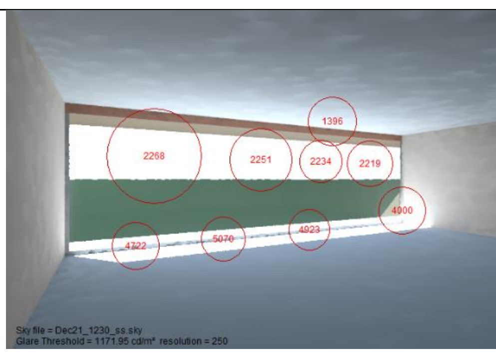
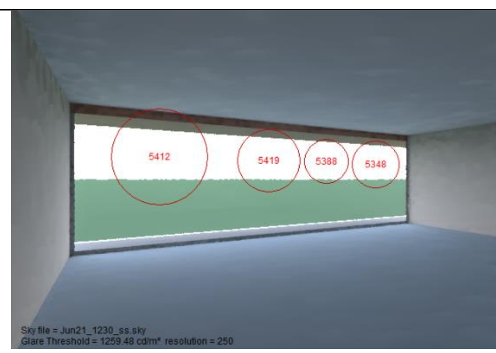
<table>
<tr><td></td><td>Scenario 1- 1800mm
21st December</td><td>Scenario 1- 1800mm
21st June</td></tr>
<tr><td>Illuminance Plan</td><td></td><td></td></tr>
<tr><td>Radiance Contour Plan</td><td>
</td><td>
</td></tr>
<tr><td>Luminance Image</td><td>
</td><td>
</td></tr>
<tr><td></td><td>Average Illuminance Level
781.37 Lux</td><td>Average Illuminance Level
1176.54 Lux</td></tr>
</table>

Table 5. 6Scenario 1 Illuminance and Radiance contour plans

5.4.3. Scenario Two Daylighting Results

In scenario two, the options were 45 and 90-degree rotation, and according to the energy consumption simulation, the 45 degrees showed better results in terms of energy efficiency. Therefore, this option is considered in the daylight analysis study. Table 5.6 illustrates that the average illuminance level has reduced compared to the base case. In December, results show 284.05 Lux and 428.10Lux in June, which is considered adequate daylight according to the Daylight Illuminance Standards in Table 5.3.

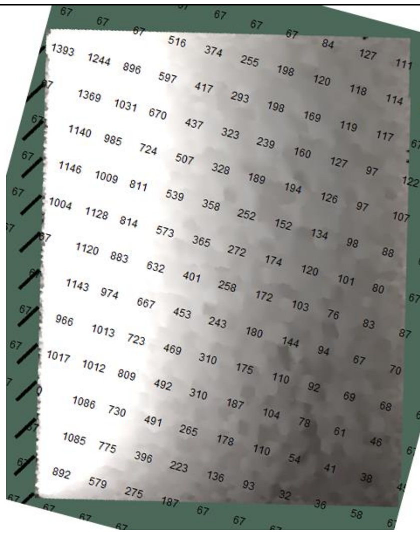
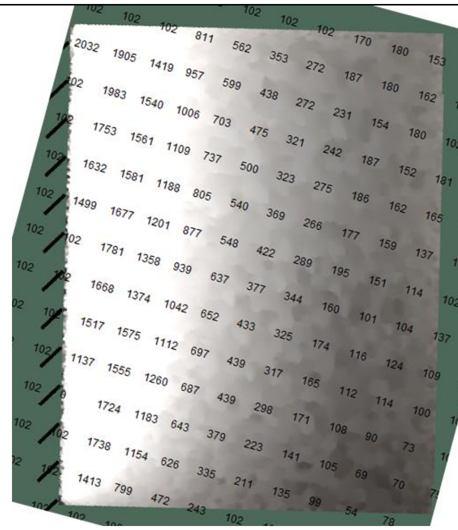
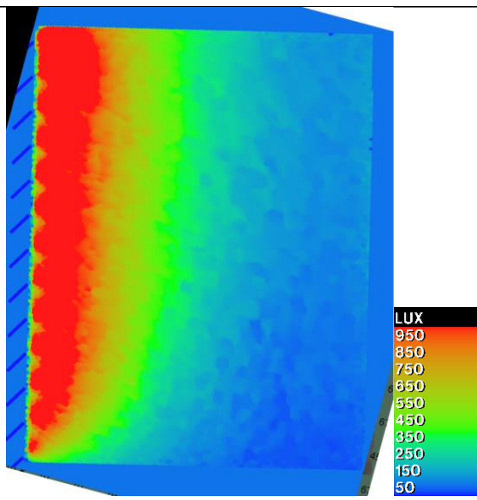
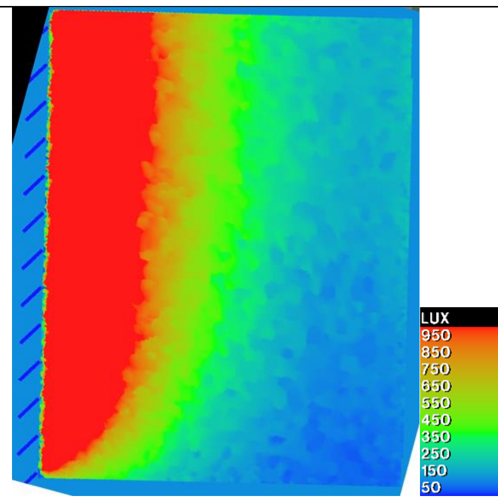
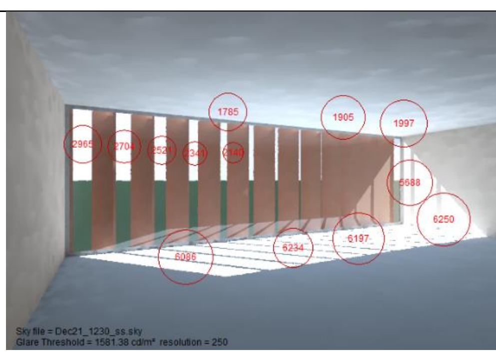
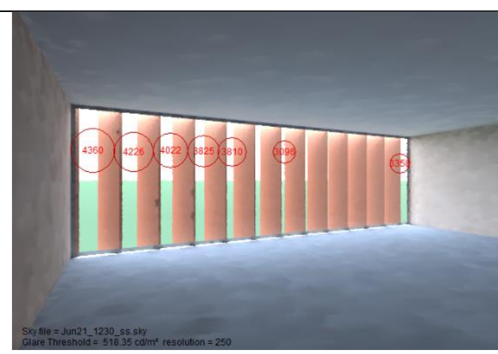
<table>
<tr><th></th><th>Scenario 2- 45 Vertical Fins
21st December</th><th>Scenario 2 – 45 Vertical Fins
21st June</th></tr>
<tr><td>Illuminance Plan</td><td></td><td></td></tr>
<tr><td>Radiance Contour Plan</td><td>
</td><td>
</td></tr>
<tr><td>Luminance Image</td><td>
</td><td>
</td></tr>
<tr><td></td><td>Average Illuminance Level
284.05Lux</td><td>Average Illuminance Level
428.10 Lux</td></tr>
</table>

Table 5. 7Scenario 2 Illuminance and Radiance contour plans

5.4.4. Scenario Three Daylighting Results

In scenario three, the egg-crate design proposal further reduces illuminance levels compared to the base case. In December, the result is reduced from 407.80 to 154.9 Lux. Moreover, in June, the results show a drop from 613.49 to 235.24 Lux. However, the radiance contour plans show low results, which might almost require more artificial lighting. Table 5.7 shows the daylight analysis results for Scenario three. Although there is an apparent reduction in illuminance levels, the luminance image in table 5.7 shows that views to the outside are almost blocked by this fixed shading design.

	Scenario 3- Eggcrate 21st December	**Scenario 3-Eggcrate 21st June**
Illuminance Plan		

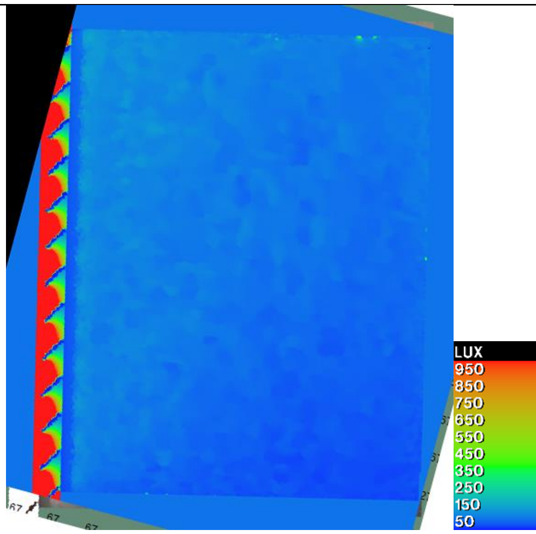
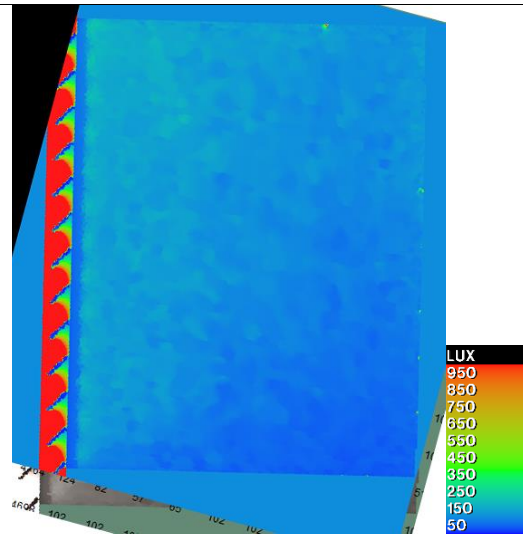
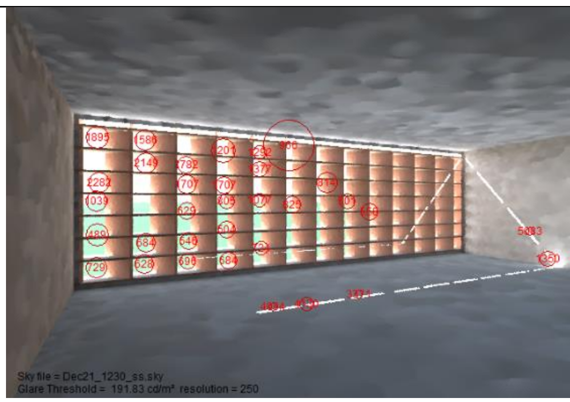
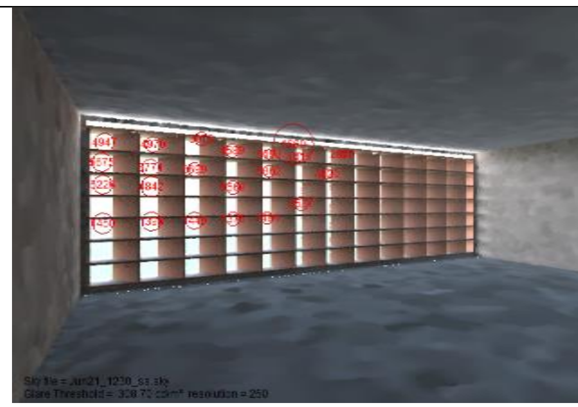
Radiance Contour Plan		
Luminance Image		
	Average Illuminance Level 154.97Lux	**Average Illuminance Level 235.24 Lux**

Table 5. 8Scenario 3 Illuminance and Radiance contour plans

5.4.5. Scenario Four Daylighting Results

Table 5.8 illustrates the daylight analysis results for scenario four. The horizontal louvers fixed shading option. The results show reduced average illuminance levels compared to the base case scenario wherein December drops from 407.80 to 201.74 Lux, and in June, the results reduce from 613.49 to 305.10 Lux. The Radiance contour plan shows an apparent reduction in sun glare. In terms of views, this option does not obstruct the views towards the outside as in the previous scenario.

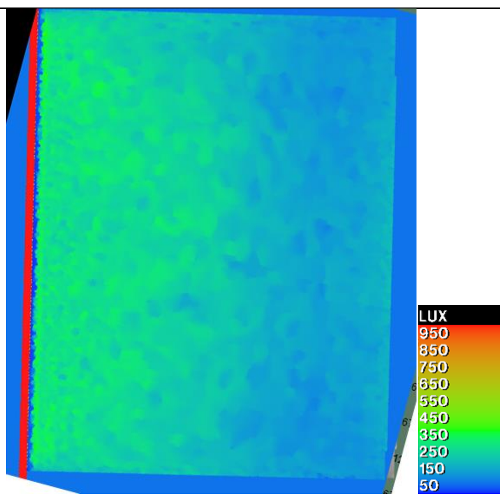
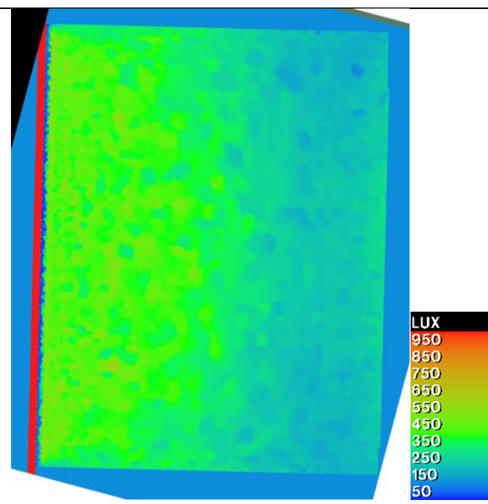
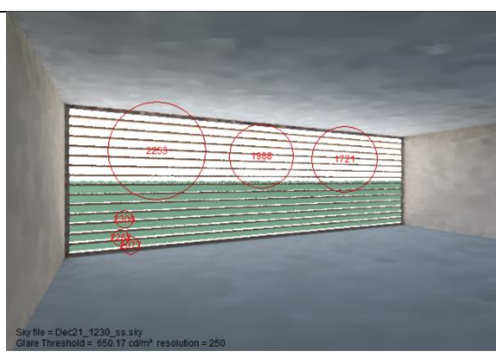
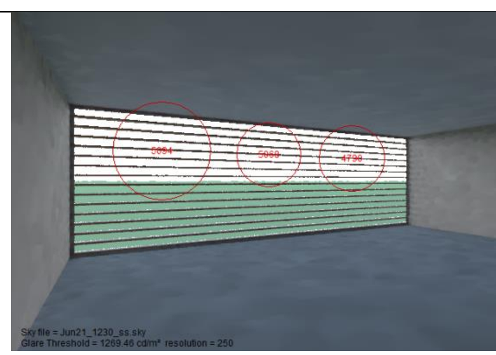
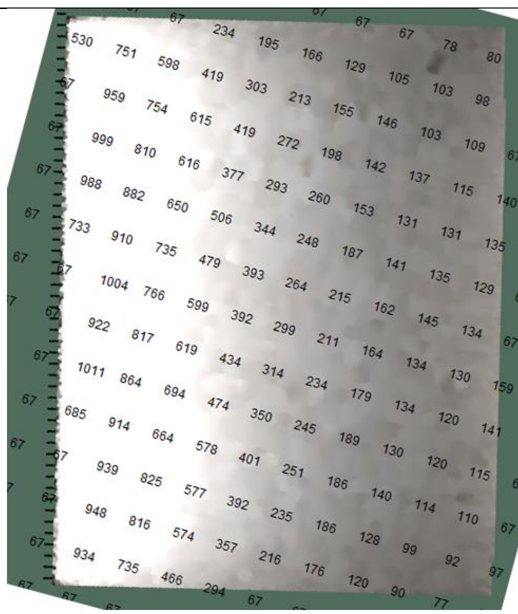
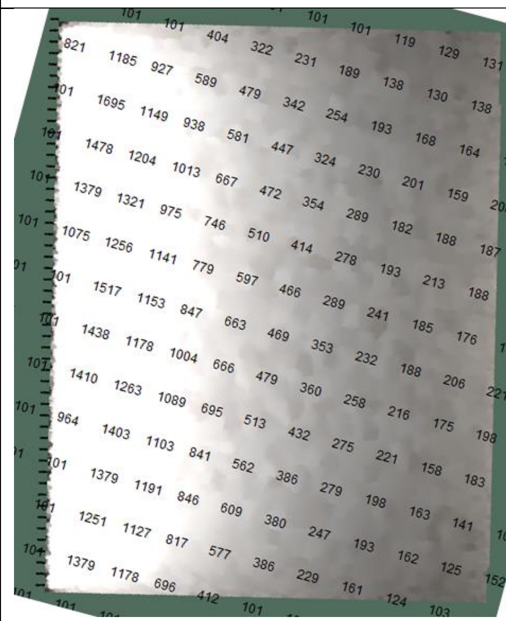
	Scenario 4 Horizontal Louvers 21st December	Scenario 4 Horizontal Louvers 21st June
Illuminance Plan		
Radiance Contour Plan		
Luminance Image		
	Average Illuminance Level 201.74Lux	**Average Illuminance Level 305.10 Lux**

Table 5. 9Scenario 4 Illuminance and Radiance contour plans

5.4.6. Scenario Five Daylighting Results

Scenario Five daylight analysis shows a slight reduction in the average illuminance levels from 407.80 to 260.22 Lux in December and from 613.49 to 392.61 in June. The radiance contour plan shows significant sun glare on the office space close to the façade. Table 5.9 shows the results of the daylight analysis of scenario five.

	Scenario 5 Vertical Louvers **21st December**	**Scenario 5 Vertical Louvers** **21st June**
Illuminance Plan		

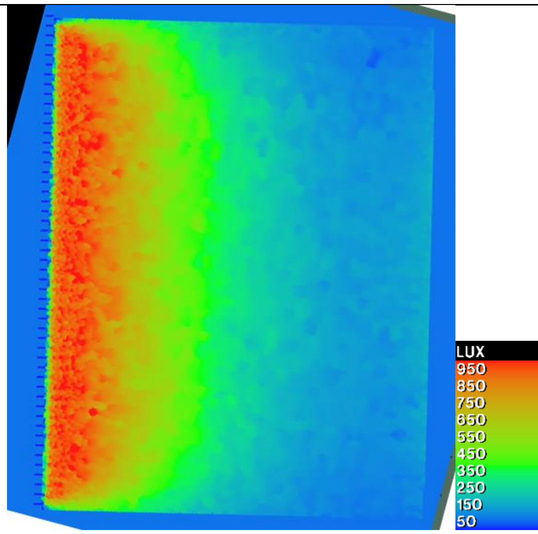
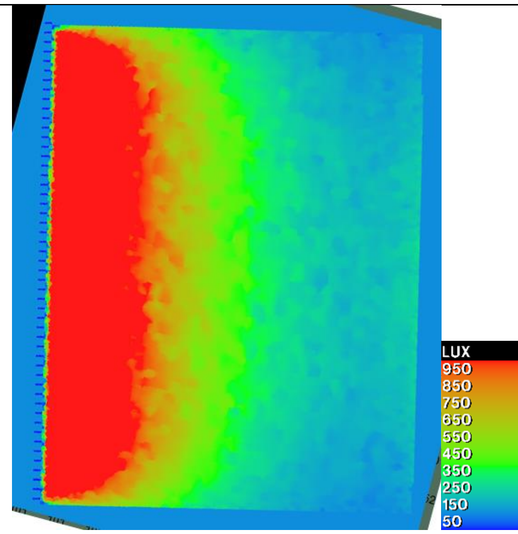
Radiance Contour Plan		
Luminance Image		
	Average Illuminance Level 260.22Lux	**Average Illuminance Level 392.61 Lux**

Table 5. 10Scenario 5 Illuminance and Radiance contour plans

5.4.7. Scenario Six Daylighting Results

Scenario Six shows the most minimum reduction in illuminance levels after the first scenario. The results show a reduction from 407.80 to 330.59 Lux in December and 613.49 to 498.6 Lux in June compared to the base case. The illuminance image in table 5.10 shows that the openings on the proposed fixed shading system create sun glare in the office space and eliminates views to the outside.

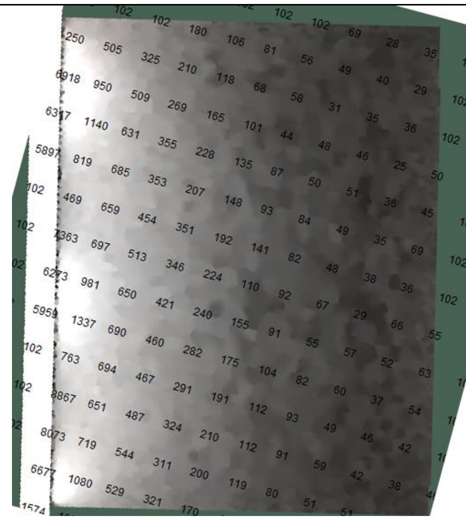
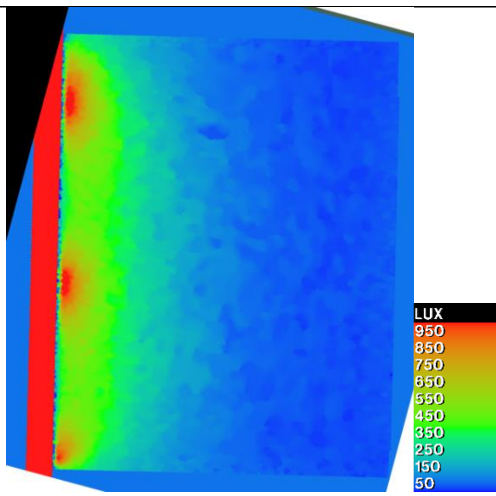
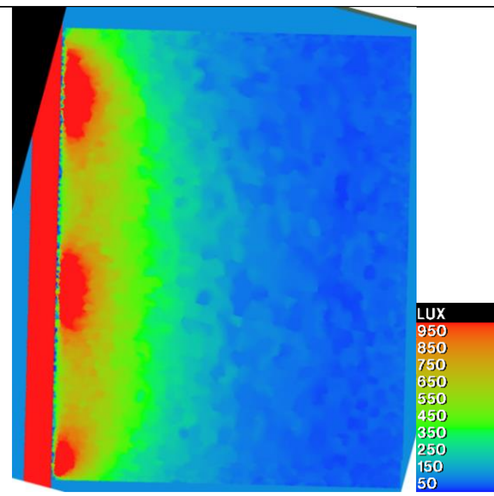
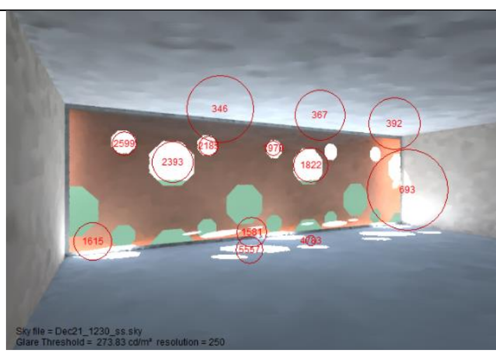
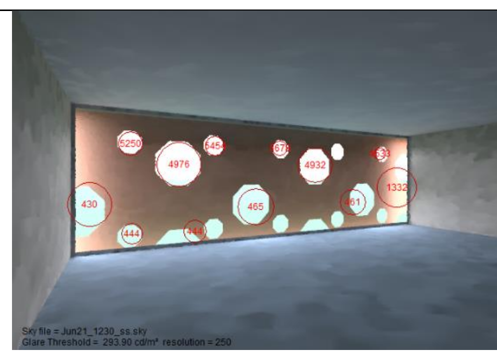
	Scenario 6 21st December	Scenario 6 21st June
Illuminance Plan		
Radiance Contour Plan		
Luminance Image		
	Average Illuminance Level 330.59 Lux	**Average Illuminance Level 498.67 Lux**

Table 5. 11Scenario 6 Illuminance and Radiance contour plans

Figure 5.7 illustrates the daylight analysis for the six scenarios against the base case and compares the simulation results. As shown in the figure, the first scenario shows a higher illuminance level than the base case, reducing its efficiency performance. The 45-degree vertical overhangs and the vertical louvers show almost similar illuminance level results, whereas scenario six shows a higher value. The most improved daylighting design option is shown in the horizontal louvers and the Egg-crate scenario. The egg-crate average illuminance levels drop by 252 Lux in December and 378Lux in June. On the other hand, the Horizontal louvers illuminance reduces by 206 Lux in December and 308 Lux in June.

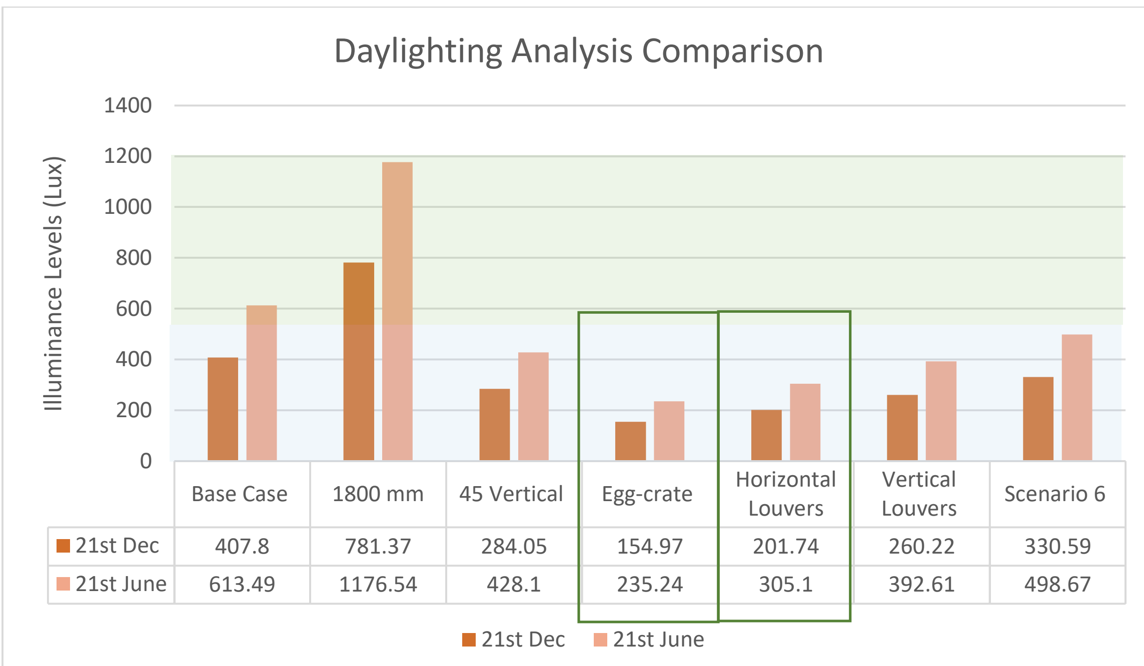


Figure 5. 7 Base case and fixed shading design proposed scenarios illuminance levels

5.5. Scenarios Energy and Daylighting Comparison

The selected simulation models for all scenarios prove their efficiency in terms of energy-saving, on most of them present enhanced illuminance levels. Therefore, this section will illustrate a comprehensive comparison to select the most optimum solution concerning energy consumption and illuminance levels.

Figure 5.8 illustrates the energy consumption and daylighting results achieved by each design scenario proposed on IES-VE. The figure clearly shows that the first scenario of the 1800mm Overhang design provides a slight reduction in energy consumption by 2% only and drastic increases in the illuminance levels by approximately 91% increase in both December and June simulations.

45-degree Vertical Fin scenario shows reductions in energy consumption and daylighting analysis compared to the base case readings as shown in figure 5.8. However, the impact on energy consumption is less than in the daylighting results. It is shown in figure 5.8 that the reduction in energy consumption is 5.2% and in illuminance levels is 62% in both December and June. Although the reductions in this scenario are better than scenario one, this scenario is not the optimum solution for this study.

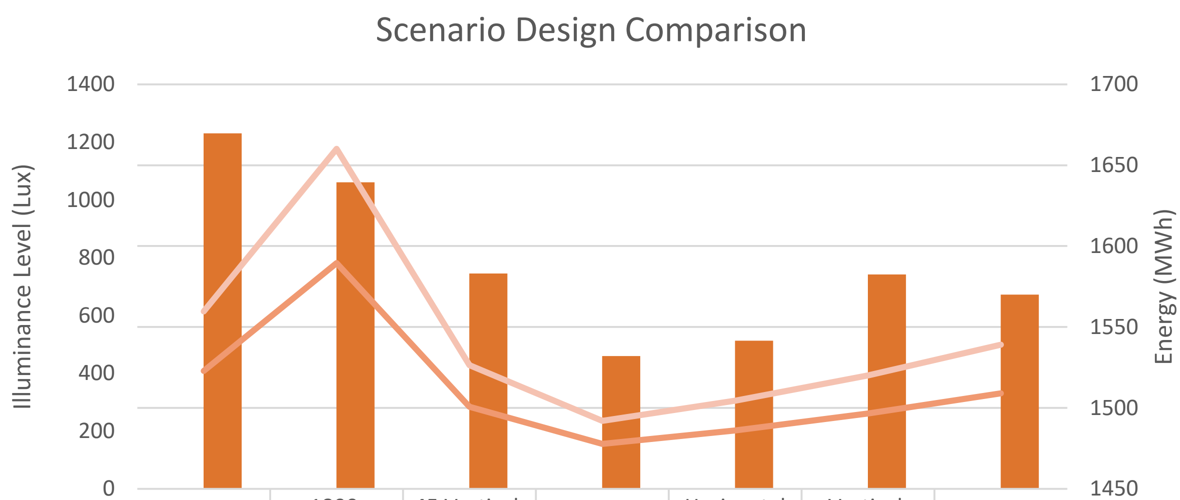
The Egg-crate model scenario presented the most optimum results for both energy consumption and daylight simulations. It is illustrated in figure 5.8 that the energy consumption results for this scenario have dropped by 8.2%, which is considered the highest of all the designs. Moreover, the daylight analysis results show a significant reduction in illuminance levels by 62% in December and June. Therefore, this scenario presents the best outcomes for this case study.

The fourth scenario, the horizontal Louvers, is the second-best scenario option. It presents good results in terms of energy efficiency and daylighting analysis after the Egg-crate Scenario. The

Energy consumption is reduced by 7.7%, and in daylight, the reduction reaches 50% in December and June, as presented in Figure 5.8.

Vertical Louvers are showing almost similar results as the Vertical Fins in Scenario 2. The energy consumption results show a reduction of 5.2% and 36% in illuminance levels, as illustrated in the figure below.

Scenario six shows an adequate reduction in energy efficiency compared to the vertical louvers and vertical fins. However, the daylighting results are lower than most of the other scenarios except for the Overhangs Scenario. The energy consumption results show a reduction of 6% compared to the base case and offer a drop of only 19% in daylighting analysis which is low compared to the other scenarios.



	Base Case	1800 Overhangs Scenario 01	45 Vertical Fins Scenario 02	Egg-crate Scenario 03	Horizontal Louvers Scenario 04	Vertical Louvers Scenario 05	Scenario 6 Scenario 06
Energy	1669.67	1639.4	1583.1	1532	1541.6	1582.5	1570
21st Dec	407.8	781.37	284.05	154.97	201.74	260.22	330.59
21st June	613.49	1176.54	428.1	235.24	305.1	392.61	498.67

Figure 5. 8 Energy and Daylight Results Comparison

5.6. Discussion

The comparison between the scenarios was considering improving the energy consumption in the case study and the illuminance level of the office space.

The results and comparison presents that the external fixed shading façade improves the energy performance and the illuminance levels for the building internal environment. It is important to note that the base case model of the Dubai Design District building six already includes a shading device design, however the energy consumption of this design is high and the illuminance levels are higher since the design is not done to reduce the energy consumption mainly rather to create an aesthetic design of the façade. Therefore, various fixed shading designs were designed for the simulation model. The selection of the proper shading device can impact the building performance drastically as shown in the previous sections depending on the design criteria and dimensions. The highest reduction percentage in the energy levels reached 8.2% reducing 137 MWh for a year. Moreover, the highest reduction results in daylighting reached 61% in scenario three.

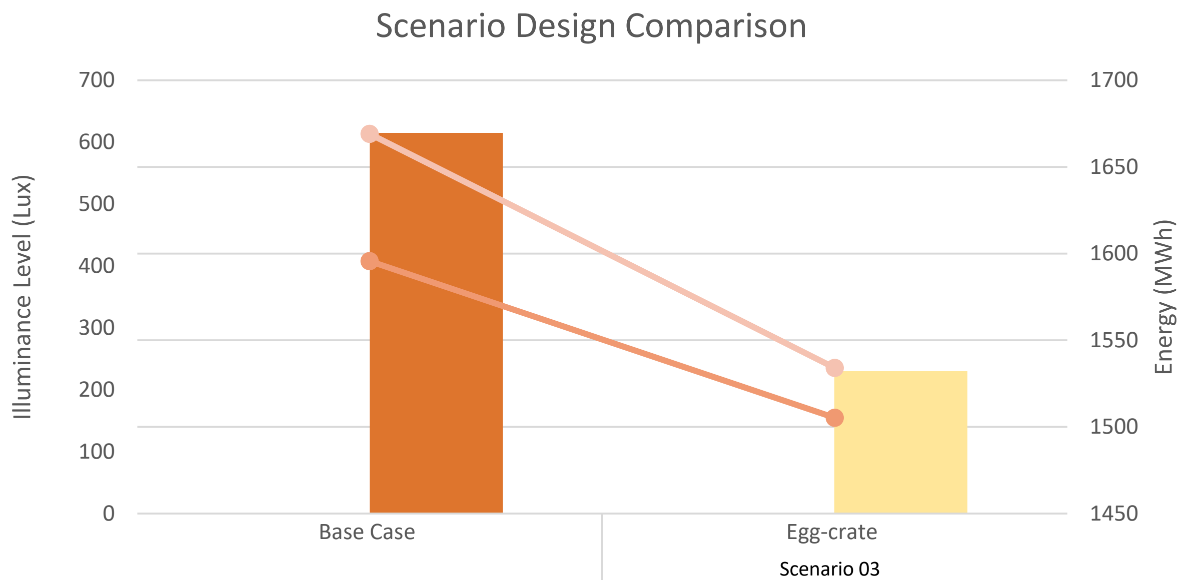
Following the literature review summary and findings, and indication of the enhancement of external fixed shading systems in terms of energy consumption and daylighting performance will be illustrated to compare with the results generated from IES VEW software for the external shading devices of the selected case study.

According to an existing literature by Hammad & Abu-Hijleh, 2010, all shading devices perform best on the south façade where the highest savings are achieved. This is due to the fact that the shading device blocks a long direct sun exposure which results in high reduction results.

This conducted study is made on a West elevation, therefore the reduction levels are not as high as the south elevation. However, figure 5.8 can clearly illustrate the ranking of the shading device according to reduction performance on the west elevation and effectiveness as follows (from least to highest): 1800mm Overhangs, Vertical Fins, Vertical Louvers, Double Skin, Horizontal Louvers and Eggcrate.

The most effective shading devices were the Eggcrate and the Horizontal Louvers. According to papers that studied the effect of shading devices on all elevations shows that the horizontal shading performs better than vertical shading on the east and west facades. And vertical louvers were less effective on the south, east and west sides in countries with similar climate as Dubai Brazil (Hammad & Abu-Hijleh, 2010 and Palmero-Marrero & Oliveira, 2010). Since the vertical louvers are not tilted in one of our scenarios, the 45 degrees' vertical fins achieved a very similar reduction results on the west elevation which means that the impact of vertical louvers on the west elevation is very minimal and not effective.

Table 5.2 summarizes all of the data from each scenario over a year, and it is clear that energy consumption is less in the winter than in the summer. This is expected, as the days are shorter throughout the winter, leading to less sun exposure. It might also mean that when the sun is low on the horizon, the shading devices are more capable of blocking solar radiation.



	Base Case	Egg-crate Scenario 03
Energy	1669.67	1532
21st Dec	407.8	154.97
21st June	613.49	235.24

Table 5. 12 Optimum Design Scenario

Based on the results discussed above, it is concluded that Egg crate fixed shading design performs best on the west façade elevation. As shown in table 5.12, the annual energy consumption of the optimal case is reduced to 1532 MWh while the base case is 1669.67MWh. The energy savings achieved by applying this configuration is a 137.2 MWh per year reduction, equivalent to 8.2%. Whereas in the daylighting analysis, the optimum design achieves an average illuminance level of 154.97Lux in December and 235.24 in June, achieving a reduction of 62% in both months compared to the base case model. The results could be higher if the base case didn't have any existing shading devices, unlike this case study, which includes shading devices that are not very efficient due to the need for an aesthetic design that contributed to the shading devices inefficiency.

CHAPTER SIX

CONCLUSION

6. Conclusion

This research aimed to study the impact of different fixed shading devices on the energy consumption and daylighting levels of an office building. The case study selected was in Dubai Design District, building six specifically. The study was conducted using the IES VE simulation tool to analyze the energy consumption reductions and the daylighting levels for one typical office space. The study included six different fixed shading models to get the optimum design method used for external fixed shading devices. These devices were; Horizontal Overhangs in three different dimensions 1200, 1500, and 1800mm. Vertical fins also in both 90 and 45 degrees orientation, Egg-crate, Horizontal Louvers, Vertical Louvers, and double skin shading element as the sixth design strategy.

The results show that all these scenarios improve the office space's energy consumption and daylighting levels compared to the base case. However, the most effective solution was the Egg-crate and Horizontal louvers, where the egg0-crate saves 8.2% of the energy consumption and 61% of the daylighting levels. On the other hand, the horizontal louvers, the second-best scenario, achieve a reduction of 7.7% in energy consumption and a 50% reduction in daylight levels.

These two design strategies showed better reduction results since they cover a more significant portion of the façade coverage than the other design strategies. The study proves that higher energy saving can be achieved through different design parameters of the fixed shading designs, mainly including; the angle, length, spacing, and coverage percent of the window.

Future recommendations were conducted from this study. While this study was conducted because it is one of the few topics studied in the region, other research areas were identified after researching and finding these research results. This research showed promising results in the energy reductions; however, future studies need to test different design criteria that are small changes that can significantly impact the outcome.

Moreover, this study only focused on the fixed shading devices. However, another important measure that came up during the research is the material selection of the shading devices, which can significantly influence the performance of these shading devices. Gutierrez & Labaki (2007) concluded that using concrete shading devices caused higher reduction levels in energy than wooden material. It is also deemed that more studies should be performed on the impact of materials on the shading devices' performance in the future.

As part of the literature review search, future studies must include a material selection of the glazing and the other technologies like photovoltaic glass technology as part of the research, which will impact the energy consumption and impact the cost. Other research recommendations would be studying all four sides' elevations of a building since this study was focused on the exposed façade, which is only the west elevation. Different fixed shading devices will have different reduction levels on each elevation.

In conclusion, after going through the literature review of this paper, it was evident that architects tend to ignore the importance of shading devices due to aesthetical reasons. A study was carried out and proved that architects disregard climate comfort and sustainability due to the extent of maintaining a specific aesthetic measurement (Menzies & Wherrett, 2005 and Kim et al., 2007). For some buildings that have shading devices, such as this research's case study of Dubai Design District, it was found that the shading devices are added for aesthetical purposes only, and no shading or any energy consumption analysis was conducted. Although the aesthetics of a building is critical yet, on the other hand, it can be achieved in parallel to the energy consumption importance.

Hence, more studies should be conducted on the aesthetical appearance and visual assessment of the shading devices, which will make them more appealing for the architects to integrate and use in their designs for a better future.

CHAPTER SEVEN

References

7. References

- Ashrae. (2013). 2013 ASHRAE handbook. Atlanta, GA.:ASHRAE.
- A Sustainable Innovative World - Class Utility, 2017. *DEWA SUSTAINABILITY REPORT 2017*. UAE.
- Altan, H., Hajibandeh, M., Tabet Aoul, K. and Deep, A., 2016. Passive Design. *Springer Tracts in Civil Engineering*, pp.209-236.
- Alhuwayil, W., Abdul Mujeebu, M. and Algarny, A., 2019. Impact of external shading strategy on energy performance of multi-story hotel building in hot-humid climate. *Energy*, 169, pp.1166-1174.
- Architonic. 2021. *Aqua Tower by Studio Gang | Office buildings*. [online] Available at: <https://www.architonic.com/en/project/studio-gang-aqua-tower/5100189> [Accessed 25 June 2021].
- Ardekani, P., 2014. *Design sunshade for western facade of residential buildings in Shiraz,Iran*. Masters Degree. UNIVERSIDAD POLITÉCNICA DE CATALUNYA.
- Aboulnaga, M. M., (2005) Towards green buildings: Glass as a building element-the use and misuse in the gulf region. Renewable Energy 31 (2006) 631–653. Available from: http://www.sciencedirect.com.
- Alkhateeb, E. and Abu-Hijleh, B., 2019. Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB). *Heliyon*, 5(6), p.e01971.
- Al Dakheel, J. and Tabet Aoul, K., 2017. Building Applications, Opportunities and Challenges of Active Shading Systems: A State-of-the-Art Review. *Energies*, 10(10), p.1672.

- Attia, S. (2017). Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE. QScience Connect, vol. 2017 (2), p. 6.
- Bellia, L., Marino, C., Minichiello, F. and Pedace, A., 2014. An Overview on Solar Shading Systems for Buildings. *Energy Procedia*, 62, pp.309-317.
- Carletti, C., Sciurpi, F. and Pierangioli, L., 2014. The Energy Upgrading of Existing Buildings: Window and Shading Device Typologies for Energy Efficiency Refurbishment. *Sustainability*, 6(8), pp.5354-5377.
- Cuce, E. and Cuce, P., 2019. Performance Assessment of Solar Chimneys: Part 2 – Impacts of Slenderness Value and Collector Slope on Power Output. *Energy Research Journal*, 10(1), pp.20-26.
- Cho, J., Yoo, C. and Kim, Y., 2014. Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis. *Energy and Buildings*, 82, pp.771-785.
- Dubai Municipality. (2007). Al Sa'fat Dubai Green Building Evaluation System. Dubai, UAE: Dubai Municipality.
- designboom | architecture & design magazine. 2021. *tago architects: sur yapi offices, turkey*. [online] Available at: <https://www.designboom.com/architecture/tago-architects-sur-yapi-offices-turkey/> [Accessed 25 June 2021].
- Daaboul, J., Ghali, K. and Ghaddar, N., 2017. Mixed-mode ventilation and air conditioning as alternative for energy savings: a case study in Beirut current and future climate. *Energy Efficiency*, 11(1), pp.13-30.

- Ejroushi, A., Smeda, M. & Bannani, F. (2013). The solar chart for designing shading devices for Tripoli City, Libya. *Solar Energy and Sustainable Development journal*, vol. *2*(1), pp. 48-61.
- Evola, G., Gullo, F. and Marletta, L., 2017. The role of shading devices to improve thermal and visual comfort in existing glazed buildings. *Energy Procedia*, 134, pp.346-355.
- Fcl.ethz.ch. 2021. *Dense and Green Building Typologies*. [online] Available at: <https://fcl.ethz.ch/research/fcl-phase2/high-density-cities/dense-and-green.html> [Accessed 25 June 2021].
- Freewan, A., 2014. Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions. *Solar Energy*, 102, pp.14-30.
- Fathy, H., Shearer, W. and Sultan, A., 1995. *Natural energy and vernacular architecture*. Chicago: Published for the United Nations University by the University of chicago Press.
- Faisal, G. and Aldy, P., 2016. Typology of building shading elements on Jalan Sudirman corridor in Pekanbaru. *IOP Conference Series: Materials Science and Engineering*, 128, p.012029.
- Gaisma. 2021. *Dubai, United Arab Emirates - Sunrise, sunset, dawn and dusk times for the whole year*. [online] Available at: <https://www.gaisma.com/en/location/dubai.html> [Accessed 25 June 2021].
- Gutierrez, G. C. R., & Labaki, L. C. (2007). An Experimental Study of Shading Devices:Orientation Typology and Material. [online]. [Accessed 3 March 2013]. Available athttp://www.ornl.gov/sci/buildings/2012/Session%20PDFs/84_New.pdf

- Glass, V., AG, G., Ltd., W., KG, s., o.o., P., B.V., e. and Spa, O., 2021. *Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE*. [online] glassonweb.com. Available at: <https://www.glassonweb.com/article/evaluation-adaptive-facades-case-study-al-bahr-towers-uae> [Accessed 25 June 2021].
- Hans, O., 2006. *Static Shading Devices in Office Architecture -Theory, Shape and Potential* -. Master of Science. Bergische Universitat Wuppertal.
- Hammad, F., & Abu-Hijleh, B. (2010). The energy savings potential of using dynamic external louvers in an office building. *Energy and Buildings* [online] Vol. *42*, pp 1888-1895. [Accessed 17 December 2012].
- Jenkins, D. and Newborough, M., 2007. An approach for estimating the carbon emissions associated with office lighting with a daylight contribution. *Applied Energy*, 84(6), pp.608-622.
- Kim, M., Leigh, S., Kim, T. and Cho, S., 2015. A Study on External Shading Devices for Reducing Cooling Loads and Improving Daylighting in Office Buildings. *Journal of Asian Architecture and Building Engineering*, 14(3), pp.687-694.
- Kim, S., Shin, K., Kim, H. and Cho, Y., 2017. A Study on the Effectiveness of the Horizontal Shading Device Installation for Passive Control of Buildings in South Korea. *International Journal of Polymer Science*, 2017, pp.1-11.
- Kim. K., Kim, B.S. & Park, S. (2007). Analysis of design approaches to improve the comfort level of a small glazed-envelope building during summer. *Solar Energy* [online]. Vol. 81, pp. 39- 51. [Accessed 17 December 2012].

- Yang, I. and Nam, E., 2010. Economic analysis of the daylight-linked lighting control system in office buildings. *Solar Energy*, 84(8), pp.1513-1525.Slideshare.net. 2021. *Sun Shading Devices*.
- Sandak, A., Sandak, J., Brzezicki, M. and Kutnar, A., 2019. Designing Building Skins with Biomaterials. *Bio-based Building Skin*, pp.65-97.
- Sandak, A., Sandak, J., Brzezicki, M. and Kutnar, A., 2019. State of the Art in Building Façades. *Bio-based Building Skin*, pp.1-26.
- Strategy and Formerly Booz & Company, 2015. *Energy efficiency in the UAE Aiming for sustainability*. [online] Dubai: Energy Working Group, pp.4-8. Available at: <https://www.strategyand.pwc.com/m1/en/reports/energy-efficiency-in-the-uae.pdf> [Accessed 23 June 2020].
- Shrestha, S., 2016. *Fixed external shading and daylight quality: four case studies*. Master of Science. KANSAS STATE UNIVERSITY.
- Sherif, A., El-Zafarany, A. and Arafa, R., 2012. External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings*, 52, pp.1-10.
- Shahdan, M., Ahmad, S. and Hussin, M., 2018. External shading devices for energy efficient building. *IOP Conference Series: Earth and Environmental Science*, 117, p.012034.
- Sandak, A., Sandak, J., Brzezicki, M. and Kutnar, A., 2019. *Bio-based Building Skin*. 1st ed. Singapore: Springer, Singapore.

- Kassem, M. and Mitchell, D., 2015. Bridging the gap between selection decisions of facade systems at the early design phase: Issues, challenges and solutions. *Journal of Facade Design and Engineering*, 3(2), pp.165-183.
- de Oliveira Neves, L. and Marques, T., 2017. Building Envelope Energy Performance of High-rise Office buildings in Sao Paulo City, Brazil. *Procedia Environmental Sciences*, 38, pp.821-829.
- Keeler, M. and Vaidya, P., 2016. Fundamentals of Integrated Design for Sustainable Buildings. 2
- Kirimtat, A., Koyunbaba, B., Chatzikonstantinou, I. and Sariyildiz, S., 2016. Review of simulation modeling for shading devices in buildings. *Renewable and Sustainable Energy Reviews*, 53, pp.23-49.
- Langston, C., 2008. Validation of the adaptive reuse potential (ARP) model using iconCUR. *Facilities*, 30(3/4), pp.105-123.
- LECHNER, N., 2020. *HEATING, COOLING, LIGHTING*. [S.l.]: JOHN WILEY.
- Lau, A., Salleh, E., Lim, C. and Sulaiman, M., 2016. Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia. *International Journal of Sustainable Built Environment*, 5(2), pp.387-399.
- Meresi, A., 2016. Evaluating daylight performance of light shelves combined with external blinds in south-facing classrooms in Athens, Greece. *Energy and Buildings*, 116, pp.190-205.
- Mumovic, D. and Santamouris, M., 2013. *A handbook of sustainable building design and engineering*.

- Menzies, G.F. & Wherrett, J.R (2005). Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows.
- *Energy and Buildings* [online]. Vol. 37, pp. 623-630. [Accessed 17 December 2012]. meteoblue. 2021. *Climate Dubai*. [online] Available at: <https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/dubai_united-arab-emirates_292223> [Accessed 25 June 2021].
- Nady, R. (2017). Dynamic Facades: Environmental Control Systems for Sustainable Design. Renewable Energy and Sustainable Development, vol. 3 (1), pp. 118-127.
- Özsavaş Akçay, A. and Alotman, H., 2017. A Theoretical Framework for the Evaluation from the Traditional Mashrabiya to Modern Mashrabiya. *Journal of History Culture and Art Research*, 6(3), p.107.
- Palmero-Marrero, A. I., & Oliveira, A. C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy* [online] Vol. *87*, pp 2040-2049. [Accessed 3 March 2013].Available at http://www.sciencedirect.com/science/article/pii/S0306261909005078
- Prowler, D., 2016. *Sun Control and Shading Devices | WBDG - Whole Building Design Guide*. [online] Wbdg.org.
- Roebig, J. H. (1983). An aesthetic impact assessment technique. *Impact Assessment* [online] Vol. *2*, pp 29-40. [Accessed March 2013].
- Stack, A., Goulding, J., & Lewis, J. (n.d.). Shading Systems; Solar Shading for the European climates. Dublin: ENERGIE. Retrieved from http://erg.ucd.ie/UCDERG/pdfs/mb_shading_systems.pdf

- Steane, M. and Steemers, K., 2013. *Environmental Diversity in Architecture*. Hoboken: Taylor and Francis.
- Tendulkar, A., 2017. Passive design strategies for cold and cloudy climate. [online] 10. Available at: <http://www.ripublication.com/irph/ijert_spl17/ijertv10n1spl_06.pdf> [Accessed 23 April 2021].
- World Green Building Council. 2021. *(Day)Lighting the way to greener and healthier buildings | World Green Building Council*. [online] Available at: <https://www.worldgbc.org/news-media/daylighting-way-greener-and-healthier-buildings> [Accessed 25 June 2021].
- World Weather & Climate Information. 2021. *Climate and average monthly weather in Dubai, United Arab Emirates*. [online] Available at: <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,dubai-ae,United-Arab-Emirates> [Accessed 25 June 2021].
- Wang, Z., Hong, T. and Piette, M., 2019. Data fusion in predicting internal heat gains for office buildings through a deep learning approach. *Applied Energy*, 240, pp.386-398.
- Yu, Z., Gou, Z., Qian, F., Fu, J. and Tao, Y., 2019. Towards an optimized zero energy solar house: A critical analysis of passive and active design strategies used in Solar Decathlon Europe in Madrid. *Journal of Cleaner Production*, 236, p.117646.
- Yüksek, I. and Karadayi, T., 2021. *Energy-Efficient Building Design in the Context of Building Life Cycle*.
- Zahiri, S. and Altan, H., 2016. The Effect of Passive Design Strategies on Thermal Performance of Female Secondary School Buildings during Warm Season in a Hot and Dry Climate. *Frontiers in Built Environment*, 2.

- zzet Yüksek and Tülay Tikansak Karadayi (January 18th 2017). Energy-Efficient Building Design in the Context of Building Life Cycle, Energy Efficient Buildings, Eng Hwa Yap, IntechOpen, DOI: 10.5772/66670.
- Zou, Y., Zhan, Q. and Xiang, K., 2021. A comprehensive method for optimizing the design of a regular architectural space to improve building performance. *Energy Reports*, 7, pp.981-996.