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The Impact of Overhangs and Side-fins on Building Thermal Comfort, Visual Comfort and Energy Consumption in the Tropics

تأثير إستخدام المظلات الأفقية و الرأسية للمبانى فى المناطق الإستوائية على الراحة الحرارية، الراحة البصرية و إستهلاك الطاقة

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ABSTRACT

The rapid booming in the field of building construction during the last few decades created many challenges for this issue in the research zone in terms of its negative effects on the environment due to large amounts of carbon dioxide emissions resulting from the excessive energy use by the building systems. In the tropics because of the hot and humid weather, the continuous need for mechanical ventilation is a necessity, which makes the problem even harder. Consequently, the world's focus now to a sustainable building approach in terms of health and environment as well as reducing the building life cycle costs, which is majorly influenced by its energy consumption. Meanwhile, passive techniques started to show up as affordable solutions that could cut off the building cost significantly, such as; building orientation, building materials and shading elements. Therefore, the motivation behind performing this research is to orient the need of countries with tropical climates to adopting passive techniques and basic shading elements in specific thorough linking its relationship to thermal comfort, visual comfort and energy consumption. The research was conducted on an office building sample which represents common office types by means of IES-VE computer simulation software. Overhangs and side-fins with various depths were assessed in different building orientations through summer and winter seasons. Afterwards, quantitative and qualitative outputs were analyzed to know the implication of each case's performance on balancing between reducing operational costs, and occupants' thermal and visual comfort. The results ensured that shading devices could provide a reduction from 13% to 55% of solar gains, leading to a significant reduction in the percentage of people dissatisfied. In addition, a significant reduction in illuminance levels up to 9.3% and lower rates of discomfort glare were detected. Meanwhile, energy consumption experienced an obvious savings of up to 27.5%. Thus, the significance of this study is adding valuable information that provide architects with support for their design decisions, as well as helping mechanical engineers to predict their cooling loads. Meanwhile, governmental authorities could refer to the study when adjusting local building guidelines and regulations.

Keywords: Passive design; Shading devices; Overhangs; Side-fins; Energy Consumption; Thermal Comfort; Visual Comfort

الملخص

إن الإزدهار السريع في مجال تشييد المباني خلال العقود القليلة الماضية قد خلق الكثير من التحديات التي تواجه الباحثين فى هذا المجال، حيث أن هذه الطفرة تؤثر سلبا على البيئة نتيجة انبعاث كميات كبيرة من ثاني أكسيد الكربون الناتج عن استخدام الطاقة المفرطة لتشغيل النظم المختلفة للمبانى. تعتبر التهوية الميكانيكية فى المناطق الاستوائية ذات المناخ الحار و الرطب ضرورة و حاجة مستمرة لا غنى عنها وهو ما يجعل المشكلة أكثر صعوبة. وبناء على ذلك، فقد بدأ العالم فى التوجه إلى منهج الإستدامة فى البناء من أجل صحة الإنسان والبيئة، فضلا عن خفض التكاليف الكلية للمبنى و التى تعتمد بشدة على كيفية استهلاك الطاقة. لذلك، بدأ التوجه إلى المعالجات المناخية البسيطة و الغير مكلفة، مثل، توجيه المبنى بالنسبة للشمس و عناصر تظليل الواجهات. لذلك، فإن الدافع وراء القيام بهذا البحث يتمثل فى توجيه حاجة المناطق ذات المناخ الاستوائي للاعتماد على التقنيات المناخية البسيطة وبالأخص عناصر التظليل، و ربط علاقتها بالراحة الحرارية، الراحة البصرية واستهلاك الطاقة. البحث قد أجري على عينة المكاتب الدارجة من حيث الأبعاد عن طريق برنامج الكمبيوتر IES -VE . فقد أجرى تمثيل للمظلات الأفقية و الرأسية بأعماق مختلفة ثم تقييم حالتها المختلفة أثناء تغيير وجهة المبنى فى فصلين الصيف و الشتاء. بعد ذلك، تم تحليل النتائج الكمية و النوعية لقياس التوازن التي حققته كل حالة بين إنخفاض تكاليف التشغيل، الراحة الحرارية والراحة البصرية. أظهرت النتائج أن المظلات قد تؤدى إلى انخفاض فى نسبة الطاقة الشمسية المكتسبة داخل المبنى إبتداءا من 13٪ و حتى 55٪ ، مما يؤدى إلى ارتفاع نسبة الراحة الحرارية للمستخدمين. بالإضافة إلى ذلك، فقد تبين إنخفاض ملحوظ في مستويات الإضاءة داخل المكان تصل إلى 9.3٪، وأيضا إنخفاض معدلات الوهج الضوئى. في غضون ذلك، شهد استهلاك الطاقة إنخفاضات واضحة تصل إلى 27.5٪. بالتالي، فإن أهمية هذه الدراسة يتمثل فى توفير بيانات للمهندسين المعماريين تساعدهم على إتخاذ قرارات تصميمية سديدة ، فضلا عن مساعدة المهندسين الميكانيكيين فى توقع أحمال التبريد. وفي الوقت ذاته، يمكن للسلطات الحكومية الإستعانة بالدراسة لتعديل مواصفات البناء واللوائح المحلية.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Throughout the decades, buildings were responsible for the largest amount of destruction and pollution caused to the environment, As communities grow and the urban sprawl extend, the demand for more buildings and services to serve the new communities is needed. This expansion has a great impact on the ecosystem and living organisms, as more Greenfields are being ruined, more natural resources and energy forms are being consumed. Moreover, the construction phase of the building is accompanied by greenhouse gas emissions and heat radiations resulting from materials manufacturing and construction waste, in addition to the building operational system emissions throughout the occupancy stage as well as the demolition process at the end of the building’s life cycle.

Especially in the last 15 years, where high mechanical cooling energy demand have become an essential in all buildings located in hot climate countries, consequently, buildings have been a very critical issue towards the environment, thus, responsible for omitting radiations and pollution to the outdoor air, since it owns the largest share of energy consumption (Simmler 2008). Eventually, energy consumption due to air conditioning systems in buildings brings the building sector to the top of the list, while, other disciplines such as traffic and industry comes afterwards in terms of the implication on the environment.

In addition, unfortunately, buildings have proved to be the major cause of the two worldwide sensitive phenomenon of global warming and urban heat island as per Radhi, (2009), meanwhile, researchers are trying their best to provide solutions for saving Earth. Global warming is the increase in the temperatures of the atmosphere ascending over the years with all pollution omitted from all sources causing depletion in the ozone layer of the atmosphere, which is supposed to protect the earth from any harmful sun rays. Lately, there have been many organizations responsible of finding technical solutions to deal with global warming, in addition, trying to increase people’s awareness about the dilemma. The Urban heat island phenomenon is the zone of heat generated over the cities because of heat generating sources that flow upwards as a result of its low density to form a heat cloud over the city, thus, it is an indication to the amount of heat emissions and the atmosphere’s pollution level.

1.2 Background of the Study

Sustainable development, which is defined as the efficient way of using renewable and non renewable resources in a way fulfilling current human needs without causing any harm to the environment or threatening to the existence of these resources in the future, which compromise the wealth share of the coming generations that depends significantly on many current human applications, habits, and activities. Sustainable theories are green concepts that highlight the contribution to many aspects to the environment and improving their performance for a better life quality for the present and the future generations, such as improving; indoor air quality, ventilation and adequate day lighting as it deals with three main aspects which are environmental aspect, the social aspect and the economical aspect. Kumar (2010) stated that it is significantly important to achieve the balance between environmental, social and economical targets.

Throughout the last ten years sustainability has started to become familiar, many organizations were founded to take care of the sustainability concepts and issue rules, guidelines and regulations in order to spread the culture and save the environment. The most important organizations are the United States Green Building Council, ”USGBC”, which was the first among those organizations, which was founded in the States then started to have branches allover the world. Also, organizations like Environmental Protection Agency “EPA”, which is concerned about issues like energy saving, water and electricity consumption to share handy solutions and give sustainability more public awareness, thus, strengthening the sense of stewardship towards the environment , however, it is still very challenging to put sustainability on the right track because of many parameters and cultural backgrounds. In general, an overall sustainable integrated plan in terms of consuming resources like water and electricity, eco-friendly use and manufacture of building materials, provides a safe and healthy environment, in addition to a long-term economic growth base and a lower ecological footprint.

1.2.1 Sustainable Construction

One of the major sustainable development applications is sustainable construction that is counted as the most dominant factor affecting the sustainable development of any country and constraining the curve of its sustainable growth. Named as "green" construction, it concerns about an overall environment friendly building process starting from the earlier project brief and design followed by the tendering process leading to the construction practice as well as continuing to the building commissioning and maintenance strategies. It studies the environmental impact of a building over its entire lifespan among all construction practices, moreover, presenting the impact and the use of ‘eco friendly' or ‘green' building materials and technologies that have been developed to substitute the current ones by means of acting more environmentally positive. Unlike the approach few years ago, sustainable construction was thought to be an expensive and inapplicable idea. However, due to more frequent environmental awareness and new building laws, the idea started to find more and more susceptibility and familiarity (Sunita,2010), thus, being approached by many companies, which started adopted sustainable constrains to their building practices focusing on energy efficiency and climatic change. In conclusion, sustainable construction has positive implications on any building’s energy profile, as well as the human’s health and comfort.

1.2.2 The Global Focus on Energy Consumption

Recently, the world’s focus has been oriented towards energy consumption and profiles trying to find approaches in order to reduce its amounts to avoid its several implications. As per US Environmental Protection Agency “EPA”, a global issue has been top ranked as a severe priority. The simplest and least expensive approach of energy reduction forms is using passive design techniques other than active systems.

1.2.3 Passive Techniques

In order to control the amount of energy consumed by the building, passive techniques are utilized, which are strategies that provides climatic treatments that work on reducing thermal and solar radiation transmitted to the indoor space. Such techniques are highly effective in hot climates such as; controlling the building’s orientation, location of different function spaces according to their daylighting and ventilation requirements, as well as shading elements, which are one of the most effective strategies widely used. Shading devices in its various forms are very essential since they have the ability to reduce the indoor temperature significantly and thus, presenting the most efficient energy behavior for the building by integrating some façade elements due to a comprehensive climatic study for its location and inclination angles. Architects play has a major role regarding sustainable construction as they contribute to adopting energy reduction orientations by using sustainable materials and elements, plus, using design features more effectively, while maintaining a low level resources consumption in order to improve the building's performance as stated by Morrissey et al. (2011).

1.2.4 The Importance of Daylighting

One of the most valuable targets of sustainability is using these passive techniques for the enhancement of natural daylighting in the buildings. Daylighting penetration in any building reflects valuable benefits, one of which is the visual acceptance of human eye due to its cheerful psychological effect, which translates occupants' visual comfort. In addition, it has a positive impact on health and improving human performance as it provides a better exposure to the outdoor view and a clearer visibility indoors (Ne'eman, 1976).

On the other hand, excessive daylight intensity causes glare, which results in occupants' visual discomfort, further more, overheat, which gained inside the space causes thermal discomfort. Consequently, overheating affects the efficiency of the air conditioning system by forcing it to work with extra power to create the required comfort zone, taking into consideration other heat emission sources such as; human activity, equipments and appliances found in the space and especially lighting fixtures, which counts as a main source of heat. Overheating and sun glare has to be taken into consideration while designing huge glazing façades in such hot and humid weather conditions (Aboulnaga, 2005).

1.2.5 The Importance of Shading

Shading devices in its various forms have the ability to reduce the indoor temperature significantly and thus, presenting the most efficient energy behavior for the building by integrating some façade elements based on the location of the shading element, its properties and inclination angles. In office buildings, daylighting penetration reflects valuable psychological benefits, in addition to improving human performance. On the other hand, they balance the amount of daylighting entering the building to avoid glare and overheating through decreasing the amount of thermal gains inside the space. Moreover, nowadays a number of studies are being performed to enhance intelligent daylighting and shading techniques, which effectively influence thermal gains as Kima (2012) studied. In addition, decrease glare resulting in a sustainable indoor environment as stated be Tzempelikos (2007). It is subjected to many factors such as; the location and the climate which determines the shading element‘s characteristics. Other studies focused on the impact of shading approaches on energy consumption such as; Hammad (2010).

1.3 Motivation of the Study

As stated by Dubai Electric and Water Authority “DEWA”, 40% of UAE’s annual average electrical loads are a result of HVAC consumption and it reaches its maximum of 60% in summer. Moreover, UAE has been ranked by the International Energy Agency “IEA” CO_2 Emissions From Fuel Combustion Highlights (2010) as one of the highest 10 countries in electric consumption per capita, in addition, the study pointed out that UAE’s rank is the second country worldwide in terms of CO_2 emissions per capita. However, the real estate revolution and the economic growth require the need for more buildings and development which complicates the situation and makes it rather more challenging.

Thus, the motivation behind this study is to seek the need of tropical countries such as; UAE, to use passive design techniques and climatic treatments, which are priorities that should be adopted as early as possible to achieve the optimum building’s energy consumption by reducing the cooling sensible loads significantly. Then, consequently influence the building’s energy consumption profile, rather than using active systems that have severe implications on the building's carbon footprint. In addition, the study reflects the influence of those passive techniques on the indoor environment shading devices would be highly effective as a huge amount of money is being spent on cooling energy, which makes it challenging. Meanwhile, using those techniques should not compromise occupants' thermal and visual comfort as stated by David (2011). Eventually, the building's annual energy consumption is majorly the result of HVAC system and the artificial lighting usage.

In addition, there is need for scientific data in UAE to cover up this area, however there are no serious efforts to decrease the use of active system, since there is a lack of passive studies addressing hot climate countries although it is a major issue. Since the high consumption rate of cooling systems in the tropics influence on indoor thermal gain, natural and artificial lighting levels inside the space and eventually mechanical cooling energy consumption. Office buildings were specifically selected for this study because of their huge glazed façades, modern trends and curtain walls. In addition, the critical procedure of maintaining a certain lighting level in such building type during office working hours without countering additional thermal gain and excessive glare, which directly affect the occupants' comfort and consequently their performance rather than other building types, for example, residential, commercial and industrial ones. Moreover, it has been stated that in the USA the highest buildings emitting carbon dioxide and consuming energy are the office buildings due to their mechanical systems' performance (Hammad, 2010). Obviously, weather conditions have the greatest impact on design and building criteria (Aboulnaga, 2001).

However, UAE was chosen as an interesting challenging case especially that it is at the beginning of a new construction stage where sustainability has been put into consideration, strategies has been made and action has been required by all governmental parties since they announced the statement "UAE is going green" (Go-Green). There is a, lack of promoting for green architecture & sustainable technologies (Sunita, 2010), depletion of knowledge & experience. Since UAE is a community with opaque financial issues, gaining government support and commitment is mandatory. Additionally, lack of life cycle cost analysis associated with predicted high initial costs as well as the poor integrated design process, contribute negatively to the path towards sustainability. Considering the environment and maintaining a sense of modern architectural design is a huge challenge as almost all architects agreed, especially that some passive techniques are costless to consider but provide relevant difference throughout the building's life cycle cost.

1.4 Information about the Location

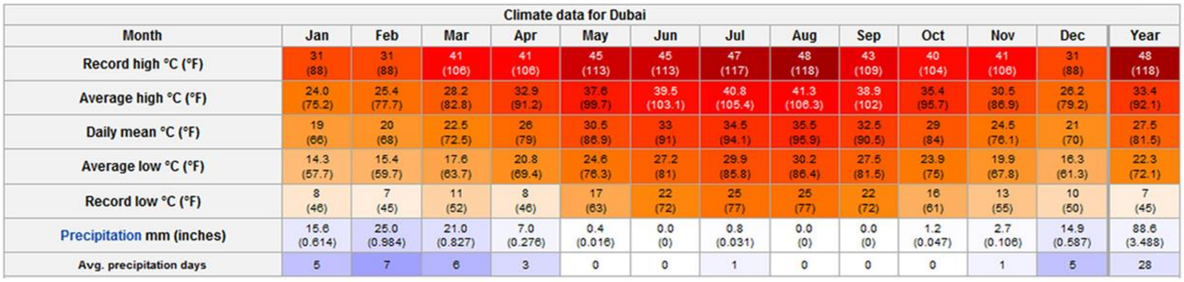
1.4.1 General Information

The United Arab Emirates (UAE) is located north of Oman and Saudi Arabia, south of the Arabian Gulf, west of Gulf of Oman and Oman, and East of Qatar and Saudi Arabia. It is located between latitudes 22° and 26.5° north, and longitudes 51° and 56.5° east, with covering a surface area of 83,600 Sq. km *[Refer to Figure 1, in Appendices]*. UAE is one of the developing countries with a population of 4.8 million (Global Energy Market Research, 2011). Dubai is located at the west of UAE on the coast of the Arabian Gulf, which is known for its hospitality and cultural heritage all over the years as well as being the central business district for the whole region. It covers a surface area of 4,110 Sq. km of the whole UAE area and lies at longitude 55.33° and latitude 25.25°. Dubai comes in the second place after Abu Dhabi in terms of the population rate. Dubai has gained a trade importance as well as being a famous tourism attraction spot due to its strategic location between Asia and Europe, in addition to the effort made by the government to facilitate commercial plans in order to provide Dubai an importance in the area with all the fascinating projects. Millions of tourists set it as an important spot either for tourism or for business as it contains enormous malls and luxurious warm welcoming hotels, pleasant beaches, deserts, sand dunes and a sunny weather throughout most of the year.

1.4.2 Climatic Data

UAE is a country with very hot climate mostly all year long with very high levels. Summer in Dubai is extremely hot, windy with an average minimum and maximum temperature of 30 °C and 40 °C respectively, where the majority of the days are sunny throughout the year. Winters are warm with an average minimum and maximum temperature of 14 °C and 23 °C respectively. As for precipitation, it has been increasing in the last few decades to reach an accumulated rain of 150 mm per year as per Table 1.1 from Dubai Meteorological office, which shows the important climatic information. It is one of the worlds best winter resorts between November and March , as it experiences warm sunny days .with an average maximum and minimum temperature of 26 °C and 15 °C respectively, on the other hand, high temperatures and high humidity levels increase between June and August. *[Refer to Figures 2,3 and 4, in Appendices]*

Table 1.1: Dubai's annual climatic data. *[Dubai meteorological office, online]*



Climate data for Dubai

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	31 (88)	31 (88)	41 (106)	41 (106)	45 (113)	45 (113)	47 (117)	48 (118)	43 (109)	40 (104)	41 (106)	31 (88)	48 (118)
Average high °C (°F)	24.0 (75.2)	25.4 (77.7)	28.2 (82.8)	32.9 (91.2)	37.6 (99.7)	39.5 (103.1)	40.8 (105.4)	41.3 (106.3)	38.9 (102)	35.4 (95.7)	30.5 (86.9)	26.2 (79.2)	33.4 (92.1)
Daily mean °C (°F)	19 (66)	20 (68)	22.5 (72.5)	26 (79)	30.5 (86.9)	33 (91)	34.5 (94.1)	35.5 (95.9)	32.5 (90.5)	29 (84)	24.5 (76.1)	21 (70)	27.5 (81.5)
Average low °C (°F)	14.3 (57.7)	15.4 (59.7)	17.6 (63.7)	20.8 (69.4)	24.6 (76.3)	27.2 (81)	29.9 (85.8)	30.2 (86.4)	27.5 (81.5)	23.9 (75)	19.9 (67.8)	16.3 (61.3)	22.3 (72.1)
Record low °C (°F)	8 (46)	7 (45)	11 (52)	8 (46)	17 (63)	22 (72)	25 (77)	25 (77)	22 (72)	16 (61)	13 (55)	10 (50)	7 (45)
Precipitation mm (inches)	15.6 (0.614)	25.0 (0.984)	21.0 (0.827)	7.0 (0.276)	0.4 (0.016)	0.0 (0)	0.8 (0.031)	0.0 (0)	0.0 (0)	1.2 (0.047)	2.7 (0.106)	14.9 (0.587)	88.6 (3.488)
Avg. precipitation days	5	7	6	3	0	0	1	0	0	0	1	5	28

1.4.3 Economical Information

UAE was economically dependant on oil as its main source of income, however, during the last few years the oil discovery has established the gates to major foreign investors, which led the cities to grow in extents three times larger than it was. The most notable emirates are Abu Dhabi, which is the capital and Dubai, which is counted as the cultural, commercial and trade capital. After it has been totally relying on oil production, nowadays oil and gas represent only 6% of its revenues. Dubai has grown economically while being oriented to focus on trade and investment sectors. As follows, the real estate have the largest share of 22.6% among the national income, the trade provides 16%, the while the other services account for 26% as per prospects of Dubai Economic Sectors, Chamber of Commerce (2003). Kazim (2007) observed that as the population rate increases, urbanization increases and the economy curve ascends, which directly reflects the energy consumption behavior in UAE after the emirates union when authorities started to look up to urban development and raising the economic level. In addition, free trade zones in Dubai, which have a positive impact on the gross domestic product (GDP) was the reason why UAE has been ranked as the highest energy consumption per capita among the world countries.

The previous decade experienced a fascinating expansion in Dubai’s economy in all sectors as the government was regularly working on enhancing the commercial integration and implementing flexible laws and regulations to enable the establishment of even the small scale projects as well as struggling to find itself a unique place through the world’s largest financial obstacles. Dubai started its free trade business that also made fame and attracted many tourists to the city, which has encountered a fast development, as it became a famous tourism destination throughout the whole year. The booming that occurred in the real estate field enabled carrying out very large scale projects such as; skyscrapers and recorded projects that became significant landmarks for the city, However, In 2008 there was a huge drop in Dubai’s economical market, causing severe drawbacks as a result of the world’s financial crisis that majorly affected the real estate sector.

1.4.4 Energy Consumption Approach

An extremely rapid construction and development booming occurred in UAE throughout the last decade, in addition, the statistics results recently showed that it is the country with the highest ecological footprint among all the world countries as per the Environmental Protection Agency (EPA) as shown in Figure 1.2. This is because of the high residential demand, which is the result of the high immigrating population within the last ten years, which would affect the implementation of sustainability as well as life qualities. The population growth (Omar, 2010) is expected to grow above 7.5 million this year, which is consequently translated into to higher residential demand and more consumption rates. Emirates Environmental Group (EEG) carried out a survey that estimated the population growth in the last 15 years, which turned out to be an increase of 5% and 6% for local and immigrant population respectively (Al Marashi, 2006).

Showing latest available data.

Rank	Countries	Amount ▼
# 1	United Arab Emirates:	15.99
# 2	United States:	12.22
# 3	Kuwait:	10.31
# 4	Denmark:	9.88
# 5	New Zealand:	9.54
# 6	Ireland:	9.43
# 7	Australia:	8.49
# 8	Finland:	8.45
# 9	Canada:	7.66
# 10	Sweden:	7.53

Figure 1.1: World's top 10 countries in terms of ecological foot print. *[http://www.nationmaster.com/graph/env_eco_foo-environment-ecological-footprint]*

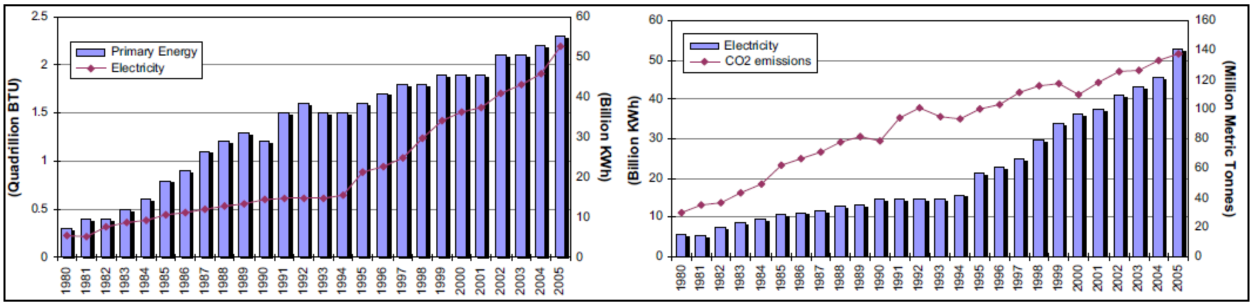


Figure 1.2: Electricity consumption increment and CO_2 emissions in UAE from 1980 to 2005 *[Radhi, 2009]*.

As shown in Figure 1.3, UAE's building sector account for more than 40% of the total energy consumption per capita, which is the largest contribution to the overall energy consumption as stated by AboulNaga (2001), which also mentioned that modern high-rise buildings account for 6 times more energy amounts compared to the traditional ones, also, as stated by Radhi (2009), the carbon dioxide rate in UAE is expected to rise to an extent of 138.4 million metric tones in a few decades period.

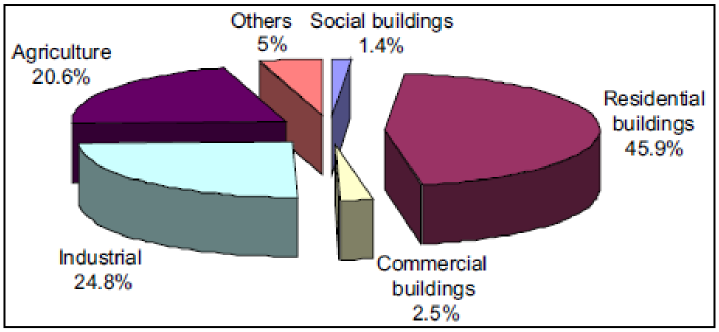


Figure 1.3: UAE energy consumption per sector in 2005 *[Radhi, 2009]*.

1.4.5 The Route towards Sustainability

As the building section was responsible for the rapid economic growth in the last two decades, that approach negatively contributed to the environment as well as the human health as stated by AboulNaga (2001). Lately, some of the organizations and the institutes started enhancing sustainability in UAE, such as; Emirates Green Building Council (EGBC). As per Reality Network Association, the capital, Abu Dhabi, started to lead the development for a carbon neutral city by signing an agreement with the global organization World Wildlife Fund (WWF) to monitor its hazardous problem of the extremely high ecological footprint on the planet by classifying building practices locally and internationally as well as tracking buildings performance.

Abu Dhabi established “Estidama” and the pearl rating system guidelines for buildings and communities, which included water and energy consumption regulations, eco-friendly materials, waste management and insulation techniques. Another huge step forward in Abu Dhabi was the carbon neutral, waste neutral empowered renewable energy and car-free Masdar city, which shows a great potential towards sustainability. Dubai also started working with the Leadership in Energy and Environmental Design (LEED) standards and recently some environmental organizations has been funded like the Emirates Environmental Group (EEG) that works among stakeholders from the authorities, businesses, communities, and civil society groups.

1.5 Significance of the Study

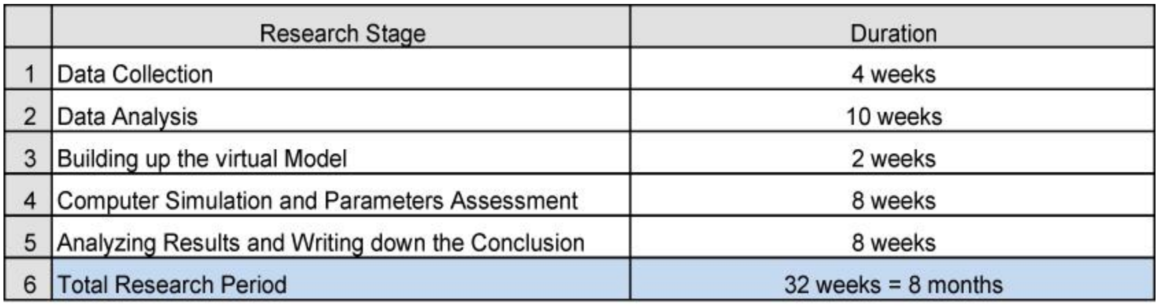
The importance of this study is focused on directing different parties involved in the building design in UAE to valuable data concerning integrating different passive techniques, such as; shading elements to the façade and monitor how they impact occupants' thermal and visual comfort as well as the amount of energy consumed by the HVAC system. Thus, the study would be very beneficial for architects in this region to enable them to take valuable decisions in their design regarding setting the building orientation and determining the best shading element properties for each façade.

In addition, it is a very good help for mechanical engineers to have a preliminary prediction about the HVAC loads to be designed for each space. In addition, façade consultants would have a comprehensive overview about the most effective shading devices sizes and properties in order to integrate this data with their manufacture line processes and plans. Moreover, the research guides developers to the long-term cost benefit of integrating passive design solution, which would encourage the implementation of green building concepts in the UAE. Furthermore, governmental authorities can take the study as a reference to adjust some rules and regulations related to building designs, required percentage of shading and building orientations in order to achieve a significant reduction in the usage of non-renewable energy sources.

1.6 Research Outline

This study is composed of eight chapters according to the hierarchy of the research. Chapter 1 is concerned about the background of the study, the incentives behind carrying it, brief information about the location and the concepts of sustainability, the significance of the study and the research outline. As for Chapter 2 it covers a comprehensive literature review in order to collect an overview on the topic and the previously made researches in this area, identifying the knowledge gap, the research questions Moreover, it addresses the aims of the research which is translated to the research questions, the objectives required to reach that aim. Chapter 3 defines the methodology used for the research, the reasons for choosing it, the details of the selected method and all the involved resources required to do the research, the parameters that will be tested as well as the method of analyzing the data. Chapter 4 presents stages of the simulation process, all the data input, as well as the assessed cases and the analysis methodology. Chapter 5 discusses these results of the simulation and analysis in through tables and graphs, while chapter 6 carry out a comprehensive discussion on the simulation results, compare it with previous studies and hypothesis and defining the reached goals and answer to the research questions. Chapter 7 provides an economical analysis to the assessed cases to an approach to payback periods. Last but not least the last chapter, Chapter 8 is the conclusion, the summary of the study including the answer for the research question, the significance of the study, how this study add to the literature and how its being useful as well as the limitations of the study and suggestions for future research. Table 1.2 presents the research schedule in terms of each stage's duration.

Table 1.2: Research Schedule



	Research Stage	Duration
1	Data Collection	4 weeks
2	Data Analysis	10 weeks
3	Building up the virtual Model	2 weeks
4	Computer Simulation and Parameters Assessment	8 weeks
5	Analyzing Results and Writing down the Conclusion	8 weeks
6	Total Research Period	32 weeks = 8 months

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction and Methodology

A comprehensive literature review has been carried out on research papers related to the subject by means of searching online articles databases such as “Science Direct” and “EBSCO”, which include most scientific journals and papers such as; “Energy and Buildings”, “Renewable Energy” and “Building and Environment”. Journal papers issued in the period between the years 2001 and 2011 have been investigated to cover up the most updated studies carried out in this area within the past few years, in addition to some old credited scientific papers. Meanwhile other resources such as; conference papers, credible websites, books and certified building standards were involved to support certain ideas and bring up the basic history of the topic.

A number of sixty five (65) journal papers were being searched with the assistance of some keywords and terms, such as “shading devices”, “passive techniques”, “indoor thermal gain”, “visual comfort” and “energy consumption”. The inclusion criteria of selecting the papers was the assessment of different passive applications and specifically shading elements, that accompanied focused objectives and assessed different parameters regardless of the method used in each study to achieve the desired output values. Moreover, other papers were selected due to linking their study of different passive applications to its impact on visual comfort, thermal comfort and energy performance, which are considered the main outcomes of this study in order to reveal more information for an exclusively relevant overview. Meanwhile, papers addressing different types of passive techniques other than shading devices have been the exclusion from the criteria, such as; natural ventilation and manipulating the construction and finishing materials. Moreover, studies assessing innovative environmental design elements, for instance; solar panels and low emissivity glass were also excluded. Figure 2.1 shows how the papers were selected and categorized.

During the searching process of journal papers, first, the abstracts of the papers were gone through to ensure its suitability for the topic discussed, which sequentially ended up with filtering the papers to forty six (46) research papers, which has proved their adaptability to the research and their inclusion to the selection criteria,. Afterwards, a more detailed reading process has been carried out for selected sections of the research papers to highlight the background of each paper and the parameters assessed in order to perform another filtration process, which ended up with the thirty two (32) research papers involved in this literature review. In addition, another fifteen (15) sources from books and guidelines were also included.

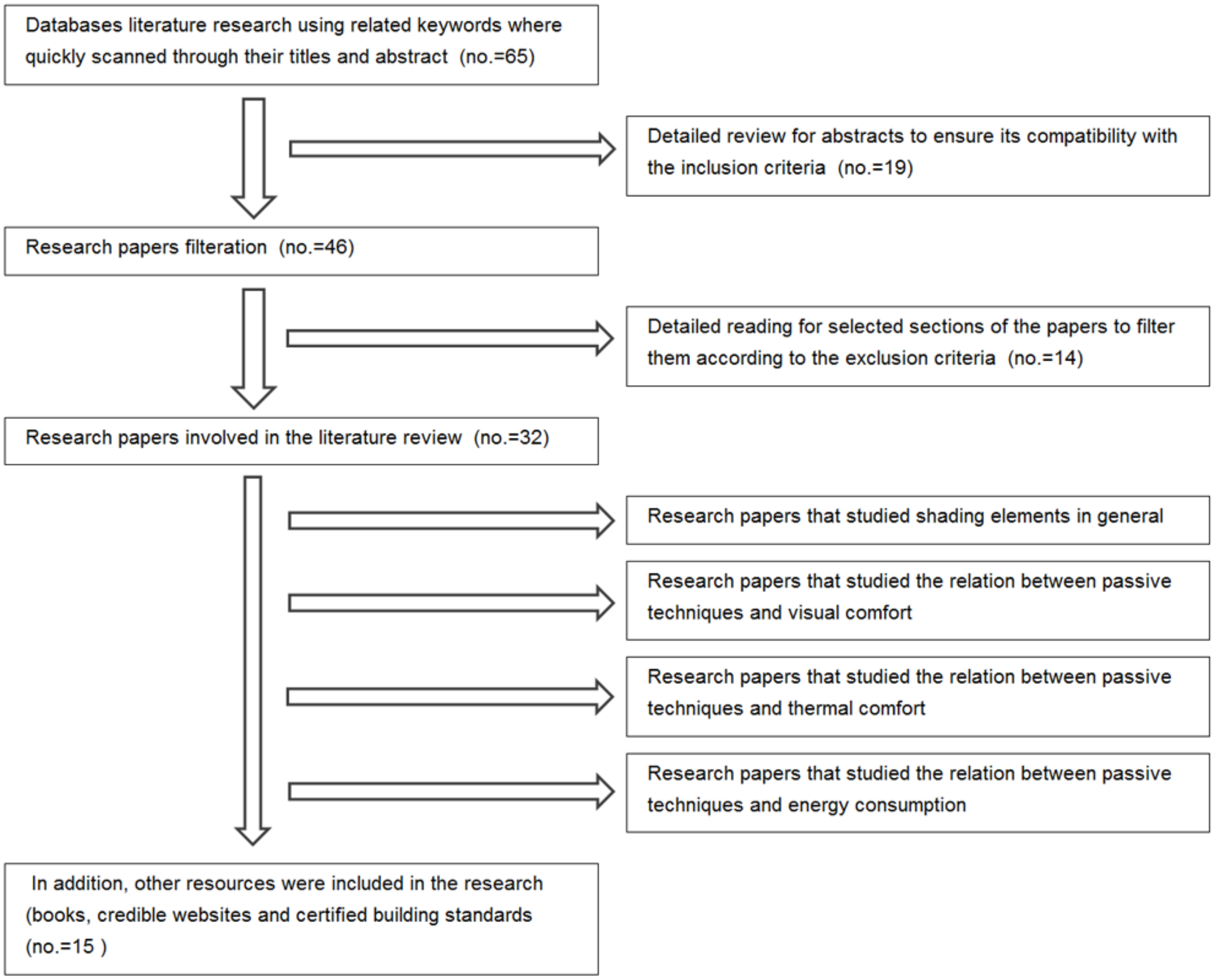


Figure 2.1: Research Papers Selection and Categorization

2.2 Literature Review Limitations

Concerning the limitations of this literature review, the time frame was considered an obstacle towards exploring more research papers in the same field; however, all the selected papers were credible scientific journal papers and credible conference papers excluding government papers.

2.3 Passive Solar Designs

Passive solar techniques is to integrate the climatic conditions in terms of solar radiation and ventilation, the building envelope and its properties to provide indoor environmental qualities inside the space such as; occupants comfort, health and psychological effect, in addition to energy consumption. Morrissey (2011) mentioned that achieving a well designed passive oriented building requires giving attention to the building geometry and orientation on site, which is strongly related to the climatic and the topographical conditions, in addition to the building proportions as well as identifying the balance between façade opaque and transparent proportions in order to achieve the benefit of solar radiation without compromising thermal comfort due to experiencing excessive solar heat gain, moreover, taking the impact of adjacent buildings into consideration. Carbonari (2001) clarified that the building envelope and its structure thermal mass is one of the significant aspects that affect passive designs since it plays a major role in the temperature flow between the outdoor and the indoor environment varying the indoor one. Consequently, the climatic building design is an essential when designing the initial building systems, which determines the operating energy behavior throughout the building’s life span (Tzempelikos, 2007).

2.3.1 The Importance of Building Envelope

Building envelope has always been one of the crucial issues varying the indoor environment conditions over the years, besides; it is responsible for the aesthetic vision of the building. In earlier years, before the invention of mechanical operation systems, where buildings where primitive and depending only on natural conditions to achieve occupant’s thermal comfort, the envelope was utilized to control the indoor temperature, humidity levels, protection from rain, the amount of daylight penetrating into the space and the noise level. Besides, it functions as the building’s structural system, which provides security (Hammad, 2010). Nowadays, after that the mechanical systems became an essential, the focus is now majorly on the glazed façades in addition to the contemporary design themes, which are considered the main burden towards implementing passive techniques. Hammad stated that the intelligent buildings designs are now the top ranked challenge that adapts the building systems and the contemporary designs together in terms of a reasonable energy profile.

2.3.2 Daylighting Design of Buildings

In order to understand the idea of daylighting penetration in the building, first the approach to understanding the sun position is essential. The sun position is defined by two complementary terms, which are the solar altitude and the solar azimuth as defined by Muneer (2004):

- *Solar Altitude:* the vertical angle position of the sun measured from the horizon levels.
- *Solar Azmith:* the horizontal angle between the sun’s normal projection and the north orientation in a clockwise direction

Baker (2002) mentioned that as solar altitude rises, illumination increases. Moreover, when the sun is at low latitude the indoor spaces gain more daylighting levels that when it is at higher latitude. Meanwhile, Lovell (2010) mentioned that required light levels in the space should be predicted on a horizontal plane to be suitable for reading and writing which, was previously measured by daylighting factor and then recently preferable to be measured by illuminance level, which is defied as follows:

- *Daylight factor:* it is the ratio between the illuminance of the outdoor environment to the illuminance of the interior space in the presence of a clear sky.
- *Illuminance:* it’s the ratio between the indoor and the outdoor illumination levels in the presence of an overcast sky

Light transmittance is another measure of solar availability in the space, which strongly counts on the sun’s incident angle, as it’s the amount of visible light penetrating into the space taking the window size and the impact of shading devices and adjacent buildings into consideration in relation with the same opening in absence of the glazing, therefore its mostly related to diffused daylight (Baker, 2002). However, the daylighting levels are majorly varied according to the surrounding blocking elements of the diffuse sky, such as; surrounding adjacent buildings and trees, these elements block parts of the diffuse sky, enabling the need for more artificial lighting and consequently higher rates of energy consumption. Other studies conducted the benefits of utilizing daylight inside the room, since it avoids or reduces the need for artificial lighting during the daytime, which requires more electricity consumption, in addition to the heat gain emitted by the lighting fixtures, which is also interpreted to additional cooling loads (Tzempelikos, 2007).

2.4 Shading as Passive Strategy

This section demonstrates the importance of shading devices as a passive strategy, the factors affecting the selection of the appropriate device as well as the different types of shading devices.

2.4.1 The Importance of Shading

Shading devices are one of the most effective passive techniques; which are simple and inexpensive. They control the amount of daylighting penetrating inside the room avoiding direct sunlight, which leads to discomfort glare and consequently limiting the heat gain that provides occupants' thermal comfort and energy saving (Kima, 2012). In addition, Baker (2002) illustrated that the presence of shading elements is the simplest way to block visibility of the outdoor bright environment that could prevent achieving visual comfort. As noticed by David (2011), the implementation of shading devices is mostly effective in case of tropical climates, which tends to have the highest building operation energy.

2.4.2 Factors affecting Shading Device Selection

Numerous factors that affect the behavior of any shading device; the most critical ones are the position of the sun in terms of solar altitude and latitude, the building faced orientation as well as the physical properties of the shading device itself.

Position of the Sun

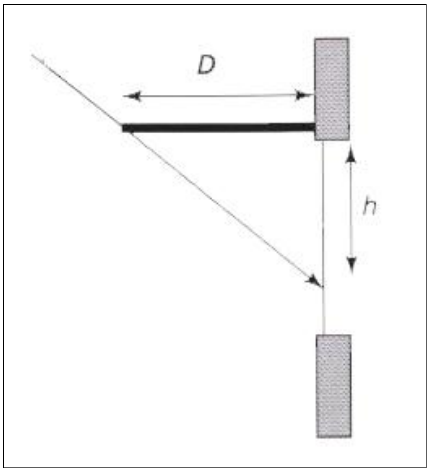
It is one of the major factors influencing the selection of the shading device since it is the indication of the daylight penetration behavior inside the space. A study by Palmero-Marrero (2010) investigated the presence of louvers on some façades. and compared them among different countries to assign a comparison. The study showed that as the latitude value grows, the window must be enlarged in height as well as the number of louvers and vice versa, which shows the influence of the sun position on the initial design of buildings

Building's Orientation

Another important factor affecting the justification of shading elements is the orientation at which the building is directed. In some orientations, implementing shading devices is crucial; therefore, a comprehensive climatic study should be done prior to the building design and determining aperture orientations. Morrissey (2011) explained how essential the impact of this issue is on the building as well as the whole development in terms of solar gains and energy consumption. Meanwhile, another study by Alzoubi (2010) pointed out that it is preferable to study the shading design according to each façade orientation in order to provide the appropriate shading intensity, because sometimes it could react negatively by consuming more energy through depending on artificial lighting to reach the required indoor lighting levels. Meanwhile, Radhi (2009) recommends orienting the building apertures towards either the north or the south direction.

Shading Device Properties

Eventually, the properties of a shading element should be carefully specified as it plays an important role in achieving the desired shading properties in terms of shading intensity and the number of hours when the façade is fully or partially shaded. As mentioned by Baker (2002), the amount of shading is usually measured by the total shading coefficient, which is the relation between the amount of sunlight penetrating through a window with an implemented single glazing, and the amount of light passing through the same window in absence of the shading device. It ranges from 1, which indicates the presence of a clear glass panel, to 0, which is interpreted to a totally opaque surface. David (2011) reported better performance shading elements whenever the shading coefficient approaches zero. The shading device behavior is strongly influenced by its depth, which is calculated upon the daylighting performance interpreted in the sun's altitude as well as its angle of incidence in relation with the space as stated by Kim (2010), and as shown in Figure 2.2 and Figure 2.3.



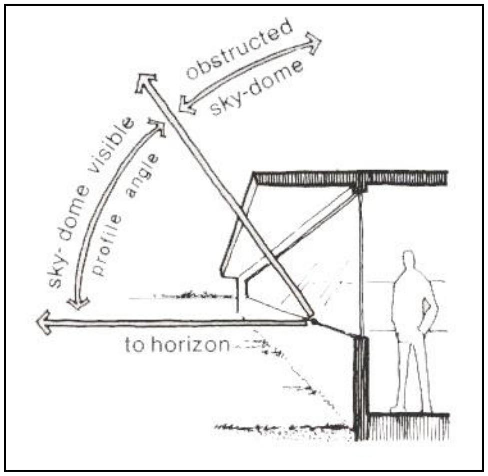


Figure 2.2: Shading Device depth *[Athienitis, 2002]*, **Figure 2.3:** Overhang visibility *[Moore, 1985]*

Meanwhile Ayoub (2007) illustrated the conventional formula that is used to predict the depth of the shading device as shown in Figure 2.1 and Figure 2.2., which is:

h= D x tan(solar azmith – window azmith),

Where, h= window's shaded part, and D= overhang depth,

2.4.3 Types of Shading Devices

There are numerous types of shading devices that could be implemented to the building façades. to get the benefit of reducing the solar and the thermal gains; however, different shading elements vary in their performance and characteristics according to their materials and geometry. As stated by Datta (2001), shading elements could be placed outside the façade or inside the façade; however, placing it externally is more beneficial as it cools down the air located between the shading element and the glass façade. Shading devices could be classified by type as follows as per Athienitis (2002) and Baker (2002):

- *Fixed Shading:* horizontal overhangs, vertical side-fins, horizontal and vertical louvers, light shelves, sun catchers, tinted and reflective glass, in addition to recessed windows.
- *Movable Shading:* retractable louvers, roller shades, venetian blinds, curtains, movable light shelves and movable sun catchers.

Among all these types, two types of shading devices were chosen to be involved in this study, which are the forms of façade projections; fixed horizontal overhangs and fixed vertical side-fins.

Façade Projections (Overhangs and Side-fins)

Façade projections are any protrusions in the façade, which could be horizontal such as; overhangs, and balconies or vertical such as; side fins as shown in Figure 2.3. Façade projections are significantly effective on or around the south oriented façades due to the high solar altitude, however, in the east and west façades, they are less effective due to the lower sun position (Baker, 2002). Meanwhile, Athienitis (2002) recommended horizontal shading for south oriented façades, while preferred vertical shades for east and west exposures. Another form of overhangs, which is represented in balconies act very effectively in reducing the cooling loads inside the space as they tend to have a notable depth providing significant shading for the lower floors in the building. They depend majorly on the façade orientation and the glazing material; in addition, they enhance daylighting and natural ventilation. Chan (2010) tested the variation in cooling loads per hour of spaces in a residential building in Hong Kong while changing the balcony orientation. First, overhangs and side-fins were assigned to the space and indicated a reduction of 7.99% of the HVAC related loads. Further then, assigning various cases of balconies, which are considered a combined overhang and side-fin resulted in a reduction that range from 3.4% to 12.3%, meanwhile, the maximum energy consumption achieved was on the southwest façade regardless of the type of glazing

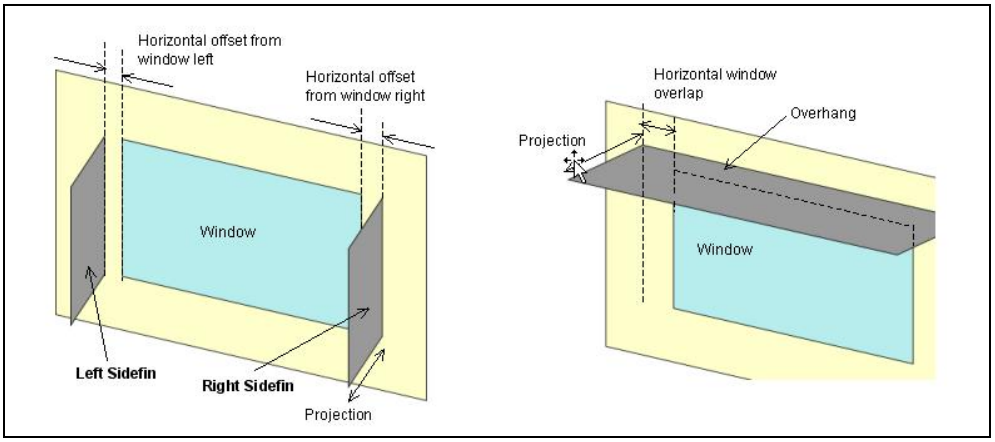


Figure 2.4: Overhangs and Side-fins *[http://www.designbuilder.co.uk]*

Other Forms of Shading Devices

Louvers, which are the most widely used shading device in commercial buildings especially in completely glazed façades, allow controlling the amount of sunlight entering the space during the day as well as adjusting the visibility level. Fixed louvers can be adjusted manually or automatically, while, solar tracking or dynamic louvers are another advanced technological type in which the slats rotate according to the sun position in order to achieve the maximum climatic benefit throughout the whole day. A research performed by Hammad (2010), addressed a comparison between implementing dynamic louvers to an office building façade in Abu Dhabi and implementing light dimmers that is adjusted by means of a light sensor in order to test the influence of each technique on the energy consumption inside the space by means of IES-VE simulation tool. Some parameters such as; the light dimmer location, the shading coefficient for the glass, the slat rotation angle and the façade direction were tested individually, however, when fixed louvers with a proper inclination angle were tested instead of the dynamic ones, the difference in energy saving was a little bit lower. Moreover, it has been proved that lower energy consumption could be obtained whenever the distance between the dimming sensor and the louvers decreases. Concerning both electric and HVAC energy consumption, focusing on energy consumption in existing buildings in UAE is very rare. Datta (2001) stated that in the case of louvers, slat length and the distance separating the slats plays the important role in the shading profile. As studied by Kuhn (2006), the tilting angle is regulated to control solar rays' penetration into the room depth, which was only concerned with avoiding the side effects of excessive daylight as in glare and energy consumption.

As for blinds, which are accompanied by manual or automatic controllers, it also an effective type of shading devices that provides an opened view and enhances privacy, as well as helping the increase in time needed for the indoor temperature to change according to the outside one by means of conduction. However, Shahid (2005) addressed the impact of the distance between the tip of the blind and the window, in addition to the blind's tilting angle, meanwhile, the results showed that the most successful outputs were recorded when the blind was in location with a minimum distance from the window.

Moreover, color of the shading device influences light reflections inside the space and contribute to the indoor temperature but enabling or avoiding light reflections (Gratia, 2007).

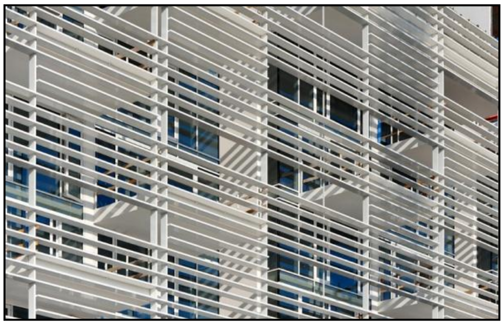


Figure 2.5: Façade Louvers
[http://www.solarchoice.net.au]

Figure 2.6: Building Intergrated Photovoltaics
[http://archreview.blogspot.com]

2.5 Thermal Comfort

Thermal comfort is the perception of the building users to feel satisfied in terms of the indoor temperatures, moisture level and ventilation. Its one of the major achievements of passive design and consequently affecting energy consumption as stated by Morrissey (2011), it is also influenced by many external and internal factors.

2.5.1 Factors affecting Thermal Comfort

There are many factors affecting occupants' thermal comfort; the most important ones are the outdoor climatic conditions, the building envelope, the occupancy status and the operation system profile.

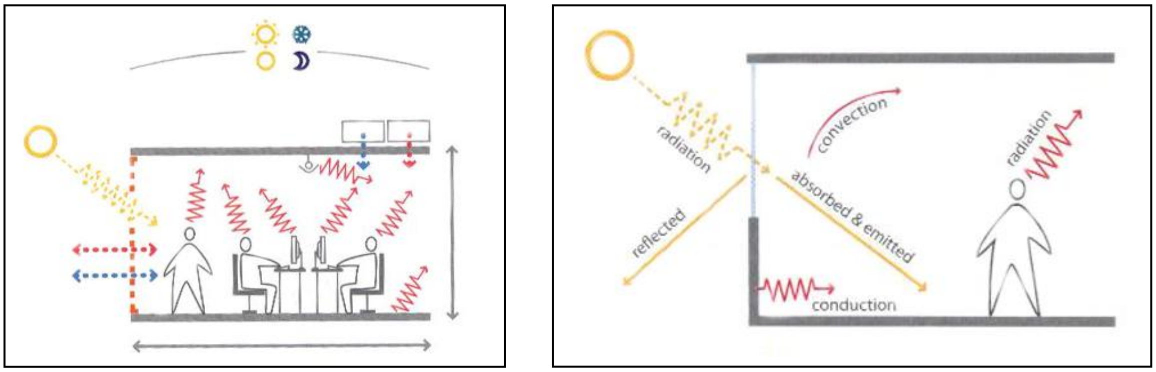


Figure 2.7: Left: Factors affecting thermal comfort, Right: Forms of heat transfer *[Lovell, 2010]*

Outdoor Climatic Conditions

External climatic conditions influence the thermal comfort for occupants because as the difference in temperature between the outdoor and the desired indoor temperatures increase, the less comfortable occupants feel.

Building Envelope

The building envelope is strongly related to thermal comfort because as the thermal insulation and the envelope’s thermal mass is well performing; they preserve the indoor temperature constant according to occupant’s needs. Also, the transparency of the façade influence the amount of solar gain and overheating inside the room (Radhi, 2009), since heat is transmitted into the space through conduction, convection or radiation. Also, as mentioned by Tzempelikos (2010), as well as the envelope is well insulated, the least it is affected by the outdoor climate.

Occupancy

As stated be ASHRAE 55 (2004), occupants’ metabolic rate influence the cooling sensible loads, in addition the clothes rate, the number of occupants, the temperature, the ventilation rate, and the type of activity in the space influence the occupants’ comfort as shown in Figure 2.4.

Operational systems efficiency

The cooling and heating system strongly affect the thermal comfort in its ability to precisely adjust to the regulated temperature and humidity level.

Shading device properties

The shading device location and distance from the glazing have a major influence on thermal comfort since as the shading device is placed closer to the glazing; it becomes more effective especially in office buildings (Tzempelikos, 2007).

2.5.2 Solar Gain and Overheating

The solar gain inside the space is strongly related to the sun position in respect to the building apertures. Tzempelikos (2007) mentioned how shading strategies significantly reduce the amount of heat gain passing through the glazing areas and consequently, achieving better thermal comfort and reduced energy profiles. There has always been a conflict that sunrays are composed of sunlight and heat, however, Baker (2002) explained that they are composed of electromagnetic rays, which is transformed to heat when the radiations hit any material surface and absorb it. Meanwhile, a study carried out by Simmler (2008) measured the total solar energy transmittance as an indication of the total thermal gains inside the space. Different types of glazing were assigned to a variety of shading elements and proved that it significantly differs according to the inclination angle of the shading device as well as the its surface material characteristics and particularly its ability to reflect solar rays. These entire parameters should combine to achieve a thermal balance inside the space for an optimum occupant's comfort.

2.5.3 Percentage of People Dissatisfied

ASHRAE 55 (2004) illustrated the idea that its difficult to achieve 100% comfortable occupants inside the space as comfort conditions differ from one person to the other, however, normally a percentage of 15 to 20% is the common percentage of dissatisfied occupants in any space. Meanwhile Harriman (2009) stated that the key to raising the number of comfortable occupants is done by giving more attention to the building insulation and precisely regulating the indoor temperature conditions. Eventually, as the percentage of comfortable occupants increase, the more there are financial savings in terms of health issues and claims. Shading devices contribute to increasing the occupant's comfort rate by decreasing heat gain levels inside the space in summer to regulate the room temperature, which consequently affects the occupants performance and productivity rate. As it is the case of an office building, monitoring the employers' performance and progress is crucial and of course is directly translated into either a profit or a loss.

2.5.4 The Relation between Thermal Comfort and Occupants' Performance

Thermal comfort of occupants has a major implication on the occupants' performance inside the space, since if they are not feeling thermally comfortable their attention is distracted, since feeling hot rises sick building syndrome symptoms, however feeling cold affects their fingers, which would affect their manual activity as explained by

Wargochi (2006). Eventually, occupants’ productivity has a major influence on the workflow rate in the office, while, decreasing the production rate due to thermal discomfort is directly interpreted into money loss. As stated by Wargochi (2006), a reduction of performance by 5% to 15% could occur if occupants feel discomfort in their workplaces.

2.6 Visual Comfort

Speaking about visual comfort requires defining the visual adaptability, which is the ability of the human eye to determine its relation to daylighting intensity in terms of general adjustment as well as the brightness and contrast idea (Moore, 1985), since the speed of changing the eye pupil diameter and the sensitivity of the retinal results in psychological adjustment issue.

2.6.1 The Impact of Illumination and Daylighting on Visual Comfort

Occupants feel visually comfortable when their eyes receive a suitable amount of light without making an effort to visualize some tasks, which strongly relate to the illuminantion levels inside the space either artificial or natural light sources. The sun altitude and latitude, the sky conditions as well as the daily and the annual time factors are the key variables affecting the quantity of daylight received inside the space (David, 2011). Eventually, the window height would be more critical than its horizontal extents due to its relation to the sun position as per Kim (2010). A study performed by Alzoubi (2010) tested the illuminance levels on some work planes in the presence and the absence of shading devices. The study found out that the shading device position strongly influence the lighting levels variation in the room, meanwhile, the space surfaces had a direct impact on the lighting levels depending on their reflectance rate and eventually on occupant’s visual comfort. Meanwhile, David (2011) concluded that illumination levels gradually reduces as the distance from the glazing increases, which is considered a challenge to provide different work spaces in different locations in the room with adequate lighting levels without compromising to the rate of heat gain. As per Baker (2002), occupants ensured that daylighting access to the indoor space is a valuable advantage. As it is the case with office buildings, employers should be provided an adequate amount and intensity of lighting in order to be capable of performing their tasks efficiently.

2.6.2 Discomfort Glare

Discomfort glare is interrupting the view region with an object, which has a large difference in illuminance causing a sense of visual discomfort that could impact the occupant’s performance, which varies in rate depending on the size and the brightness of that object (Baker, 2002). Moore (1985) stated that excessive levels of brightness could lead to discomfort glare whether it comes from a defined physical source or because of indoor finishing materials reflections inside the space. Hence, the light present in the space is the output of all causes and different materials found. Meanwhile, David (2011) pointed out that in offices, a great attention should be directed to the glazing areas and the position of the workspaces in relation to it since occupants feel discomfort when facing direct sunlight into their eyes or on their work plane. Hence, as the shading element depth increases, the possibility of facing direct sun beams decreases. In conclusion, the building envelope seems to play a major role in controlling the amount of daylight penetrating into the space, its intensity and shading duration. However, Lovell (2010) argued that nowadays the reason behind the poor contribution of daylight in buildings is because of designing large foot print buildings with inadequate relations between the area of the floor and the glazing area. In addition, Tzempelikos (2007) expressed the importance of controlling illumination levels in office buildings especially on south façades, which are known to gain the largest share of sunlight in order to protect occupants against discomfort glare.

2.6.3 The Effect of Shading Devices on Visual Comfort

Eventually, according to ASHRAE 55 (2004), the role of shading techniques is exclusive but not limited to preventing the entry of direct solar rays and adjusting light intensity inside the space by diffusion or reflection when striking interior finishing. Therefore, implementing shading devices proved a significant influence on the daylighting levels and the occupants’ visual comfort for a sustainable indoor environment. However, Alzoubi (2010) noted that vertical elements providing shading has the advantage of not obstructing the outdoor view and at the same time providing appropriate shading, which enriches the benefits of the device.

2.6.4 The Relation between Visual Comfort and Human Performance

There is a strong relation between the lighting of the space and the occupants comfort and performance, since Baker (2002) indicated the benefits gained upon allowing daylighting into the space, which have a positive impact on the occupants in terms of their health and physiological status. In general, better visual comfort in directly interpreted to a better work performance (Mayhoub, 211), however, Baker (2002) constrains this phenomenon to other variations, such as; personal skills and concentration rate. As an example, Winterbottom (2009) performed a research on venetian blinds and noticed that inadequate daylighting penetrated through the blinds is a main cause of glare and headaches.

2.7 Building Energy Consumption

Energy Consumption is one of the major building related implications, which is linked to its impact on the environment and specifically on global warming. Recently, it has been noticed that there are some trials to achieve zero energy building although, there are huge obstacles facing this process. However, nowadays energy simulation programs made it possible to get an overview of the energy behaviors in terms of daylighting, thermal gains and eventually the cooling loads. In general, buildings account for the largest share of energy consumption in the ecosystem, since it consumes a lot of energy throughout all its processing stages, which is sometimes known as the embodied energy. Embodied energy represents the total energy consumed starting from the manufacturing of building materials, construction process, building operation, commissioning, and finally the building demolishing. The total energy consumption of any building mainly depend on electricity and air conditioning bills, which reflects the amount of energy consumed by space cooling and heating, lighting and appliances.

Therefore, especially in hot climate countries, passive solutions are required to help with providing adequate daylighting levels in the space, in addition to thermal comfort for the occupants through decreasing thermal gains inside the space. As per AboulNaga (2001), the behavior of recent intelligent buildings gives an indication of a better greenhouse gases emissions profile, which would progress on the long run.

2.7.1 Factors affecting Building Energy Consumption

There are many factors that affect the building’s energy behavior, which could be categorized under four main parameters; the outdoor climatic conditions, the building envelope, the occupancy status and the operation system efficiency. As mentioned by Harriman (2009), heat gained inside the space is firstly caused by the building envelope, followed by the lighting system then finally the parameters related to occupants

Outdoor Climatic conditions

External climatic conditions influence the building’s energy consumption rate since, as the temperature outside gets further from the required human comfort level, more energy is being consumed by the HVAC system.

Building Envelope

The building envelope is the main controller of operational energy, as a well performing thermal insulation and envelope’s thermal mass, the more the building satisfy occupant’s needs. As mentioned by Tzempelikos (2010), as well insulated the building envelope is the least it’s affected by the outdoor climate, such as using low emissivity glass, wall insulation layers and adopting the idea of the building’s thermal mass (Harriman, 2009). Meanwhile, a study performed by Radhi (2009) found that regulating the glazed area proportions could result in saving from 6.8% to 8.1% of the space’s energy consumption. Furthermore, Tzempelikos (2007) expressed the significant contribution of dimming light systems on the indoor space’s cooling profile on the long run, which reflects its positive impact throughout the building life cycle.

Occupancy

As stated be Tzempelikos (2007), the occupants rate is the realistic measure of cooling and heating load demands, since it is also an indication of the number of appliances found inside the space, in addition, they influence the regulation of cooling and heating set points as well as their impact in terms of internal gains (Morrissey, 2011). A study done by Young Yun (2012) ensured that occupant's behavior in terms of using the lighting system has dominant consequences on the energy consumption scenarios.

Operational system efficiency

The cooling and heating system efficiency strongly regulates the energy consumption rate inside any space. Harriman (2009) advised that when designing cooling systems, they have to be designed in a way that provides an airtight system, besides, a margin of safety should be always provided when calculating cooling loads, which is beneficial in terms of adjusting to occupants' comfort as well as for maintenance reasons. In addition, depending on the climatic conditions dehumidification and ventilation tools should be installed.

2.7.2 Energy Consumption in Office Buildings

In general, the building sector is classified into two categories; the domestic sector and the commercial sector, which office buildings belong to. Office buildings are considered one of the major non-domestic buildings in terms of energy consumption as Pérez-Lombard (2008) stated that in USA, they account for 17% of commercial buildings and 18% of building energy use. Meanwhile, the domestic sector in UK consumes 17% of the total energy, however, this percentage increases to become around 30% in Spain. In general, office buildings are obviously containing multiple and complex operational systems that places it at the top rank of the energy consumption by type of building, which is a challenge to balance between integrating high technology systems and reducing energy consumption.

2.7.3 Building Energy Consumption in UAE

In UAE, buildings are the main variable controlling the building's energy behavior profile, since HVAC systems has become mandatory in all buildings and not considered as a luxurious tool. In the last 20 years, the high population growth rate has been consequently interpreted into a significant rise in energy demands, which resulted that the country has scored the first place in terms of the energy consumption rate per capita as stated by Ayoub (2007). Also, leading to a crucial raise in carbon dioxide emissions that has reached ten multiples of the mean global rate which clarify what Ayoub (2007) noted that most of UAE building constructions have no implementation of energy consumption measures. As explained by Harriman (2009), designing huge glazed façades while disregarding environmental attributes results in an extensively huge operational cost. Thus, implementing energy regulating guidelines and restrictions in UAE should be the major focus of the building sector and at the same time not obstructing the country's development and the economic raise (Ayoub, 2007).

2.7.4 The Relation between Carbon Dioxide Emissions and Energy Consumption in UAE

As explained earlier, as ambient temperatures in the outdoor environment increase, more cooling loads are being consumed in order to reach the occupants' comfort temperature, thus, more electricity is being consumed by the mechanical system leading to excessive emissions of carbon dioxide to the atmosphere, consequently contributing to the global warming phenomenon (Radhi, 2009). AboulNaga (2001) studied carbon dioxide emissions of UAE buildings through a computer simulation tool (T-Sol) in order to get an overview of the average emissions rate, however, the results recorded an average value of 213 kWh/m^2, which is considered a huge value. On the other hand, Ayoub (2007) ensured that there was a significant growth in energy performance in UAE in the period between 1980 and 2003, resulting in severe implications on the environment.

2.7.5 The Effect of Shading Devices on Energy Consumption

Shading techniques has proved to majorly influence the energy consumption in any building, as a study by Tzempelikos (2007) stated that it is rarely integrated within the mechanical system's initial design. The study found out that shading elements can save up to 50% of the cooling energy consumed by the building and a minimum of 12% when adjusting the portions of the solar and heat gains. Palmero-Marrero (2010) studied the louvers position and found that for east and west façades, vertical louvers are more adaptable, while, on the south façade the horizontal ones achieve the ultimate effectiveness. Afterwards, a comparison was carried out to evaluate several climatic locations that achieved a significant energy progress when implementing façade. louvers reported that for example; countries where there is a huge difference in energy consumption is due to their strong summer solar radiations. Meanwhile, other locations where much smaller solar radiations are present, the annual energy loads were less than the minimum required due to the decrease in solar radiations in winter when it is most needed. Other studies discussed the difference in energy savings achieved by integrating different shading elements to various façade orientations but it was mostly found effective on the south façades that receives the highest amount of solar radiations. In summary, energy behavior is a key issue regulated through HVAC and lighting parameters, which should be directed towards a balanced sustainable environment (Alzoubi, 2010).

2.8 Knowledge Gap

Referring to the previously performed literature review, it was noticed that some studies addressed overhangs and side-fins, which are considered similar topics; however, there is a lack of comprehensive study that adopt these types of shading devices when assigned to office buildings in the tropical regions and specifically in Dubai. Although there is a vital need for it, especially when they are the simplest and the least expensive passive solution. Moreover, the study assess the balancing influence of those shading devices on the thermal comfort, visual comfort and energy behavior, which act as the knowledge gap that would be filled in this research.

2.9 Research Question

Framing the research questions and setting boundaries for the study is a necessity in order to identify the most vital parameters that needs to be studied as well as the research objectives. The following are the research questions assigned for this study:

- What would be the effect of the base case at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?
- What would be the effect of different overhangs’ depths at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?

- What would be the effect of different side-fins' depths at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?
- What would be the effect of combining overhangs and side-fins with different depths and different building orientations on thermal comfort, visual comfort and energy consumption in the UAE climate?
- What would be the most economical shading element suitable for each façade orientation?

2.10 Research Aim

The aim of this research is to compare the level of efficiency of a variety of shading techniques (overhangs and side-fins) that could be integrated within office building façades and examine how they contribute to appropriate indoor thermal gain, lighting levels and eventually would have implications on the building's energy.

2.11 Research Objectives

The research objectives are the key ports that would lead the researcher to reach the required aim upon completion of the research process. The following are the research objectives of this study:

- To examine the effect of the base case at different building orientations (North, South, East and West) on thermal comfort, visual comfort and energy consumption in UAE climate.
- To examine the effect of different overhangs' depths (0.5 m, 0.75 m and 1 m) at different building orientations (North, South, East and West) on thermal comfort, visual comfort and energy consumption in UAE climate.
- To examine the effect of different side-fins' depths (0.5 m, 0.75 m and 1 m) at different building orientations (North, South, East and West) on thermal comfort, visual comfort and energy consumption in UAE climate.
- To examine the effect of combining overhangs and side-fins at different depths (0.5 m, 0.75 m and 1 m) and different building orientations (North, South, East and West) on thermal comfort, visual comfort and energy consumption in UAE climate.

- To examine the most economical shading method to be implemented to each façade orientation through an economic analysis based on the simulation outputs.

The following chapters demonstrate and justify the research methodology as well as the research conduction tool.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the work plan and its sequence of activity. It includes highlighting the integrated research parameters either the variable or the constant ones, followed by determining the most common methods used for conducting similar researches, comparing them and selecting the most appropriate method depending on the availability and suitability. Afterwards, the selection and justification of the instrumentation tool and its explaining its functions and capabilities would be explained. Afterwards, the analysis method will be highlighted, in addition to the required resources needed to carry out this research.

The methodology of conducting the research is divided into two main tasks. The first task is the literature review that has been presented in details in Chapter 2, which is based on studying a large number of research papers to have a strong base for orienting the research aims through gaining knowledge and experience. The second task is to conduct the research, which will be using the research objectives to formulate the research matrix. Consequently, the matrix utilizes the instrumentation tool in order to achieve the determined outputs (annual and peak solar gain, percentage of dissatisfied people, average illuminance, glare threshold, annual cooling plant load and the annual system energy).

3.2 Parameters to be studied

Identifying the constant and the variable parameters is the key issue and it is important to get exposed to all possible parameters that could influence the performance of any shading element, which are a range of dependent and independent parameters. Some parameters were chosen to be tested which are the variable parameter, while others were kept fixed in order to achieve the required outputs which are the constant parameters.

3.2.1 Constant Parameters

Location and Weather Data

The location has been chosen to be Dubai as an example of hot and humid climates in the tropics. Data about the geographic location has been collected, which defines the sun position (solar altitude and azimuth angles) and the sky conditions. The climatic details would be imported which includes all relevant information about the dry bulb temperature, the wet bulb temperature, the relative humidity, the rain fall perception, prevailing winds with their frequency and strength.

Office Model

The design model is an open plan office as it's the most common and flexible type of offices available nowadays. Open plan offices were chosen as their design is very critical in terms of the large space, how the daylight is distributed in the space as well as the solar radiation heat effect due to locating different workstations at different distances from the windows. A previously performed research by Ayyad (2011) including its simulation details were used to build up the simulation model due to the similarity in the purpose of the research, which was also assessing office buildings, in addition to the similarity in the location (Dubai). The author performed a comprehensive survey on twelve (12) office buildings in Sheikh Zayed road to find out the most common open plan offices dimensions, opening dimensions and wall-to-opening area.

Internal Gains

Information about elements responsible for the internal heat gains where set constant, such as; the space activity, which was determined to be an office, number of occupants per square meter, number of equipments found in the office, the lighting power density and the illuminance level.

External Gains

Information about elements regarding the exterior building envelope, which is responsible for the external heat gains where also fixed, for instance; the building envelope's infiltration rate to clarify the influence of the external conditions on the interior space.

HVAC System Design

The mechanical system’s data provides information about the system’s operation profiles according to the office working hours, heating and cooling set points inside the space, humidity saturation range, the type of fuel, the chiller energy efficiency and the method of heat rejection.

Construction and Finishing Materials

Information about building materials are classified into opaque and transparent construction categories. The opaque construction category includes layers of the external walls, internal walls, internal slabs (ceiling or floor) as well as doors, while the transparent construction category includes elements like external windows and internal ones as well as skylights including glazing properties. Properties and layers of the opaque and transparent construction categories were specified referring to Dubai municipality circular no. 197 (2010), which presents several prototypes for common construction properties and specifications in Dubai.

Shading Devices Properties

All types of shading elements involved in the simulation would have fixed construction and finishing materials as well as the same color, in addition to the fixation of the inclination angle.

Space Furniture

All furniture located in the office model such as; work station desks, chairs and partitions where set to be fixed in materials, properties and color to avoid any interior reflections inside the space.

3.2.2 Variable Parameters

Types of Shading Devices

Different shading elements categories would be assessed; overhangs; which are horizontally aligned façade. projections at the top of any window, and side-fins; which are vertically aligned shading devices at the sides of the window. In addition, a combination of horizontal overhangs and vertical side-fins would be assed as well.

Shading Device Depth

Different projections of shading elements would be assessed in order to test the effect of changing the depth of any shading element and monitor its impact on different output values.

Building Orientation

The building will be tested in all orientations in order to investigate the contribution of the sun position to the building façade and how it would influence the results.

Simulation Timings

All simulation cases would be performed once in summer and another time in winter seasons to get an overview about the influence of changing seasons on the simulation results. A specific day was selected to perform the simulation representing the summer season (20th June) as well as another day to represent the winter season (20th December), which are considered the design days in UAE as per Hammad (2010).

3.3 Common Research Methods Used

Examining the effect of different shading devices has been performed by various methods throughout the research history in this field. However, there were four commonly used methods by the researchers, which are the real simulation, numerical and experimental methods, case studies and the computer simulation, which were the different methods used by the studied papers used to conduct the literature review.

Real Simulation

It consists of a real sun and sky simulators that could be adjusted to any climatic conditions. Some parameters could be kept constant, while others could be assessed in order to obtain the needed outputs as performed by Cheung (2007) as well as the research held by Aghemo (2008).

Combination between Numerical and Experimental Methods

This method was used by Daum (2010), Simmler (2008) as well as by the research performed by Shahid (2005). It is based on identifying basic procedures to assess effective parameters by means of constant formulas addressing various cases to obtain the required outputs. Researchers use mathematical formulas and equations to calculate and obtain the relationship between attributes, following it with an experiment to verify the results. Its outputs are reliable; however, there is an error level, which should be considered.

Case Studies

As for the third method, it was the conventional method used since long time ago with the beginning of the environmental studies history of research in order to perform measurements and analysis on real existing buildings to obtain the desired outputs as per Pfafferott (2007). It provides a real reference for the study but it is subjective to users' error, in addition, it is time consuming.

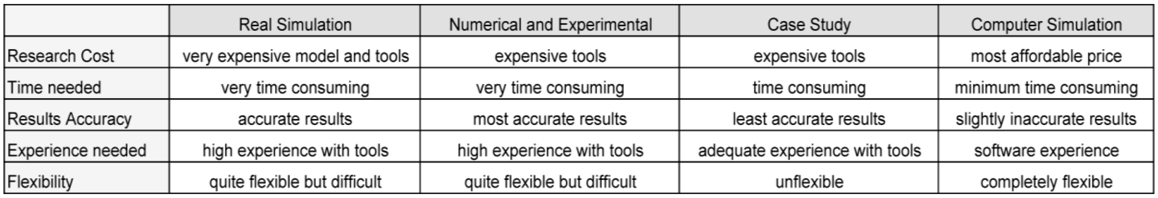
Computer Simulation

This method is the most advanced method performing through computer software used to simulate the building and change the climatic conditions whenever required. Chan (2010) as well as Hammad (2010) used this method to obtain the required output values and give quantitative results on the building's energy performance. It is very accurate and gives an unlimited range of parameters to be studied.

3.3.1 Selection and Justification of the Used Research Method

As shown in Table 3.1, a comparison between the different methods has been performed to clarify the advantages and disadvantages of each method in terms of the research cost, the time needed to conduct the research, the accuracy of the results, the experiences needed to conduct the research as well as the method flexibility to change the assessment parameters. For many reasons, the computer simulation method was selected among the four different methodologies that were addressed formally, to be used for this research as a result of the following argument that compares all methods in terms of advantages and disadvantages of each method and pointing out its benefits as well as its points of weakness.

Table 3.1: Comparison between common research methods



	Real Simulation	Numerical and Experimental	Case Study	Computer Simulation
Research Cost	very expensive model and tools	expensive tools	expensive tools	most affordable price
Time needed	very time consuming	very time consuming	time consuming	minimum time consuming
Results Accuracy	accurate results	most accurate results	least accurate results	slightly inaccurate results
Experience needed	high experience with tools	high experience with tools	adequate experience with tools	software experience
Flexibility	quite flexible but difficult	quite flexible but difficult	unflexible	completely flexible

As for the Real Simulation, the main advantage of this method is that a physical real model is very close in feeling to real conditions with a high precession accompanied by output photos to document the results. Sun location and the sky parameters could be controlled, which makes quantitative assessment easy. Moreover, a wide selection of model sizes makes it flexible and applicable for a large number of researches. As for the disadvantages of this method, the cost of the construction and transportation of the simulator comes at the first place; besides, a lot of time is needed to create a model at a certain level of detailing to be able to get convenient results. In addition, some innovative materials that need to be tested are not subjective to scaling to an appropriate size that matches the model size. Furthermore, due to many factors such as; the user, the parameters tested and the accuracy of the built model, a percentage of errors in the model is present.

The advantages of using the Numerical and the Experimental methods are that they usually tend to give relevant results. Although they are considered accurate methodologies but a researchers' percentage of error should be taken into account. However, following the numerical models with an experimental method decreases the error percentage generated out of the quantitative calculations significantly. Meanwhile, it has other disadvantages such as; the required period to perform the research as well as the construction and operation costs.

As for the Case Studies, its advantage is that it gives a valid real reference for the reader, which is represented in the building being tested but at the same time gives credibility to the research as it acts as a proof. Poor accuracy is the main disadvantage as it depends on many factors affecting the climatic properties inside the space that a researcher could miss consider them, as well as the precession of the instruments used to assess the required parameters. In addition, it is very time consuming especially if the parameters need to be tested on a weekly, seasonal or yearly basis.

The most advanced method, which is the Computer Simulation, has a wide range of advantages as follows. First, it is the most available and affordable method that any researcher could use since the only resources needed are some software training and the software licence costs. Second, it saves a lot of time spent on studying some climatic characteristics for long time intervals, for instance; testing some parameters on annual or seasonal basis. Third, it enables the researcher to get exposed to a huge variety of parameters, which was not expected to support his research, for example, setting the weather data, the outdoor and indoor air quality conditions and the characteristics of the finishing materials used, moreover, it offers parameters' adjustment, flexibility and repetition whenever required. Finally, it has proved a very high level of accuracy, although, a minute level of error depending on the inputs provided as the base of the study has been recorded. Therefore, computer simulation has proved to be the most suitable method to deal with this research especially that it requires assessing many cases and testing different parameters. In conclusion, it is the most likely to use method for climatic researches nowadays that significantly affect any design especially at its initial design stages.

3.4 Instrumentation Tool

This section will discuss the possible available computer simulation programs to select and justify the research conduction software, more information and details about the software, its attributes,its functions and capabilities as well as the software limitations.

3.4.1 Selection and Justification of the Instrumentation Tool

In the last twenty years, architects became more involved in building performance tools after it was only limited to HVAC engineers, researchers, building scientists and experts. There are multiple building simulation softwares in the market, which have been developing rapidly to enhance options that are more technical, flexibility and accuracy. Referring to a study done be Attia (2009), ten building performance simulation tools were compared, in addition to a survey for different parties working closely in the building design was performed. However, most architects declared that their choice of the appropriate software is significantly made according to the integration of other inputs from related databases as well as how user-friendly interface the software is. The ten simulation tools were IES-VE, ECOTECT, Energy Plus, DOE-2, Green Building Studio, eQUEST, Energy Plus-SketchUp Plugin and HEED. Recently, the familiarity of the use of these tools has been growing rapidly after their ability to integrate programs to them such as; AutoCAD, BIM tools as well as integrating data from global standards, such as; LEED and ASHRAE standards, which helped the implementation of integrated design processes by involving architects, engineers and other disciplines involved in the construction process.

The survey results showed that the most “Architect Friendly” softwares are IES-VE, eQUEST and HEED in descending order respectively. IES-VE was strongly recommended for its effectiveness in all design stages starting from the concept to the detailed design; in addition, it is based on thermal templates, which allow an easy input and modification of parameters. HEED is very useful in comparing several designs together, plus providing guidelines for diverse climates. As for eQUEST, its has a lot in common with IES-VE in terms of the ability to simulate different types of systems, however, it is a bit inflexible when dealing with innovative and intelligent building systems. The next category simulation tools includes ECOTECT, DB, GBS and E10, which are familiar for being simple simulation tools, however, the disadvantage behind using those tools is that they can’t integrate other program’s architectural features, which is incompatible for a complete architectural design stages process. The last category includes EPSU, EP and DOE-2, which are restricted to deal with very simple building models.

Therefore, the selection of the simulation software has been decided according to some values, for instance; the ability to integrate valid weather data, having a friendly user interface, the flexibility to perform different types of simulations, the ability to import materials and thermal data, its popularity in the market as well as providing accurate and reliable results. Integrated Environmental Solutions, Virtual Environment (IES-VE) has been chosen to conduct this research since it has recently proved to be the leading building performance simulation software recommended by architects for environmental studies purposes for its flexibility, reliability and accuracy.

3.4.2 Details of the Instrumentation Tool

IES-VE is one of the advanced climatic studies building performance tools. It provides architects with flexibility as it has the option of importing models from other design programs, such as; AutoCAD, Sketch Up and Revit. It provides adequate modeling tools to build any model together with its adjacent features. Moreover, the software is able to link the climatic properties of any specific location to the indoor mechanical and lighting systems for conducting a real simulation. It has options to include thermal templates, construction templates as well as the input of technical building system data. In addition, it can create hourly, weekly and annually building operation profiles, meanwhile, providing a wide range of outputs that help in the design stage as well as providing the sufficient data for the occupancy stage plan. The software was exclusively launched and developed by IES Company and proved to be a credible tool, since it has achieved many certificates, in addition, it is being used by many well known firms in the global market.

IES-VE contains several modules; each of these control modules is responsible for certain tasks and related parameters. The “ModelIT” module is responsible of creating the building geometry, its details as well as the building’s adjacent architectural features, such as; shading devices. While, the “Solar” module provides visualization for the solar radiation performance to assess its impact on the exterior building envelope as well as the interior space, which contributes to heat gains and energy performance results. As for “ApacheSim” module, it is responsible for performing the building’s thermal simulation, which involves the climatic data, the internal and external heat gains, the model construction materials and their properties. Moreover, it provides results for solar gains, ventilation as well as the performance profiles for the building’s cooling and heating systems. However, “ApacheHVAC” is a technical module used by mechanical engineers to design cooling and heating systems. The “FlucsDL” function is to measure daylight quantity in terms of daylighting illuminance and daylight factors at the required spaces of the model; in addition, it could provide results based on the LEED specifications, while “FlucsPro” is utilized to measure daylight as well as artificial light intensities inside the space. The “Radiance” module is a visualization tool to output photorealistic images by means of ray tracing methods, in addition to its ability to provide data on the quantity of light received to the occupants and performing glare analysis. As for “MacroFlo”, it is the module capable of performing natural ventilation simulation by indicating the airflow direction and speed. However, “MicroFlo” is a more advanced module that deals with computational fluid dynamics model (CFD). Most of these module results could be linked together in order to benefit from the other simulation results and in order to consider their parameters. More information could be found on the software’s official website “www.iesve.com”.

3.5 Research Plan

This section explains the research flow process as shown in Figure 3.1, which gives an overview on the sequence of the research. After determining the constant and variable parameters as well as selecting the method and the research instrumentation too. In addition, the resource needed to conduct the research would be presented as well as the analysis method that would help to achieve the objectives that is the way to answer the research question and reach the aim of the research. Moreover, the limitations of the research would be highlighted at the end of the section.

3.5.1 Required Resources

In order to conduct any research, certain resources must be provided to be capable of carrying it out and this differs from one study to another as some researches might require simple resources, while others would have some restrictions like high costs of instrumentation and special requirements. Resources could be either objective resources or subjective resources. This section will list both types of resources in order to perform this study.

Objective Resources

Objective resources are physical resources that could participate in the research process, the main required equipments needed for this research such as; IES-VE Software Program, as well as training or tutorials in order to use the software, and a valid Dubai weather file imported from IES-VE database. In addition, a compatible model of the office building typical floor is required accompanied with modeled shading devices to be assigned to the building windows. The cost related issues are important resources to carry out any research, which is represented in the software license fees. As per IES-VE official website, the student’s license costs 50£, which is affordable, while, the commercial licence costs between 3000£ and 3500£, in addition to the training workshops costs. The training should be organized in advance in correspondence with the research time frame, otherwise, self-investigating the program through the help of the available tutorials that comes as a complete package together with the software licence could also be an option. In addition to these resources, guidelines and standards, such as; ASHRAE, CIBSE and IESNA standards are considered the reference for basic data specifications.

Subjective Resources

Subjective resources are virtual inputs involved in the research. One of which are the preliminary activities, which are the scientific reading of journal papers, the enhanced data collection, which definitely require a comprehensive knowledge and experience in the environmental science field to be capable of selecting the appropriate research papers, classifying them and comparing their outputs and conclusions. Another critical resource addresses the time-frame defined for this research, which is an eight months period for the whole research plan to be accomplished practically and theoretically, which frames the level of detail of the research and consequently restricts the number of cases to be assessed.

3.5.2 Simulation Process

To attempt the process, two main stages would be followed. The first one is simulation process followed be the analysis the whole building together with all the involved elements, such as; the different shading elements, adjusting the climate and the layout. Plus, setting up all input variables and constants such as; natural and artificial lighting, shading techniques, natural and mechanical ventilation, energy sources, the building's life cycle cost, the economical status, the building's carbon footprint in addition to the safety of the users. The details of the simulation process would be handled in Chapter 4 “Simulation Process”.

3.5.3 Analysis Method

The analysis stage is transforming the input data into output quantitative and qualitative results. It has been concluded from the type of quantitative data collected and the variety of parameters that the best analysis comparisons would be performed through IES-VE software, which could plot tabular output data and graphs giving minimum, maximum and average values of several parameters of different cases. In addition, excel sheets will be used for further analysis of the graphs in order to achieve relevant relations.

3.5.4 Limitations of the Study

Concerning the limitations of this research, the time frame constrains comes at the first place, as more types of shading elements and innovative design strategies could have been tested, such as; the integrated photovoltaic self-shaded windows. Also, examining the impact of different types of opaque and transparent materials, for example; glazing properties and external wall layers. Moreover, more variable parameters and cases could have been assessed if the time limit was more spacious. The study is restricted to shading devices as the only type of passive techniques and it is limited to certain types of shading devices, which are the overhangs and side-fins.

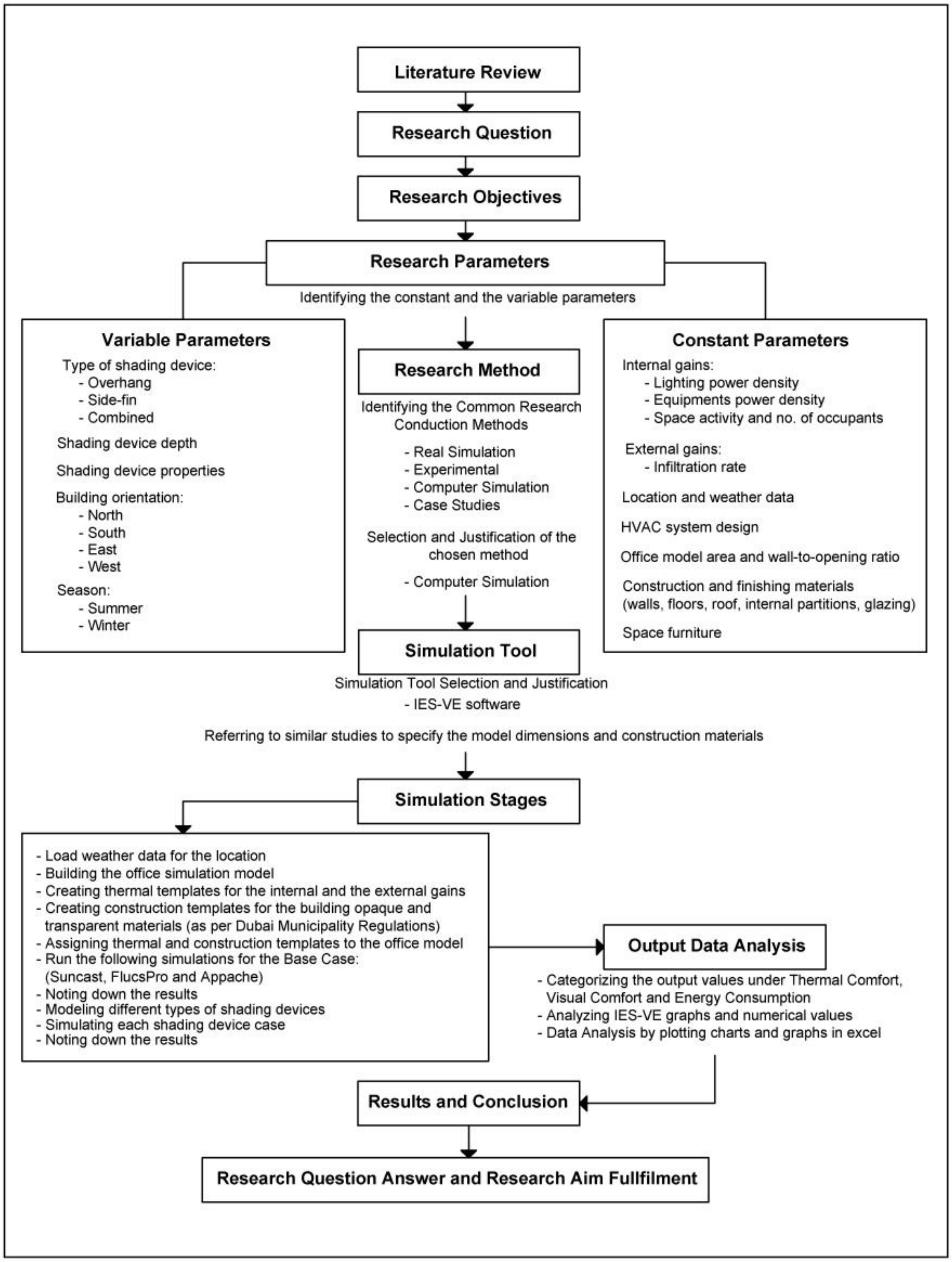


Figure 3.1: Research Flow Diagram

CHAPTER 4: SIMULATION PROCESS

4.1 Introduction

The simulation tool of this study is the IES-VE software that was selected and justified in the last chapter, which performs the whole job of the modeling and the simulation for the building as well as providing tabular results and graphs to be used afterwards in the data analysis stage. This chapter presents the simulation steps, in addition to the numerical input parameters, which are either default inputs from the software database or other values imported from credible guidelines and standards. Meanwhile, the model has been regularly checked and followed up with an official IES tutor to ensure reliability.

4.2 Steps of performing the Simulation

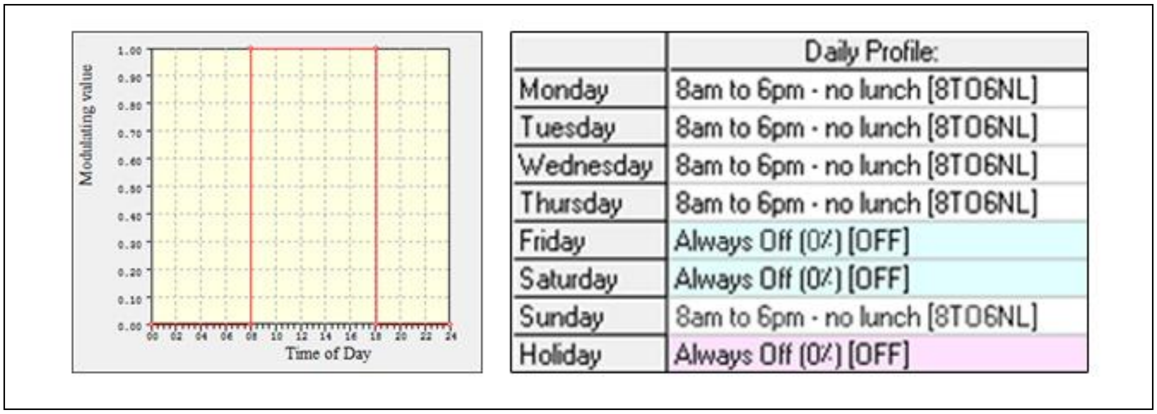
4.2.1 Loading Weather Data

Loading valid weather data by means of a tab called “Aplocate” that provides many weather files. Dubai weather file was chosen and station of “Dubai Intl Airport, United Arab Emirates” was chosen, which provided that the longitude is 55.33° and latitude is 25.25°, while, the altitude is 5m above sea level. It also provides information on the time zone and the site. According to ASHRAE, information about the cooling loads weather data was provided as follows, dry bulb temperature to be set as 29.49°C and the wet bulb as 19.17°C.

4.2.2 Setting Operation Profiles

Setting operation profiles to determine the schedule for the operation of equipments, mechanical systems and lighting systems as well as thermal data parameters, which are identified by the timings where there are occupants. In case of the office, the operation profiles will follow the office hours, which are from 8 to 6 (no lunch), while, on the weekends all the systems are completely off. This is done through the “ApPro” tab or “Apache Profile Database Manager”, which is located under the “Apache” Module. It allows setting daily, weekly and annual profiles as modulating or absolute profiles. Modulating profiles deal with setting parameters, for example; thermal gains, cooling system operating times and ventilation profiles, while, absolute profiles deal with determining the changing intervals of variable parameters, such as; the temperature set points. As shown in Figure 4.1, the following profiles were assigned:

- Modulating Profile: 8am to 6pm – no lunch [8TO6NL]



	Daily Profile:
Monday	8am to 6pm - no lunch [8TO6NL]
Tuesday	8am to 6pm - no lunch [8TO6NL]
Wednesday	8am to 6pm - no lunch [8TO6NL]
Thursday	8am to 6pm - no lunch [8TO6NL]
Friday	Always Off (0%) [OFF]
Saturday	Always Off (0%) [OFF]
Sunday	8am to 6pm - no lunch [8TO6NL]
Holiday	Always Off (0%) [OFF]

- Absolute Profile: -[15]

Figure 4.1: Modulating daily profile (left) and [8TO6NL] weekly profiles (right)

4.2.3 Building the Model

The model was built through the “ModelIT” module, which is responsible for creating the building geometry as well as its adjacent architectural features such as; shading devices. The dimensions of the office model were determined as per the study performed by Ayyad (2011), which performed a comprehensive survey on twelve towers including office and mixed use in Sheikh Zayed road. Offices were checked in terms of office plan geometry, their area, the length of the office exterior wall, the area of glazing as well as the glass-to-wall ratio. The largest percentage of offices had an area of 150m^2 with a length of 16.37m and width of 9.2m, while, the clear height from the floor finishing level to the bottom of the false ceiling is 3.5m, meanwhile, the exterior wall area is 43.9 m^2 including a glazed opening of an area of 29.8 m^2 (11.1m length x 2.7m height). This prototype was chosen to perform this study as shown in Figure 4.2.

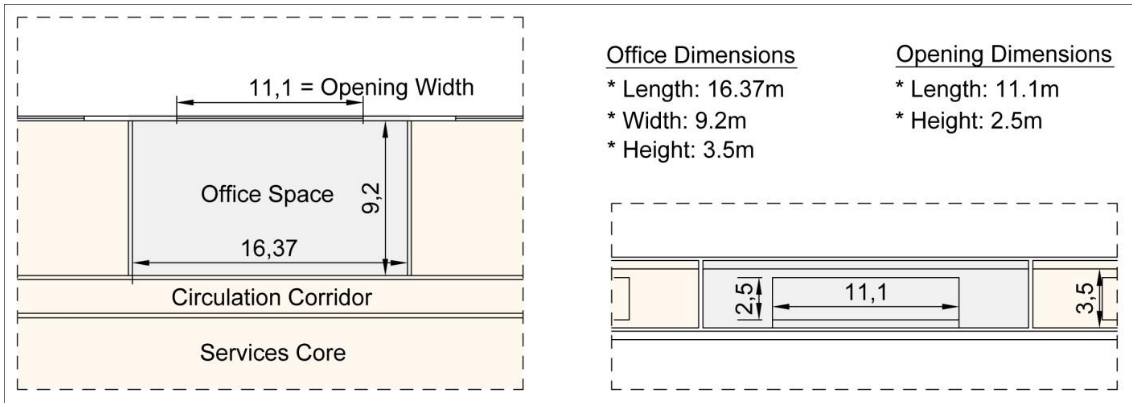


Figure 4.2: Office model prototype – Plan

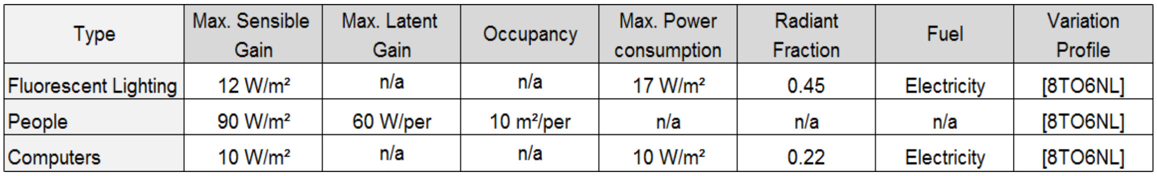
4.2.4 Creating Thermal Templates

Thermal templates are patterns of internal heat gains inside the building, such as; people, lighting and equipments found in the space, and external heat gains from outside the building, such as; the ventilation and infiltration rate as well as technical input concerning the cooling and heating systems.

Internal and external heat gains

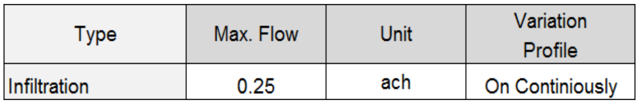
As for internal heat gains as shown in Table 4.1, lighting is selected as fluorescent lighting as it’s the most common type of office lighting with a maximum power consumption of 17 W/m^2 and a radiant fraction of 0.45, while, the variation profile is set to be from 8am to 6pm continuously. As for the number of occupants, a ratio of 10 m^2 per person is determined. Meanwhile, the sensible and the latent heat gain for occupants are 90 W/ m^2 and 60 W/ m^2 respectively, accompanied by the variation profile, which are the office hours from 8am to 6pm. As for the computers provided in the space, their maximum sensible gain is 10 W/ m^2 with a maximum power consumption of 10 W/ m^2 and a 0.22 radiant fraction, and operating continuously from 8am to 6pm. As for external heat gains as shown in Table 4.2, only infiltration is specified to be the external source of heat with a maximum flow of 0.25 ach and the variation profile is set to be on continuously.

Table 4.1: Thermal template internal heat gains



Type	Max. Sensible Gain	Max. Latent Gain	Occupancy	Max. Power consumption	Radiant Fraction	Fuel	Variation Profile
Fluorescent Lighting	12 W/m²	n/a	n/a	17 W/m²	0.45	Electricity	[8TO6NL]
People	90 W/m²	60 W/per	10 m²/per	n/a	n/a	n/a	[8TO6NL]
Computers	10 W/m²	n/a	n/a	10 W/m²	0.22	Electricity	[8TO6NL]

Table 4.2: Thermal template external heat gains

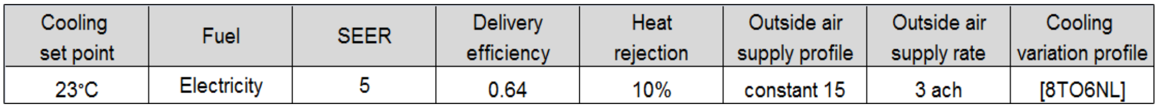


Type	Max. Flow	Unit	Variation Profile
Infiltration	0.25	ach	On Continiously

HVAC system data

Concerning the information regarding mechanical systems as shown in Table 4.3, where the heating system is set to be off continuously, while, the cooling system is set to operate through weekdays from 8am to 6pm according to the office working hours. The cooling set point is set on 23°C, the chiller efficiency of 5.0 and a delivery efficiency of 0.64. In addition, the heat rejection is set for 10%. The outside air supply is assigned to the absolute profile [15]. Meanwhile, the maximum and minimum humidity saturations are set to be 70% and 30% respectively, in addition, the heating and the cooling radiant fractions for the system are set to be 0.3 and 0.0 respectively.

Table 4.3: HVAC system input values



Cooling set point	Fuel	SEER	Delivery efficiency	Heat rejection	Outside air supply profile	Outside air supply rate	Cooling variation profile
23°C	Electricity	5	0.64	10%	constant 15	3 ach	[8TO6NL]

4.2.5 Creating Construction Templates

Construction templates are patterns concerning the opaque constructions, such as; external walls, internal partitions, internal floors or ceilings, exposed floors, roofs and doors, in addition to transparent constructions, such as; external and internal windows as well as roof lights. All specification values were determined according to Dubai municipality circular number 197 (2010), which illustrated common prototypes for the most common construction layers followed in Dubai. In addition, U-values for materials were determined according to ASHRAE 55 (2004).

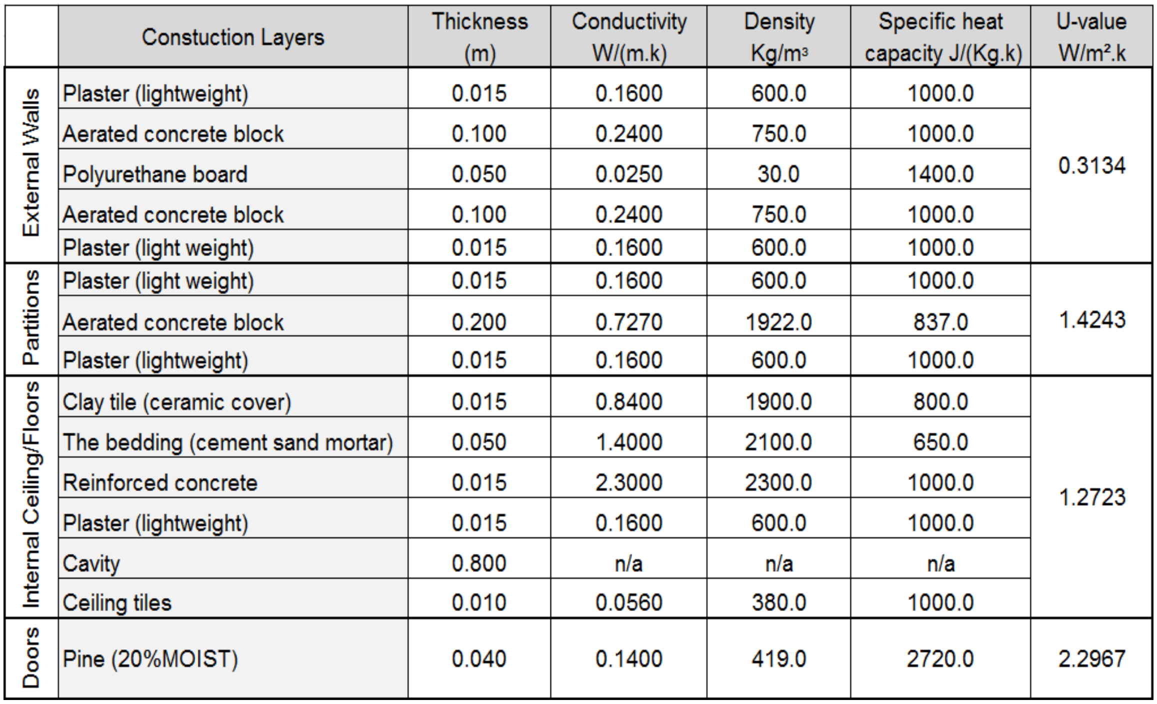
Opaque constructions

As for external walls, the total wall thickness is 28cm composed two layers of aerated concrete block (15cm each) with an insulating layer between them (5 cm polyurethane board) and topped with lightweight plaster layers on the interior and the exterior face (1.5cm each). As for internal partitions, their total thickness is 23cm, which is composed of one layer of concrete block wall (20cm thick) and coated with lightweight plaster layers on the interior and the exterior face (1.5cm each). As for internal ceilings or floors, their total thickness is 23cm and composed of the typical reinforced concrete slab (15cm thick) topped with a cement sand mortar bedding (5cm) and floor tiles (1.5 cm thick), while the slab's bottom is coated with a layer of lightweight plaster (1.5cm thick). The type of doors is specified to be PINE (20%Moist) with a thickness of 4cm. Refer to Table 4.4 for details on opaque construction layers. As for shading devices, the common reinforced concrete is used as it's the most common types with a thickness of 10cm.

Transparent constructions

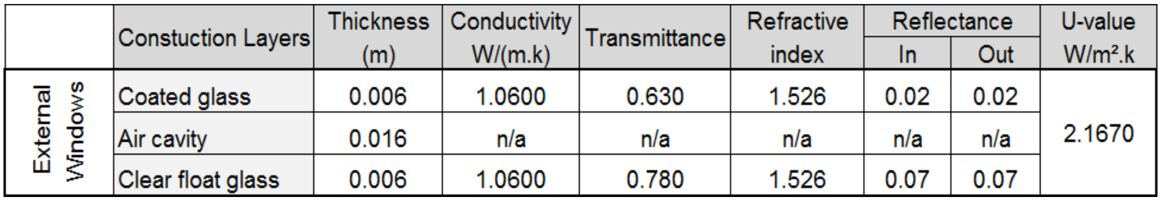
As for external windows, the total thickness is 2.8cm composed of one layer of coated glass (6mm thick) from the exterior followed by an air cavity with a distance of 1.6cm for insulation and then a layer of clear float glass towards the interior space (6mm thick). Refer to Table 4.5 for details on transparent construction layers.

Table 4.4: Opaque constructions data



	Constuction Layers	Thickness (m)	Conductivity W/(m.k)	Density Kg/m³	Specific heat capacity J/(Kg.k)	U-value W/m².k
External Walls	Plaster (lightweight)	0.015	0.1600	600.0	1000.0	0.3134
	Aerated concrete block	0.100	0.2400	750.0	1000.0	
	Polyurethane board	0.050	0.0250	30.0	1400.0	
	Aerated concrete block	0.100	0.2400	750.0	1000.0	
	Plaster (light weight)	0.015	0.1600	600.0	1000.0	
Partitions	Plaster (light weight)	0.015	0.1600	600.0	1000.0	1.4243
	Aerated concrete block	0.200	0.7270	1922.0	837.0	
	Plaster (lightweight)	0.015	0.1600	600.0	1000.0	
Internal Ceiling/Floors	Clay tile (ceramic cover)	0.015	0.8400	1900.0	800.0	1.2723
	The bedding (cement sand mortar)	0.050	1.4000	2100.0	650.0	
	Reinforced concrete	0.015	2.3000	2300.0	1000.0	
	Plaster (lightweight)	0.015	0.1600	600.0	1000.0	
	Cavity	0.800	n/a	n/a	n/a	
	Ceiling tiles	0.010	0.0560	380.0	1000.0	
Doors	Pine (20%MOIST)	0.040	0.1400	419.0	2720.0	2.2967

Table 4.5: Transparent constructions data



	Constuction Layers	Thickness (m)	Conductivity W/(m.k)	Transmittance	Refractive index	Reflectance		U-value W/m².k
						In	Out	
External Windows	Coated glass	0.006	1.0600	0.630	1.526	0.02	0.02	2.1670
	Air cavity	0.016	n/a	n/a	n/a	n/a	n/a	
	Clear float glass	0.006	1.0600	0.780	1.526	0.07	0.07	

4.2.6 Assigning Thermal and Construction Templates to the Model

The next step is to assign thermal and construction templates to the office model in order to use the parameters and input values of the templates in the simulation process.

4.2.7 Simulation Process

The simulation process is then performed; “Solar” module is used to perform the solar radiation analysis and determine the percentage of the shading and its intensity on the façade, the “ApacheSim” module is used to perform the building thermal analysis taking all construction and thermal templates into account. In addition, “FlucsPro” module is used to determine the average illuminance of combined daylighting and artificial lighting inside the space to determine the average illuminance and compare it with IESNA standards (2000), which requires a minimum illuminance of 500 Lux for offices and workplaces, however, “Radiance” is used to generate photorealistic images and to perform a glare analysis.

4.3 Research Matrix

The research matrix will include all the cases that will be assesed in the simulation, which could be classified as per the following variations. All the cases are tested in all orientations (North, South, East and West) in UAE climatic design days, which are the 20th of June and the 20th of December for summer and winter respectively as stated by Hammad (2010).

Research assessed variation cases:

- Base Case without integrating any shading devices
- Base Case + overhang 0.5m depth
- Base Case + overhang 1m depth
- Base Case + overhang 1.5m depth
- Base Case + side-fins 0.5m depth
- Base Case + side-fins 1m depth
- Base Case + side-fins 1.5m depth
- Base Case + combined overhang and side-fins 0.5m depth
- Base Case + combined overhang and side-fins 1m depth
- Base Case + combined overhang and side-fins 1.5m depth

Refer to Figure 4.3, 4.4 and 4.5, which shows base case and different assessed cases.

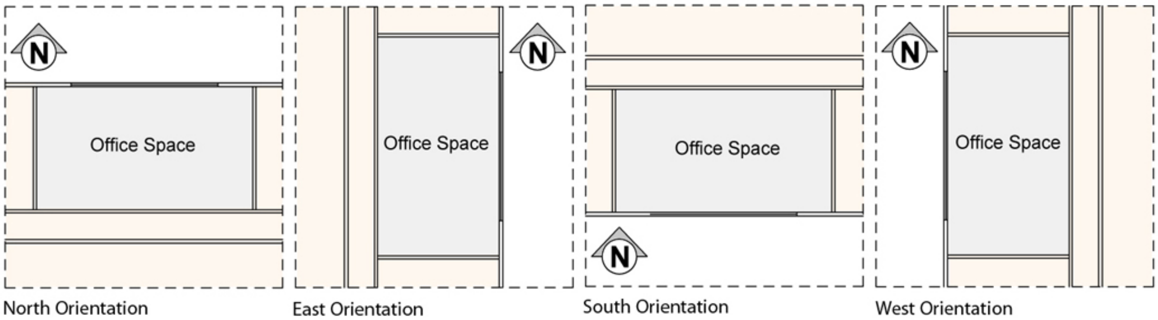


Figure 4.3: Different building orientations assessed in the simulation process

Figure 4.4: Office model selected for the simulation – base case

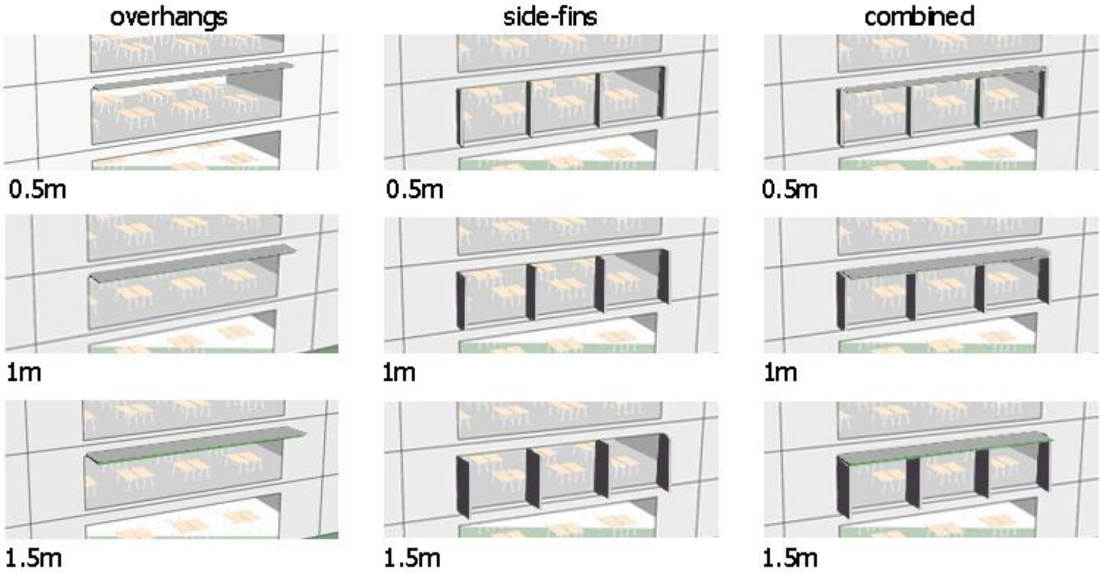


Figure 4.5: Different types of shading devices integrated in the simulation

4.3.1 Limitation of Measurement

There are some limitations of the measurements taken, which concerns the minute error found in the measurement because of possible inaccurate inputs from the author or from the software. The measurement is limited to the previously mentioned dates to get an overview of the average measurements; however, performing the research on four selected days that represent the four seasons could have provided information that is more comprehensive.

4.4 Analysis Method

Analysis comparisons would be performed through IES software, which could plot tabular output data and graphs giving minimum, maximum and average values of several parameters of different cases. In addition, excel sheets will be used for further analysis of the graphs in order to achieve relevant relations.

The analysis method of the research results would be based on the following:

- Comparing different building orientation effect on the outputs in each of the research matrix cases
- Comparing the results of each case with the base case to determine its impact
- Comparing each of the cases throughout the winter and the summer seasons to determine the climatic effect on the output results
- Based on Dubai Municipality systems' construction templates, different shading devices materials and costs would be compared to evaluate the best effective and economical scenario for each orientation

Many outputs were generated from the simulation; some of them related to thermal comfort, others are related to visual comfort, while other outputs are related to energy consumption. Chapter 5 "Results" will present the results of the simulation in details as per the result sheet.

CHAPTER 5: RESULTS

This chapter explains the output results of the computer simulation process, which was presented in details in the last chapter. The values has been expressed in graphs and numerical tables extracted from the software (IES-VE), in addition, output values has been used to plot charts and graphs into excel for a comprehensive further analysis.

5.1 Result Sheet Formulation

A result sheet has been prepared to include all numerical outputs from the simulation process. The four building orientations (North, East, South and West) were located on the vertical axis, while, the simulation cases (base case, overhangs 0.5m, overhangs 1m, overhangs 1.5m, side-fins 0.5m, side-fins 1m, side-fins 1.5m, combined 0.5m, combined 1m and combined 1.5m.) were located on the horizontal axis. Outputs have been conducted for each case of the shading devices types and depth as shown in Table 5.1 and Table 5.2.

After that, the results were classified under each building orientation into three categories based on the research question and objectives; thermal comfort, visual comfort and energy consumption, in order to simplify the analysis process. Finally, the whole procedure was conducted once in summer and another time in winter on the selected climatic design days for the simulation, 20th June and 20th December respectively (Hammad, 2010), to feel the season variation impact on the simulation results.

5.1.1 Thermal Comfort Outputs

Three outputs related to thermal comfort were recorded during the simulation process; the annual solar gain, the maximum solar gain as well as the percentage of people dissatisfied, which are defined as follows:

- *Annual solar gain (measured in MWh):* The total solar radiation amount entering the space throughout the year
- *Maximum solar gain (measured in MWh):* Describes the daily peak solar gain amount reached through out the design day

- *Percentage of people dissatisfied (PPD):* Percentage of occupants who feels thermally uncomfortable towards the indoor space temperature, measured on that particular design day

5.1.2 Visual Comfort Outputs

Two outputs related to visual comfort were recorded during the simulation process; the average illuminance, and the glare threshold, which are defined as follows:

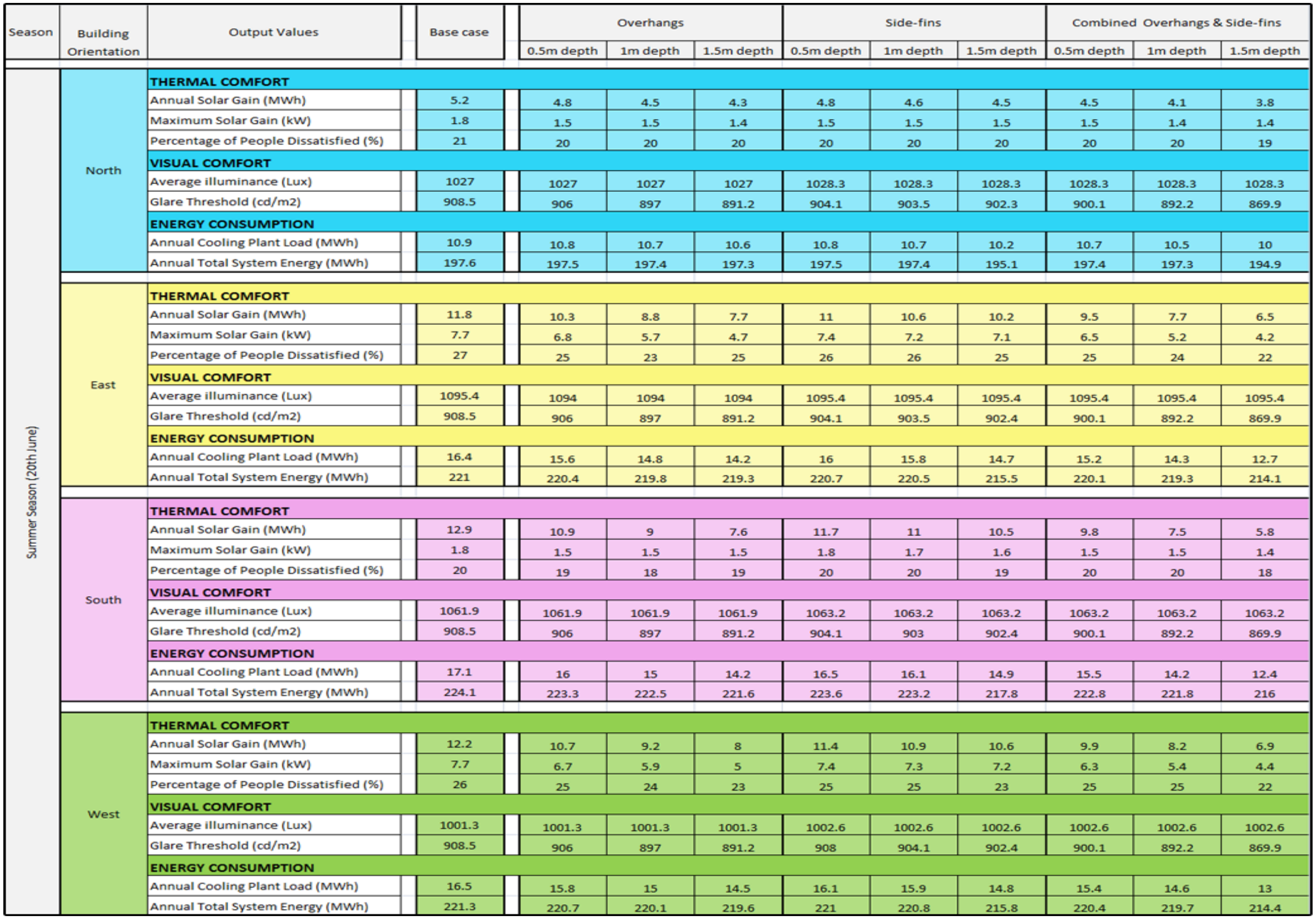
- *Average illuminance (measured in Lux):* The average of daylighting and artificial lighting illuminance levels inside the space (measured at 12:00 pm), which provides an indication for the daylighting illuminance as the artificial lighting is one of the constant parameters in this research.
- *Glare Threshold (measured in cd/m^2):* The amount of glare delivered to the occupants' eyes as a result of the excessive daylighting on a particular day and time (measured at 12:00 pm)

5.1.3 Energy Consumption Outputs

Two outputs related to energy consumption were recorded during the simulation process; the annual cooling plant sensible load and the annual total system energy which are defined as follows:

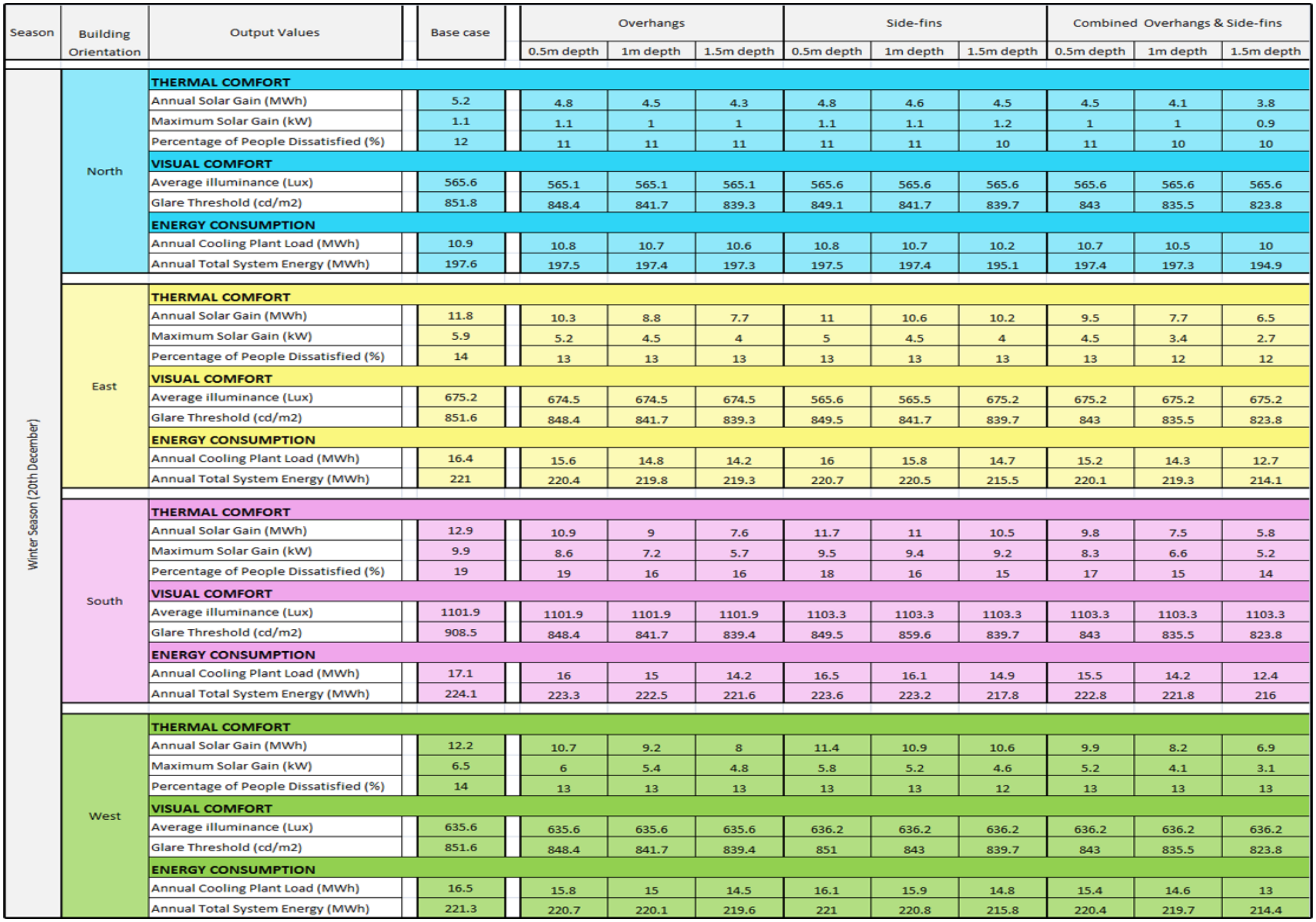
- *Annual cooling plant sensible load (measured in MWh):* The HVAC system cooling load amount needed to cool the inside space to the required temperature throughout the year
- *Total system energy (measured in MWh):* The HVAC system cooling plant sensible load, chiller load, room dehumidification load, auxiliary ventilation sensible and latent load, and system air sensible and latent load throughout the year.

Table 5.1: Summer season results sheet



Season	Building Orientation	Output Values	Base case	Overhangs			Side-fins			Combined Overhangs & Side-fins		
				0.5m depth	1m depth	1.5m depth	0.5m depth	1m depth	1.5m depth	0.5m depth	1m depth	1.5m depth
Summer Season (20th June)	North	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	5.2	4.8	4.5	4.3	4.8	4.6	4.5	4.5	4.1	3.8
		Maximum Solar Gain (kW)	1.8	1.5	1.5	1.4	1.5	1.5	1.5	1.5	1.4	1.4
		Percentage of People Dissatisfied (%)	21	20	20	20	20	20	20	20	20	19
		VISUAL COMFORT										
		Average illuminance (Lux)	1027	1027	1027	1027	1028.3	1028.3	1028.3	1028.3	1028.3	1028.3
		Glare Threshold (cd/m2)	908.5	906	897	891.2	904.1	903.5	902.3	900.1	892.2	869.9
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	10.9	10.8	10.7	10.6	10.8	10.7	10.2	10.7	10.5	10
		Annual Total System Energy (MWh)	197.6	197.5	197.4	197.3	197.5	197.4	195.1	197.4	197.3	194.9
	East	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	11.8	10.3	8.8	7.7	11	10.6	10.2	9.5	7.7	6.5
		Maximum Solar Gain (kW)	7.7	6.8	5.7	4.7	7.4	7.2	7.1	6.5	5.2	4.2
		Percentage of People Dissatisfied (%)	27	25	23	25	26	26	25	25	24	22
		VISUAL COMFORT										
		Average illuminance (Lux)	1095.4	1094	1094	1094	1095.4	1095.4	1095.4	1095.4	1095.4	1095.4
		Glare Threshold (cd/m2)	908.5	906	897	891.2	904.1	903.5	902.4	900.1	892.2	869.9
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	16.4	15.6	14.8	14.2	16	15.8	14.7	15.2	14.3	12.7
		Annual Total System Energy (MWh)	221	220.4	219.8	219.3	220.7	220.5	215.5	220.1	219.3	214.1
	South	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	12.9	10.9	9	7.6	11.7	11	10.5	9.8	7.5	5.8
		Maximum Solar Gain (kW)	1.8	1.5	1.5	1.5	1.8	1.7	1.6	1.5	1.5	1.4
		Percentage of People Dissatisfied (%)	20	19	18	19	20	20	19	20	20	18
		VISUAL COMFORT										
		Average illuminance (Lux)	1061.9	1061.9	1061.9	1061.9	1063.2	1063.2	1063.2	1063.2	1063.2	1063.2
		Glare Threshold (cd/m2)	908.5	906	897	891.2	904.1	903	902.4	900.1	892.2	869.9
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	17.1	16	15	14.2	16.5	16.1	14.9	15.5	14.2	12.4
		Annual Total System Energy (MWh)	224.1	223.3	222.5	221.6	223.6	223.2	217.8	222.8	221.8	216
	West	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	12.2	10.7	9.2	8	11.4	10.9	10.6	9.9	8.2	6.9
		Maximum Solar Gain (kW)	7.7	6.7	5.9	5	7.4	7.3	7.2	6.3	5.4	4.4
		Percentage of People Dissatisfied (%)	26	25	24	23	25	25	23	25	25	22
		VISUAL COMFORT										
		Average illuminance (Lux)	1001.3	1001.3	1001.3	1001.3	1002.6	1002.6	1002.6	1002.6	1002.6	1002.6
		Glare Threshold (cd/m2)	908.5	906	897	891.2	908	904.1	902.4	900.1	892.2	869.9
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	16.5	15.8	15	14.5	16.1	15.9	14.8	15.4	14.6	13
		Annual Total System Energy (MWh)	221.3	220.7	220.1	219.6	221	220.8	215.8	220.4	219.7	214.4

Table 5.2: Winter season results sheet



Season	Building Orientation	Output Values	Base case	Overhangs			Side-fins			Combined Overhangs & Side-fins		
				0.5m depth	1m depth	1.5m depth	0.5m depth	1m depth	1.5m depth	0.5m depth	1m depth	1.5m depth
Winter Season (20th December)	North	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	5.2	4.8	4.5	4.3	4.8	4.6	4.5	4.5	4.1	3.8
		Maximum Solar Gain (kW)	1.1	1.1	1	1	1.1	1.1	1.2	1	1	0.9
		Percentage of People Dissatisfied (%)	12	11	11	11	11	11	10	11	10	10
		VISUAL COMFORT										
		Average illuminance (Lux)	565.6	565.1	565.1	565.1	565.6	565.6	565.6	565.6	565.6	565.6
		Glare Threshold (cd/m2)	851.8	848.4	841.7	839.3	849.1	841.7	839.7	843	835.5	823.8
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	10.9	10.8	10.7	10.6	10.8	10.7	10.2	10.7	10.5	10
		Annual Total System Energy (MWh)	197.6	197.5	197.4	197.3	197.5	197.4	195.1	197.4	197.3	194.9
	East	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	11.8	10.3	8.8	7.7	11	10.6	10.2	9.5	7.7	6.5
		Maximum Solar Gain (kW)	5.9	5.2	4.5	4	5	4.5	4	4.5	3.4	2.7
		Percentage of People Dissatisfied (%)	14	13	13	13	13	13	13	13	12	12
		VISUAL COMFORT										
		Average illuminance (Lux)	675.2	674.5	674.5	674.5	565.6	565.5	675.2	675.2	675.2	675.2
		Glare Threshold (cd/m2)	851.6	848.4	841.7	839.3	849.5	841.7	839.7	843	835.5	823.8
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	16.4	15.6	14.8	14.2	16	15.8	14.7	15.2	14.3	12.7
		Annual Total System Energy (MWh)	221	220.4	219.8	219.3	220.7	220.5	215.5	220.1	219.3	214.1
	South	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	12.9	10.9	9	7.6	11.7	11	10.5	9.8	7.5	5.8
		Maximum Solar Gain (kW)	9.9	8.6	7.2	5.7	9.5	9.4	9.2	8.3	6.6	5.2
		Percentage of People Dissatisfied (%)	19	19	16	16	18	16	15	17	15	14
		VISUAL COMFORT										
		Average illuminance (Lux)	1101.9	1101.9	1101.9	1101.9	1103.3	1103.3	1103.3	1103.3	1103.3	1103.3
		Glare Threshold (cd/m2)	908.5	848.4	841.7	839.4	849.5	859.6	839.7	843	835.5	823.8
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	17.1	16	15	14.2	16.5	16.1	14.9	15.5	14.2	12.4
		Annual Total System Energy (MWh)	224.1	223.3	222.5	221.6	223.6	223.2	217.8	222.8	221.8	216
	West	**THERMAL COMFORT**										
		Annual Solar Gain (MWh)	12.2	10.7	9.2	8	11.4	10.9	10.6	9.9	8.2	6.9
		Maximum Solar Gain (kW)	6.5	6	5.4	4.8	5.8	5.2	4.6	5.2	4.1	3.1
		Percentage of People Dissatisfied (%)	14	13	13	13	13	13	12	13	13	13
		VISUAL COMFORT										
		Average illuminance (Lux)	635.6	635.6	635.6	635.6	636.2	636.2	636.2	636.2	636.2	636.2
		Glare Threshold (cd/m2)	851.6	848.4	841.7	839.4	851	843	839.7	843	835.5	823.8
		ENERGY CONSUMPTION										
		Annual Cooling Plant Load (MWh)	16.5	15.8	15	14.5	16.1	15.9	14.8	15.4	14.6	13
		Annual Total System Energy (MWh)	221.3	220.7	220.1	219.6	221	220.8	215.8	220.4	219.7	214.4

5.2 Results and Discussion based on Research Objectives Categories

5.2.1 Thermal Comfort

A. Annual and Peak Solar Gain

North Orientation

Referring to the results sheet, north oriented façades seems to receive the lowest amount of solar radiation compared to the other building orientations in summer and in winter throughout all the cases; either base case, overhangs, side fins or combined. As shown in Figure 5.1, the maximum annual solar gain reduction, which belongs to the maximum depth combined overhangs and side-fins, provides a 26.9% reduction from the base case, while, the deepest overhang and side-fin provides 17.3 % and 13.5% reductions respectively.

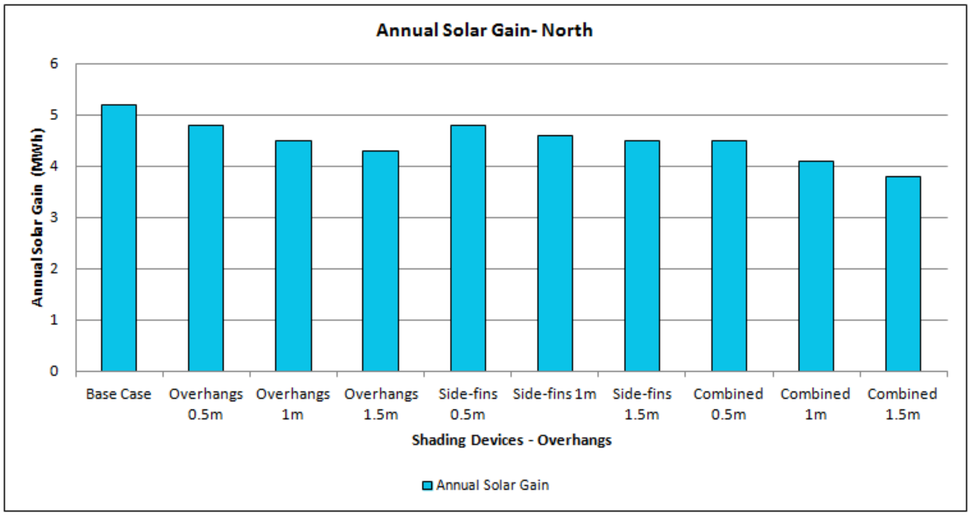


Figure 5.1: The annual solar gain of different shading device cases on north oriented façades

The base case annual solar gain is 5.2 MWh, while, its daily peak solar gain determined for summer and winter seasons is 1.8 MWh and 1.1 MWh respectively, which are considered close values.

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 7.7%. Meanwhile, increasing the depth to 1m provides a further reduction of 6.2% only from the 0.5m depth, while, a further increase in the depth to 1.5m provides a 10.4% reduction from the 1m case. Figure 5.2 illustrates the profile of overhangs performance in summer and winter, where in summer the peak solar gain radiation seems to be constant throughout most of the building occupation time, while, in winter the solar gain curve gradually go up to reach its maximum by mid-day and then gradually fade by the daytime.

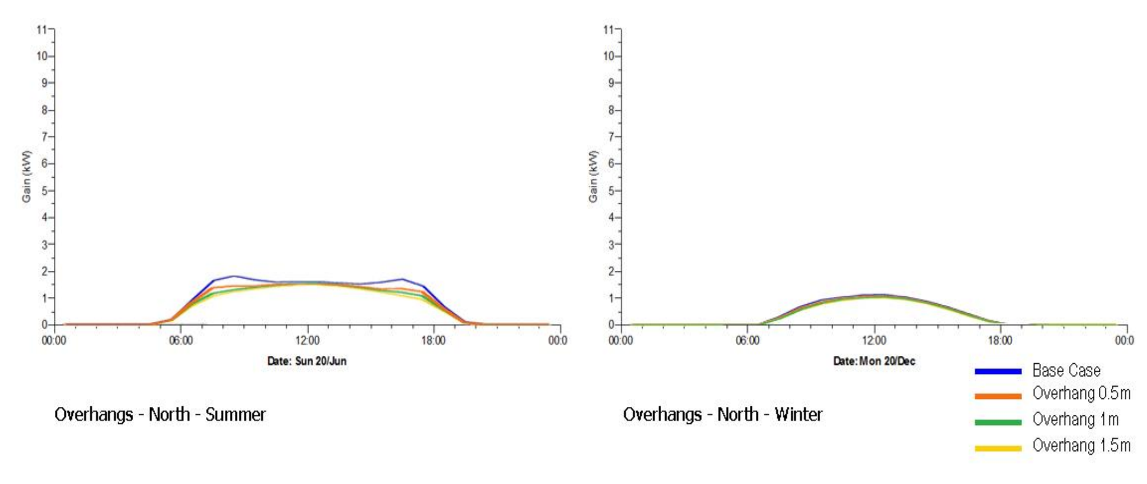


Figure 5.2: A graph showing the solar gain profile of north orientation overhangs in summer and winter

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 7.7% (same as the overhang 0.5m depth). Meanwhile, increasing the depth to 1m provides a very small reduction of 2.2% only from the 0.5m depth; however, a further increase in the depth to 1.5m does not provide any further reductions from the 1m case. Figure 5.3 illustrates the profile of side-fins performance in summer and winter, which is very similar to the overhangs profile that shows a continuous peak solar radiation on the façade in summer.

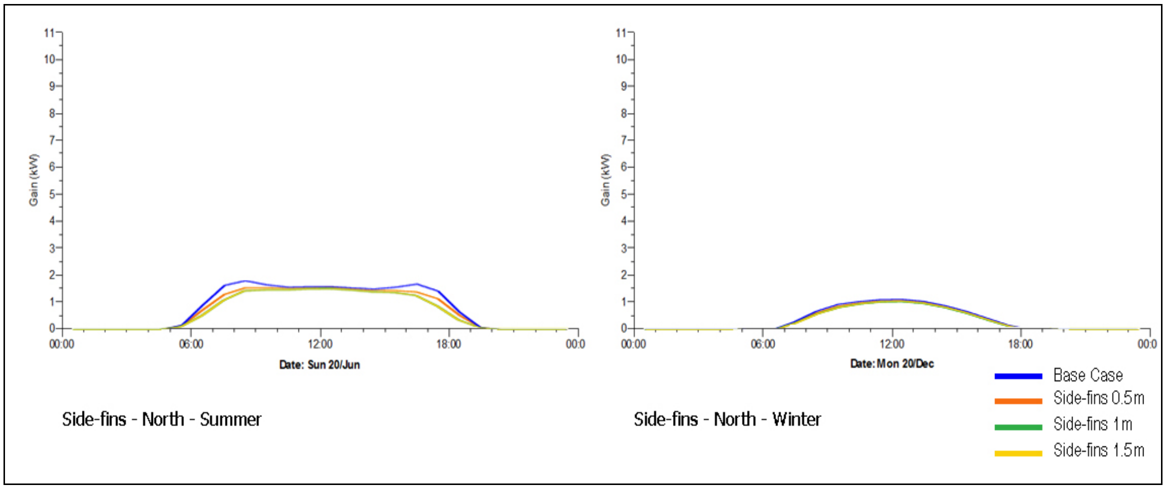


Figure 5.3: A graph showing the solar gain profile of north orientation side-fins in summer and winter

As for combined overhangs and side-fins, when compared according to their different depths (0.5m, 1m and 1.5m), the results obtained indicates a solar gain reduction of 13.5% between the base case and the 0.5m depths. Meanwhile, increasing the depth to 1m provides a further reduction of 8.9% from the 0.5m depth, further more, increasing the depth to 1.5m provide a reduction of 7.3% from the 1m case.

South Orientation

Referring to Figure 5.4, south oriented façades seem to receive a huge amount of solar radiation compared to the other building orientations in summer and winter throughout all the cases either base case, overhangs, side fins or combined. As shown in the same figure, integrating shading devices makes a significant reduction in solar radiation since the ultimate annual solar gain reduction, which belongs to the maximum depth combined overhangs and side-fins, provides a 55% reduction from the base case, while, the deepest overhang and side-fin provides 41.1 % and 18.6% reductions respectively.

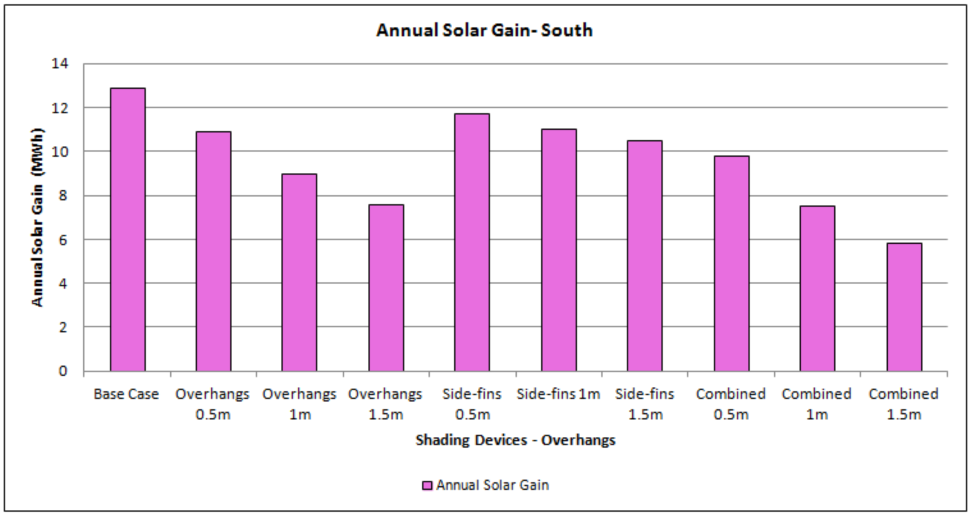


Figure 5.4: The annual solar gain of different shading device cases on south oriented façades

The base case annual solar gain is 12.5 MWh, while, it's daily peak solar gain determined for summer and winter seasons is 1.8 MWh and 9.9 MWh respectively, which is considered a huge solar gain difference.

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 15.5%. Meanwhile, increasing the depth to 1m provides a further reduction of 17.4% only from the 0.5m depth, while a further increase in the depth to 1.5m provides a 15.6% reduction from the 1m case. Figure 5.5 illustrates the profile of overhangs performance in summer and winter, where in summer the peak solar gain radiation seems to be constant throughout most of the building occupation time, on the other hand, in winter the solar gain curve gradually go up to reach its maximum by mid-day and then gradually goes off by the daytime. In addition, the profiles show a significantly higher solar gain amounts in winter due to the sun position.

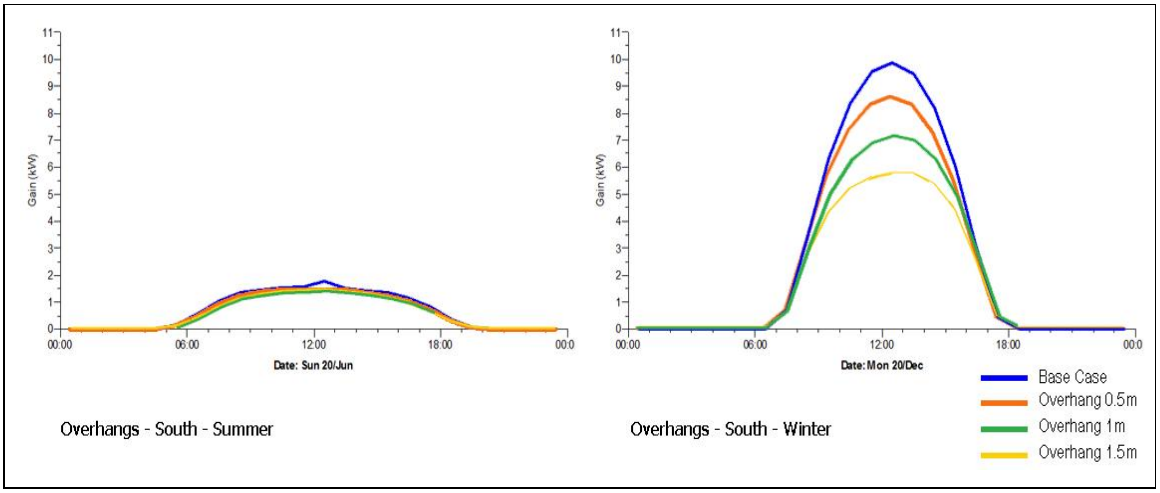


Figure 5.5: A graph showing the solar gain profile of south orientation overhangs in summer and winter

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 9.3% (same as the overhang 0.5m depth). Meanwhile, increasing the depth to 1m provides a reduction of 5.9% from the 0.5m depth, while, a further increase in the depth to 1.5m provides a further reduction of 13.6% from the 1m case. Figure 5.6 illustrates the profile of side-fins performance in summer and winter, which is very similar to the overhangs profile that shows a highly remarkable peak solar radiation on the façade in winter and at the same time indicating very minute differences resulting from the side-fins depth variation.

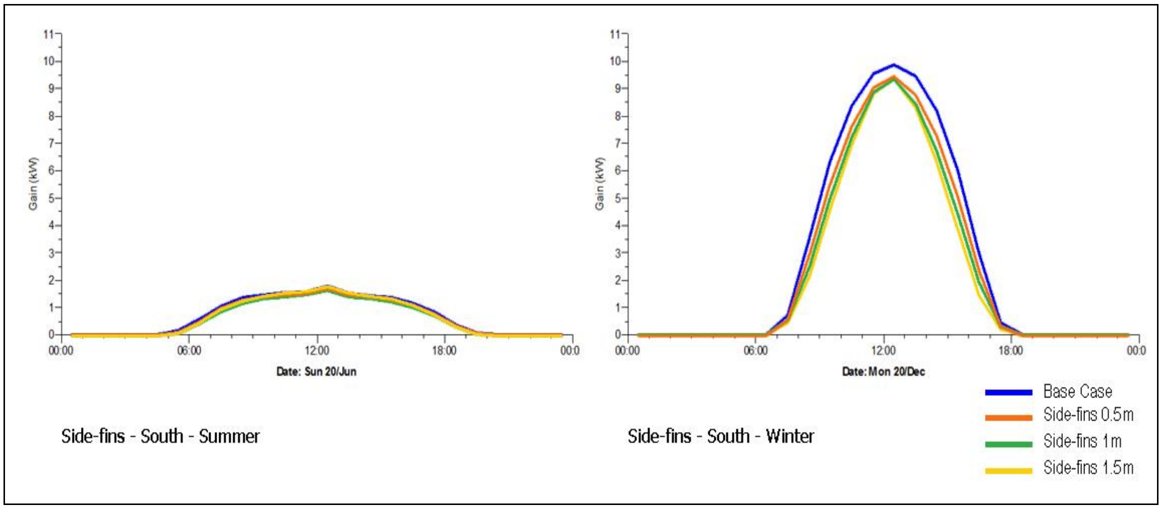


Figure 5.6: A graph showing the solar gain profile of south orientation side-fins in summer and winter

As for combined overhangs and side-fins, when compared according to their different depths (0.5m, 1m and 1.5m), the results obtained indicates a solar gain reduction of 24% between the base case and the 0.5m depths. Meanwhile, increasing the depth to 1m provides a further reduction of 23.5% from the 0.5m depth, further more, increasing the depth to 1.5m provide a reduction of 22.7% from the 1m case.

East Orientation

Referring to Figure 5.7, east oriented façades seems to receives a significant amount of radiation throughout all the cases either base case or overhangs or side-fins throughout all the cases either base case, overhangs, side fins or combined. As shown in the same figure, integrating shading devices makes a significant reduction in solar radiation since the ultimate annual solar gain reduction, which belongs to the maximum depth combined overhangs and side-fins, provides a 44.9% reduction from the base case, while the deepest overhang and side-fin provides 10.2% and 13.6% reductions respectively.

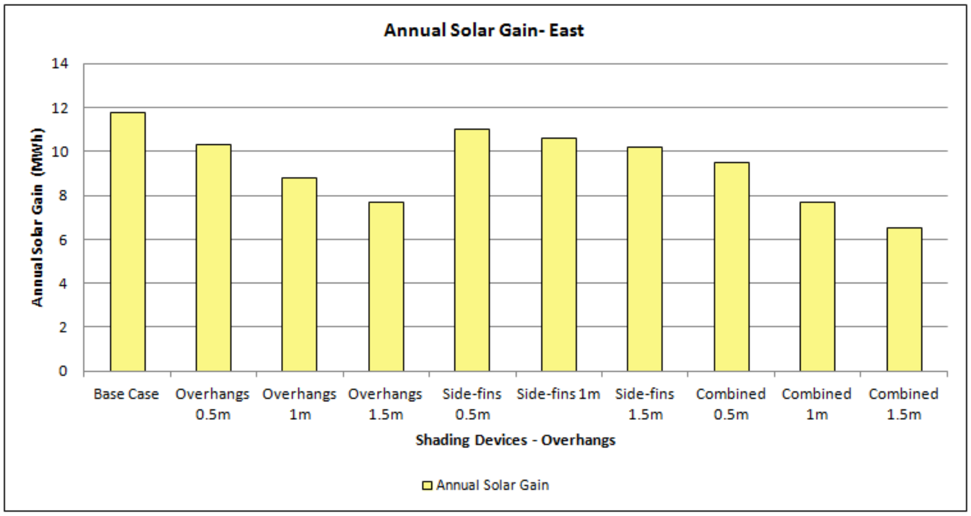


Figure 5.7: The annual solar gain of different shading device cases on east oriented façades

The base case annual solar gain is 11.8 MWh, while its daily peak solar gain determined for summer and winter seasons is 7.7 MWh and 5.9 MWh respectively, which is considered a relatively large difference in value.

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 8.7%. Meanwhile, increasing the depth to 1m provides a further reduction of 14.6% only from the 0.5m depth, while a further increase in the depth to 1.5m provides a 12.5% reduction from the 1m case. Figure 5.8 illustrates the profile of overhangs performance in summer and winter, where summer and winter profiles seem to be similar in attitude. Most of the solar gain received to the façade lies from the early morning (6am) to mid-day (12 pm), however, the profiles show a significantly higher solar gain amounts in summer due to the solar altitude.

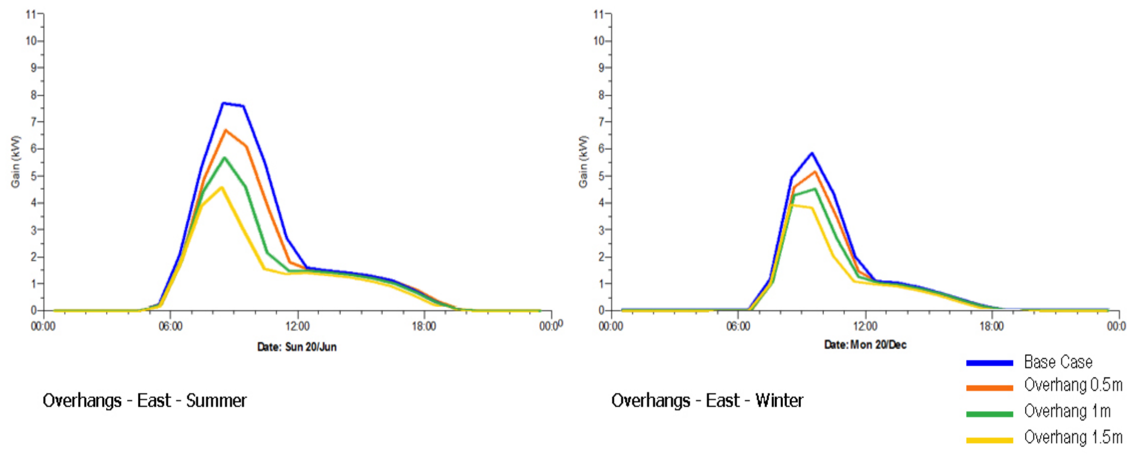


Figure 5.8: A graph showing the solar gain profile of east orientation overhangs in summer and winter

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 9.3% (same as the overhang 0.5m depth). Meanwhile, increasing the depth to 1m provides a reduction of 9.6% from the 0.5m depth, while, a further increase in the depth to 1.5m provides a further reduction of 10.4% from the 1m case. Figure 5.9 illustrates the profile of side-fins performance in summer and winter, where in summer and winter profiles seem to be similar in attitude in which most of the solar gain received to the façade lies from the early morning (6am) to mid-day (12 pm), however, the profiles show higher solar gain amounts in summer due to the solar altitude. In addition, increasing the depth of side-fins is more effective in winter in terms of annual solar gains.

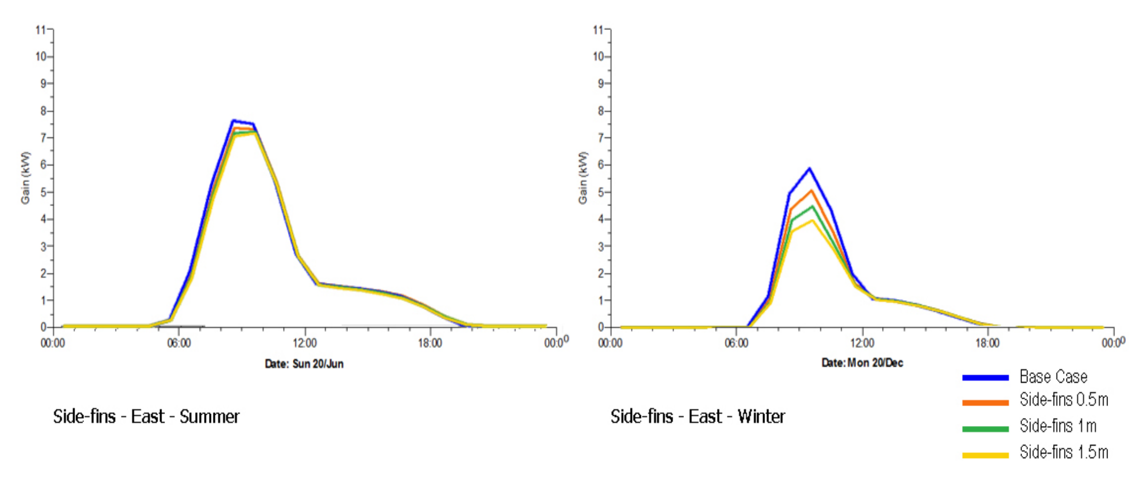


Figure 5.9: A graph showing the solar gain profile of east orientation side-fins in summer and winter

As for combined overhangs and side-fins, when compared according to their different depths (0.5m, 1m and 1.5m), the results obtained indicates a solar gain reduction of 19.5% between the base case and the 0.5m depths. Meanwhile, increasing the depth to 1m provides a further reduction of 18.9% from the 0.5m depth, further more, increasing the depth to 1.5m provide a reduction of 15.6% from the 1m case.

West Orientation

Referring to Figure 5.10, west oriented façades seems to receives a moderate amount of radiation throughout all the cases either base case or overhangs or side-fins throughout all the cases either base case, overhangs, side fins or combined. As shown in the same figure, integrating shading devices makes a significant reduction in solar radiation since the ultimate annual solar gain reduction, which belongs to the maximum depth combined overhangs and side-fins, provides a 55% reduction from the base case, while the deepest overhang and side-fin provides 41.1% and 18.6% reductions respectively, which indicates that overhangs are more effective.

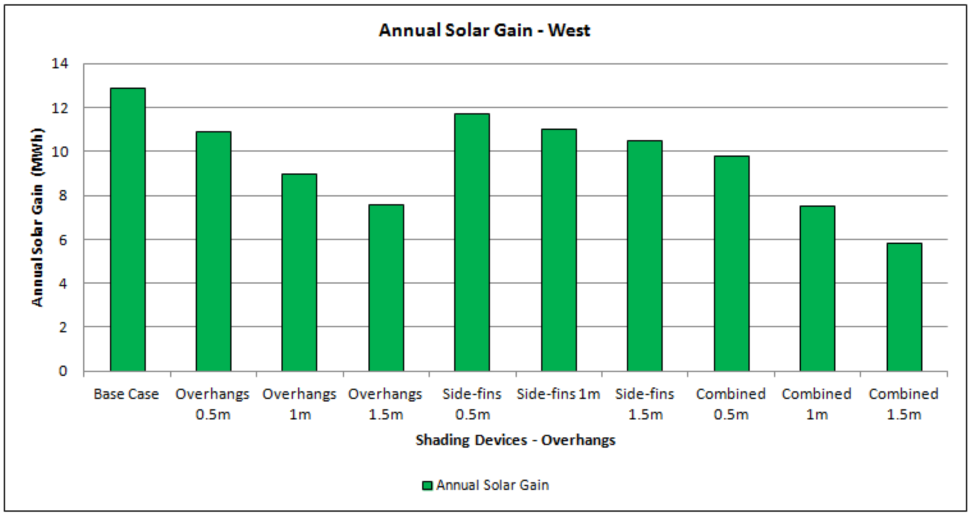


Figure 5.10: The annual solar gain of different shading device cases on west oriented façades

The base case annual solar gain is 12.2 MWh, while it’s daily peak solar gain determined for summer and winter seasons is 7.7 MWh and 6.5 MWh respectively, which is considered a relatively large difference in value

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 15.5%. Meanwhile, increasing the depth to 1m provides a further reduction of 6% only from the 0.5m depth, while a further increase in the depth to 1.5m provides a 4.5% reduction from the 1m case. Figure 5.11 illustrates the profile of overhangs performance in summer and winter where summer and winter profiles seem to be similar in attitude in which most of the solar gain received to the façade lies from mid-day (12 pm) to the late afternoon (6 pm), however, the profiles show a bit higher solar gain amounts in summer than in winter.

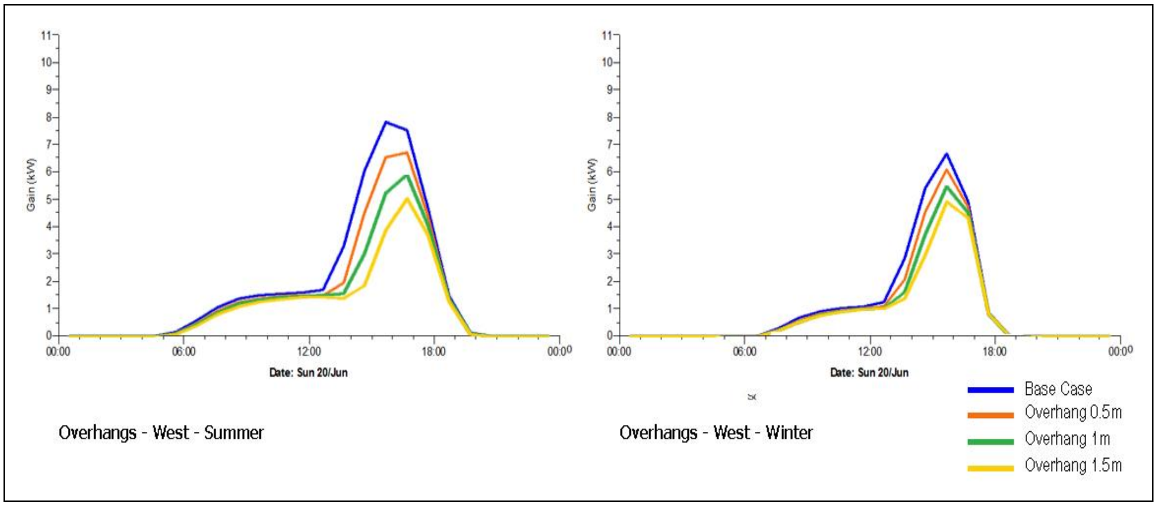


Figure 5.11: A graph showing the solar gain profile of west orientation overhangs in summer and winter

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), solar gain reduction between the base case and the 0.5m depths turns out to be 9.3% (same as the overhang 0.5m depth). Meanwhile, increasing the depth to 1m provides a reduction of 6% from the 0.5m depth, while a further increase in the depth to 1.5m provides a further reduction of 4.5% from the 1m case. Figure 5.12 illustrates the profile of side-fins performance in summer and winter, where summer and winter profiles seem to be similar in attitude. Most of the solar gain received to the façade lies from mid-day (12 pm) to the late afternoon (6 pm), however, the profiles show slightly higher solar gain amounts in summer due to the solar altitude. In addition, increasing the depth of side-fins is more effective in winter in terms of annual solar gains.

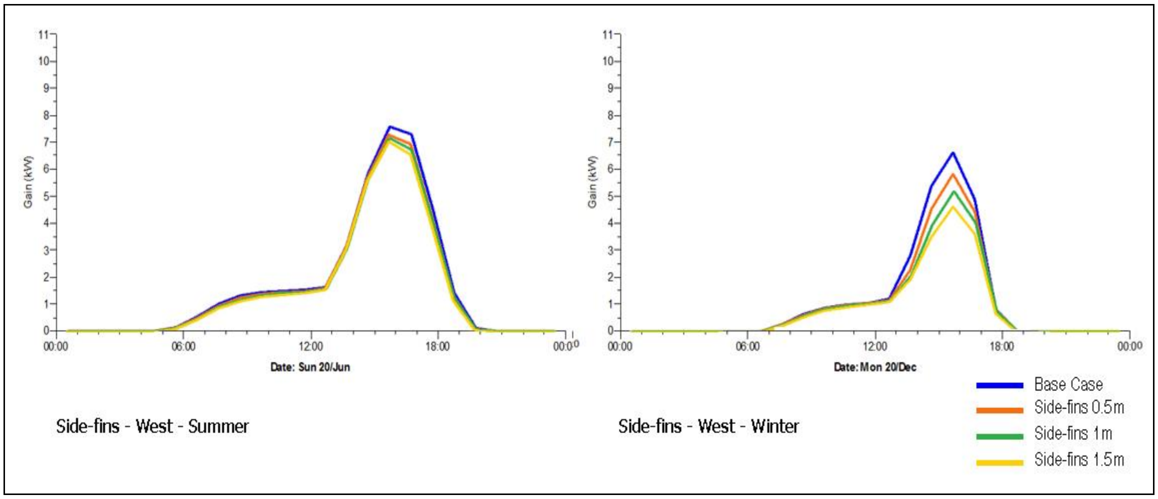


Figure 5.12: A graph showing the solar gain profile of west orientation side-fins in summer and winter

As for combined overhangs and side-fins, when compared according to their different depths (0.5m, 1m and 1.5m), the results obtained indicates a solar gain reduction of 24% between the base case and the 0.5m depths. Meanwhile, increasing the depth to 1m provides a further reduction of 23.5% from the 0.5m depth, further more, increasing the depth to 1.5m provide a reduction of 22.7% from the 1m case.

Comparing North and South Orientations

When comparing the annual solar gain behaviors on the north and south oriented façades, the ultimate solar gain reductions in comparison with the base case as shown in Figure 5.13 are 26.9% and 55% for the combined, 17.3% and 14.1% for the overhangs and 13.5% and 18.6% for the north and south façades respectively. In addition, north and south façades have equal values in summer; however, the winter peak solar gain for the south oriented façades exceeds the north façade by 88% of its value.

Comparing East and West Orientations

When comparing the annual solar gain behaviors on the east and west oriented façades, the ultimate solar gain reductions in comparison with the base case as shown in Figure 5.14 are 44.9% and 55% for the combined, 10.2% and 14.1% for the overhangs and 13.6% and 18.6% for the east and west façades respectively. In addition, east and west façades have equal values in summer; however, the winter peak solar gain for the west oriented façades exceeds the east façade by 9.23% of its value.

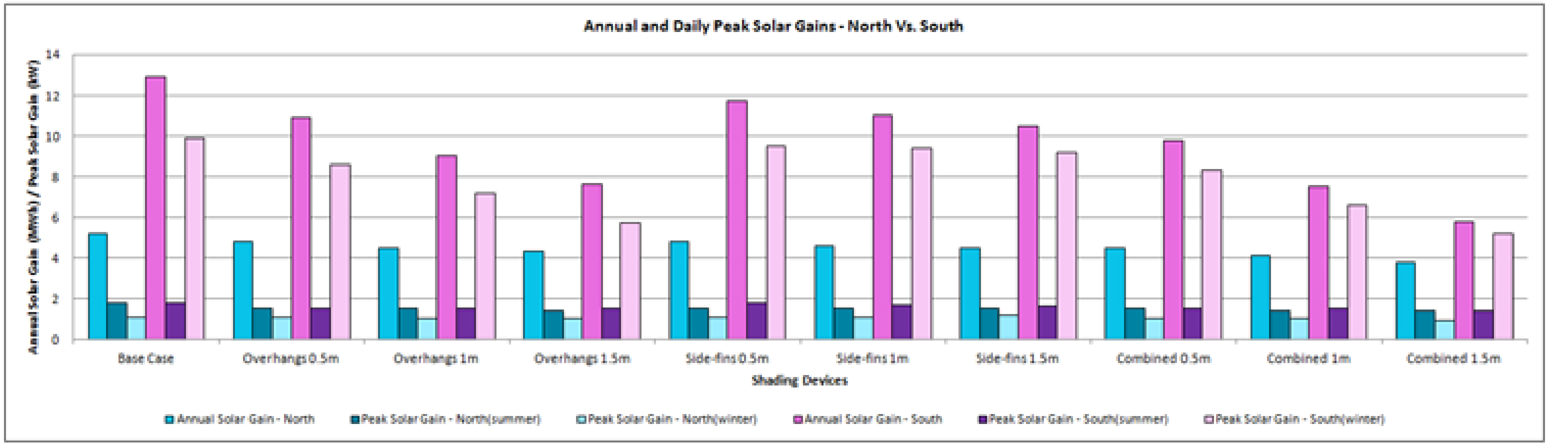


Figure 5.13: A chart comparing north and south orientations annual and daily peak solar gain.

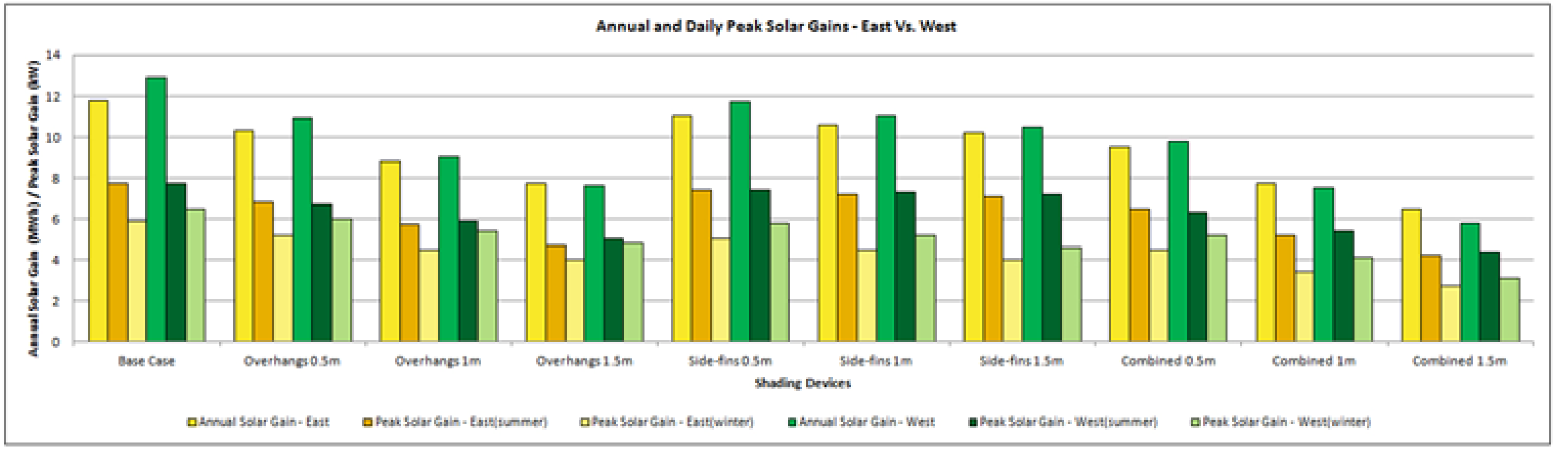


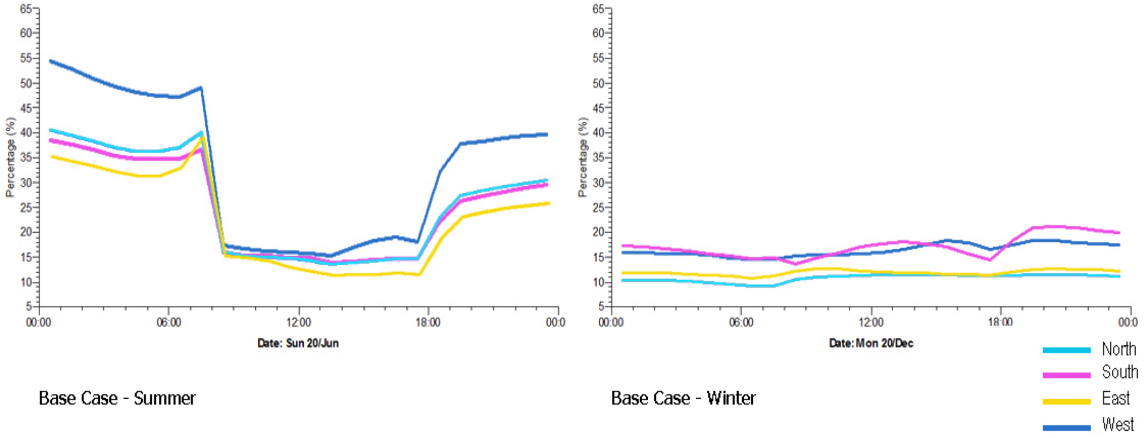
Figure 5.14: A chart comparing east and west orientations annual and daily peak solar gain.

B. Percentage of People Dissatisfied

Base Case

As for the percentage of people dissatisfied concerning the base case, Figure 5.15 compares the summer and winter profile and clarified that in general, the HVAC system operating during the summer remarkably contribute to the thermal comfort of occupants since the temperature outside the space is extremely hot and humid.

In the north orientated façades, Figure 5.15 shows that the PPD is 21% in summer and 12% in winter, while, in case of the south façades, PPD is 20% in summer and 19% in winter, which clearly shows that there is almost no difference in the thermal comfort perception for occupants. East and west orientations are almost similar in performance, since the PPD is 27% and 26% during summer and 14% and 14% in winter respectively. Meanwhile, the north orientation tends to achieve the highest reduction in PPD between the summer and winter due to the small amount of solar radiation falling on the façade in winter.


Base Case - Summer

Base Case - Winter

Figure 5.15: A graph showing the PPD profile of the base case in all orientations in summer and winter

Overhangs (eg. 1m depth)

In the north orientated façades, PPD is 20% in summer and 11% in winter, while, in case of the south façades, PPD is 18% in summer and 16% in winter, which clearly shows that there is almost no difference in the thermal comfort perception for occupants. East and west orientations are almost similar in performance, since the PPD is 23% and 24% during summer and 13% and 13% in winter respectively. Meanwhile, north, east and west orientations tend to maintain the same range of PPD between the summer and winter, however, the south oriented façades report a small improvement in PPD between summer and winter as illustrated in Figure 5.16.

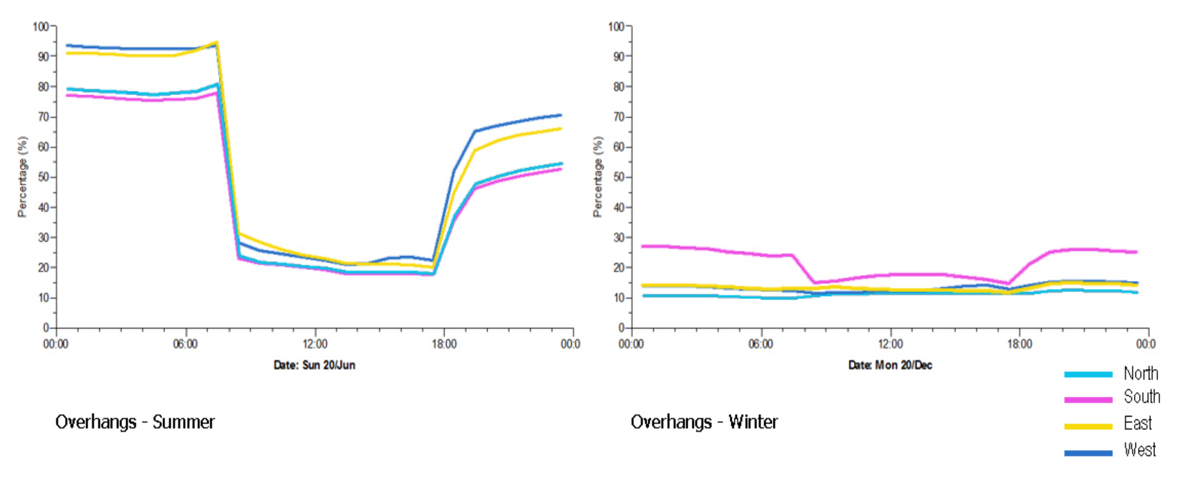


Figure 5.16: A graph showing the PPD profile of overhangs 1m in all orientations in summer and winter

Side-fins (eg. 1m depth)

In the north orientated façades, PPD is 20% in summer and 11% in winter, while, in case of the south façades, PPD is 20% in summer and 16% in winter, which clearly shows that there is almost no difference in the thermal comfort perception for occupants. East and West orientations are almost similar in performance, since the PPD is 26% and 25% during summer and 13% and 13% in winter respectively. Refer to Figure 5.17.

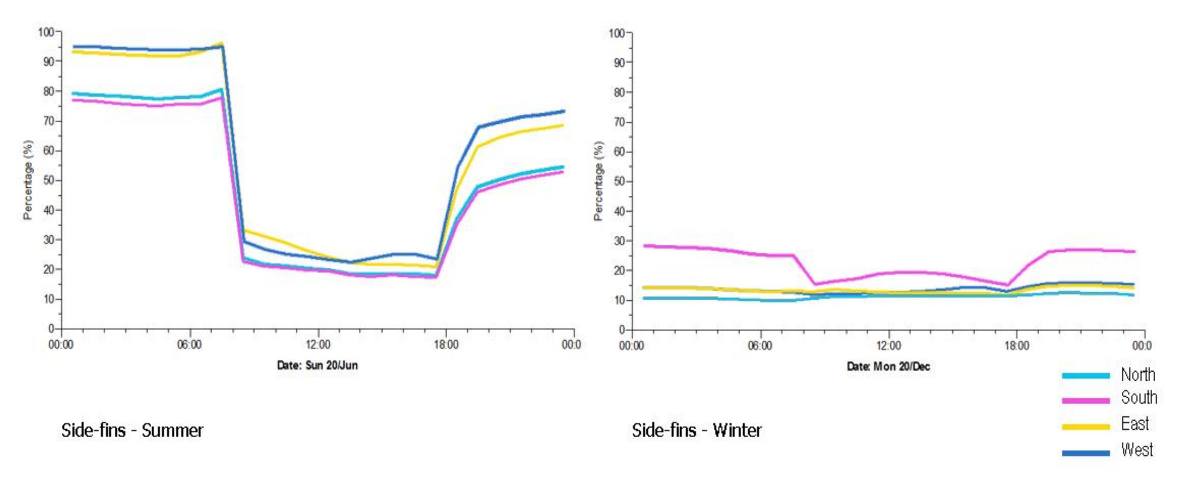


Figure 5.17: A graph showing the PPD profile of side-fins 1m in all orientations in summer and winter

Combined (eg. 1m depth)

As shown in Figure 5.18, in the north orientated façades, PPD is 20% in summer and 10% in winter, while, in case of the south façades, PPD is 20% in summer and 15% in winter, which clearly shows that there is almost no difference in the thermal comfort perception for occupants. East and west orientations are almost similar in performance, since the PPD is 24% and 25% during summer and 12% and 13% in winter respectively.

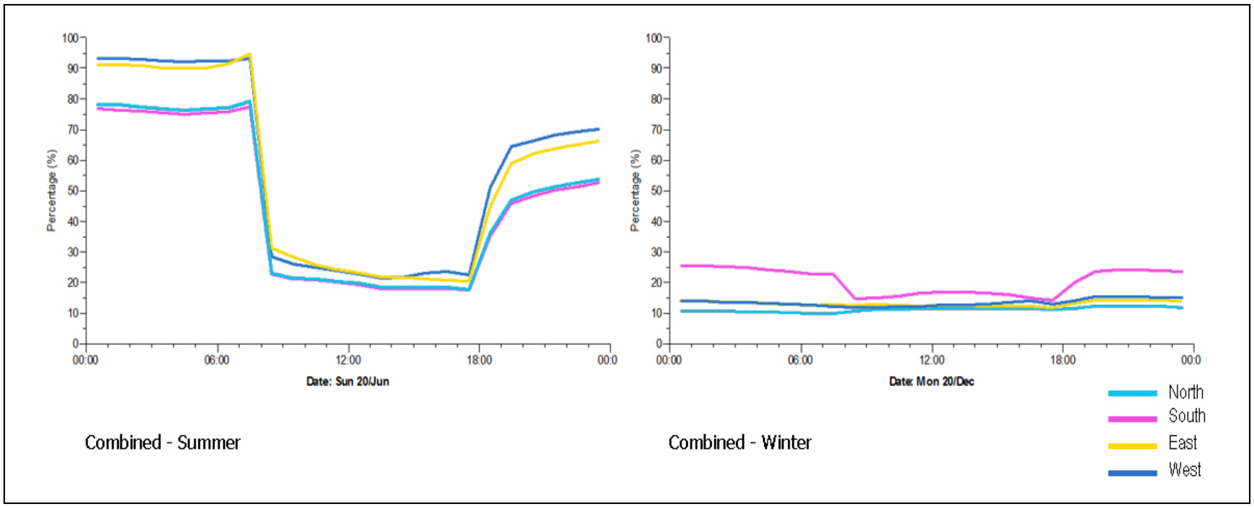


Figure 5.18: A graph showing the PPD profile of combined 1m in all orientations in summer and winter

Comparing different orientations

When comparing different orientations in summer, in the north there is almost no difference resulting from the integration of either overhangs, side-fins or both as shown in Figure 5.19. Meanwhile, integrating overhangs seems to be effective in the south direction, which is shown in the difference in PPD, while, side-fins do not contribute much to the PPD. In the east oriented façades, overhangs contribute to PPD reduction as well as the combined, however, side-fins are less effective. In the west oriented façades, overhangs contribute more than side-fins in the PPD reduction, while, combining overhangs and side-fins achieves similar results to that obtained by integrating only side-fins.

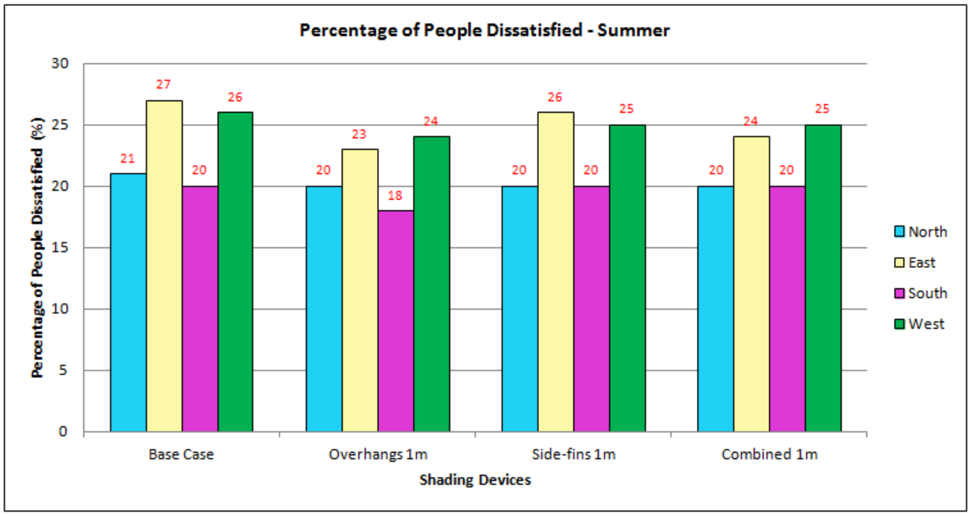


Figure 5.19: A chart illustrating the PPD of the different cases in all orientations in summer

When comparing different orientations in winter as shown in Figure 5.20, north oriented façades maintain a very slight reduction in PPD resulting from the integration of either overhangs, side-fins or both, while, in case of the south oriented façades, integrating overhangs seems to be more effective than side-fins. In the east orientation, overhangs contribute to PPD reduction as well as the combined, while; side-fins are less effective. In the west orientation overhangs and side-fins seems to achieve the same results in terms of PPD reduction.

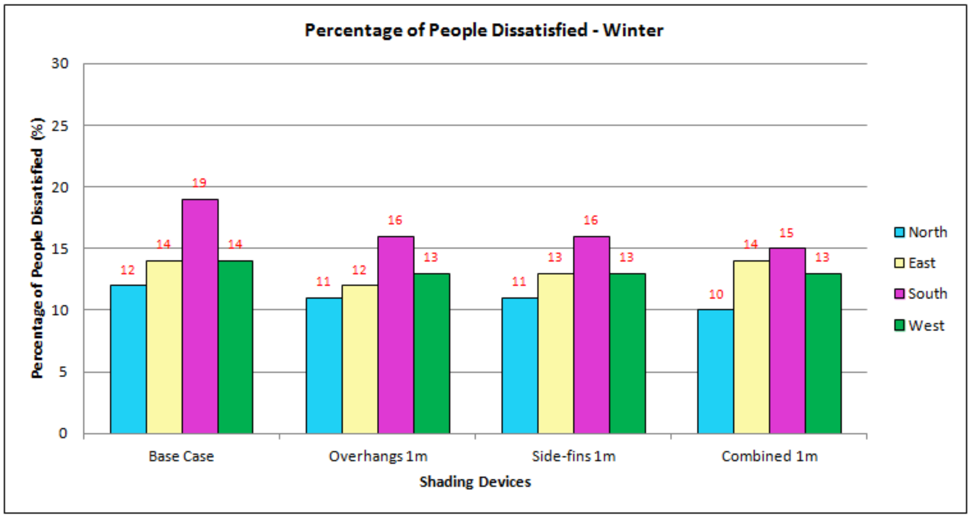


Figure 5.20: A chart illustrating the PPD of the different cases in all orientations in winter

Comparing North and South Orientations

When comparing north and south orientations in terms of PPD as shown in Figure 5.21, it is concluded that in summer, north and south orientations seem to have almost the same PPD. While, in winter the north orientation seems to have an acceptable PPD, while, the south orientation maintains a high PPD rate and at the same time, integrating shading devices significantly contribute to the reduction of occupant's dissatisfaction.

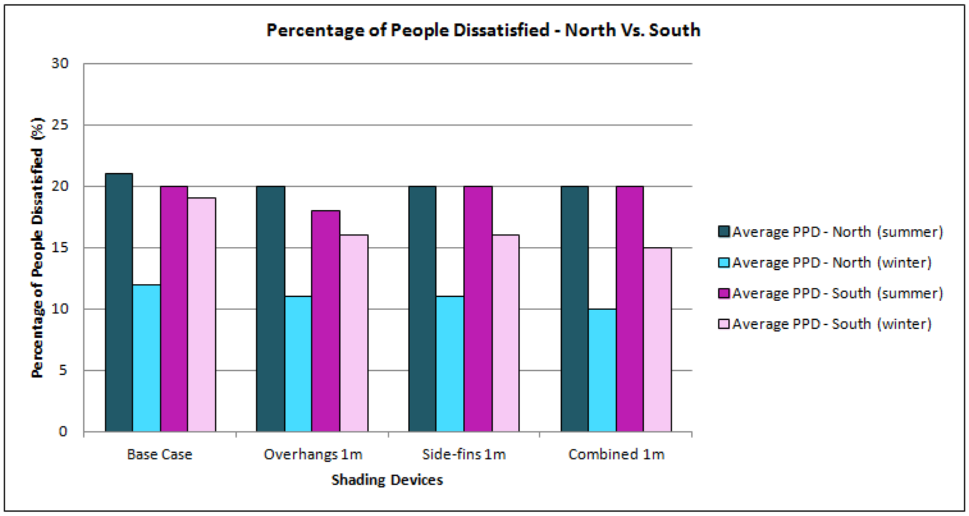


Figure 5.21: A chart comparing the PPD of North and South orientations in winter and summer

Comparing East and West Orientations

When comparing east and west orientations in terms of PPD as shown in Figure 5.22, it is concluded that in summer, east and west orientations seem to have almost the same PPD. While, in winter, the east orientation seems to have an acceptable PPD, meanwhile, west orientation maintains a high PPD rate and at the same time integrating shading devices significantly contribute to the reduction of occupant's dissatisfaction.

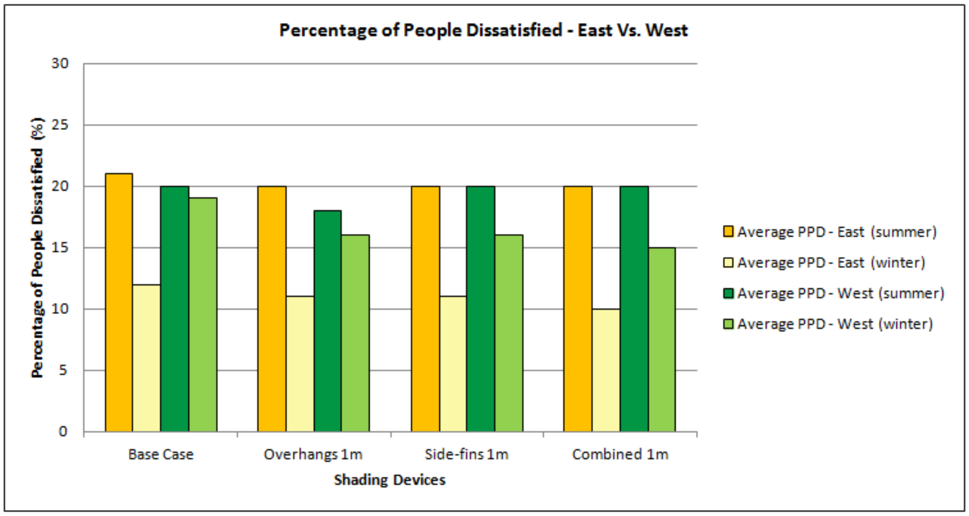


Figure 5.22: A chart comparing the PPD of east and west orientations in winter and summer

5.2.2 Visual Comfort

A. Average Illuminance

The illuminance on each orientation and case was analyzed by means of charts as an hourly illuminance table. The table contains the months of the year on the vertical axis and the daily hours on the horizontal axis, the shadows generated illustrate the percentage of sunlight falling on this façade throughout the year, in addition to the intensity of sun light, expressed in a percentage form.

North Orientation

The average illuminance on the north oriented façade demonstrates the large difference between illuminance levels in summer and in winter. Even though, there is fairly any illuminance reduction occurring when integrating all the shading devices as its almost equal throughout the whole year as shown in Figure 5.23.

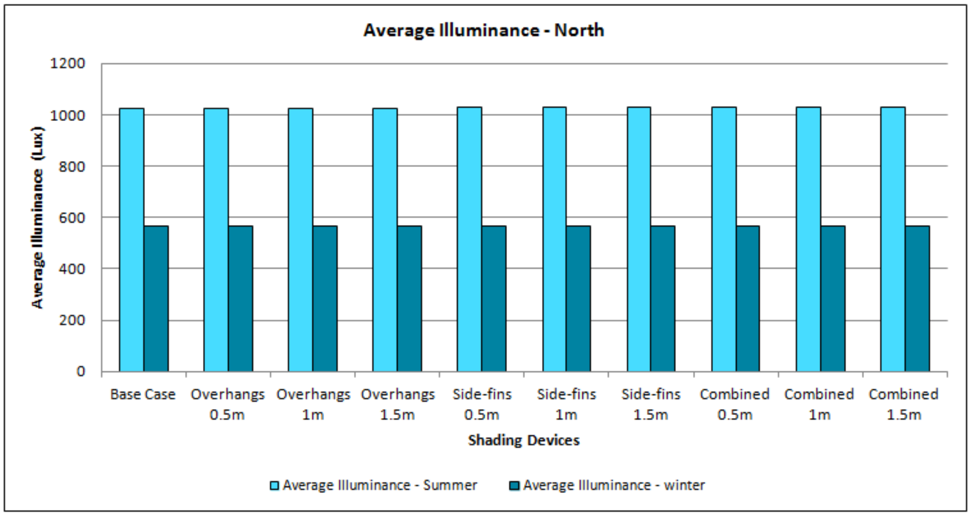


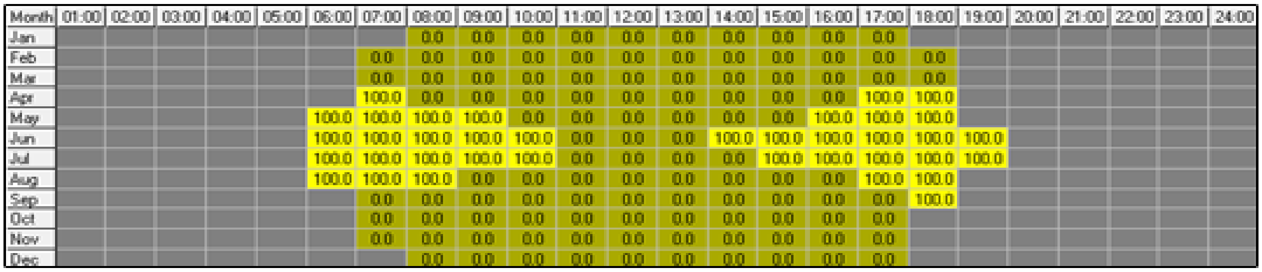
Figure 5.23: A chart showing the average illuminance of all cases on north oriented façades in summer and winter

In general, north façades are completely shaded the whole day in winter, while, in summer they receive sunlight among 78% of the sunny hours of the day distributed between the periods from 6am to 10am and from 2pm to 7pm, which is different in intensity depending on the shading device and its depth.

Base case

Table 5.1 shows that the illuminance intensity for the base case is 100% in summer and 0% in winter, which means that it is already completely shaded. Meanwhile, Figure 5.24 shows the difference between illuminance levels for the base case in summer and in winter, which shows how the first row workstations are more illuminance in summer represented by the red false color, which causes discomfort glare.

Table 5.3: Base case hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0						
May						100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0						
Jun						100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0					
Jul						100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0					
Aug						100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

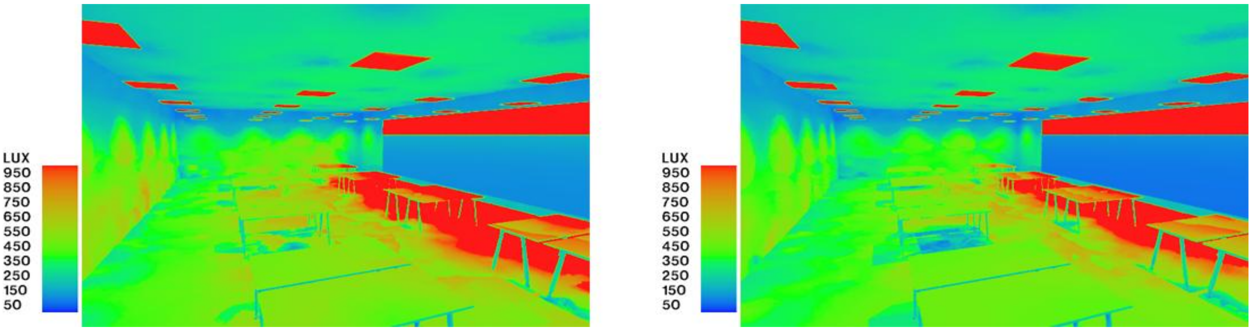
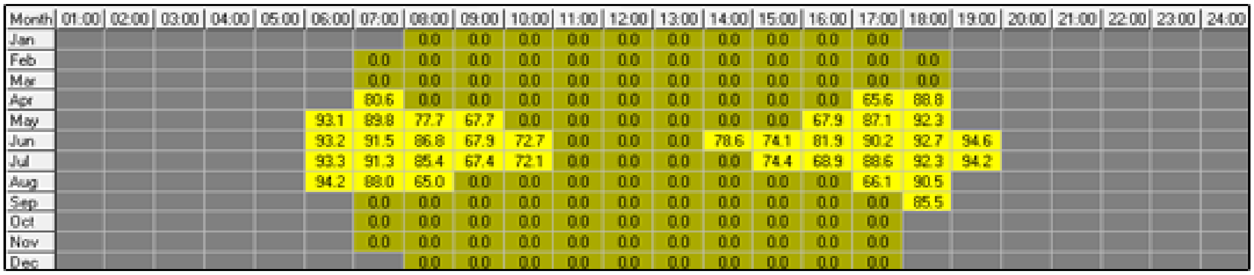


Figure 5.24: Left: North façade false colors lux levels in summer (20th June, 12:00pm), Right: North façade false colors lux levels in winter (20th December, 12:00pm) – Base Case

Overhangs

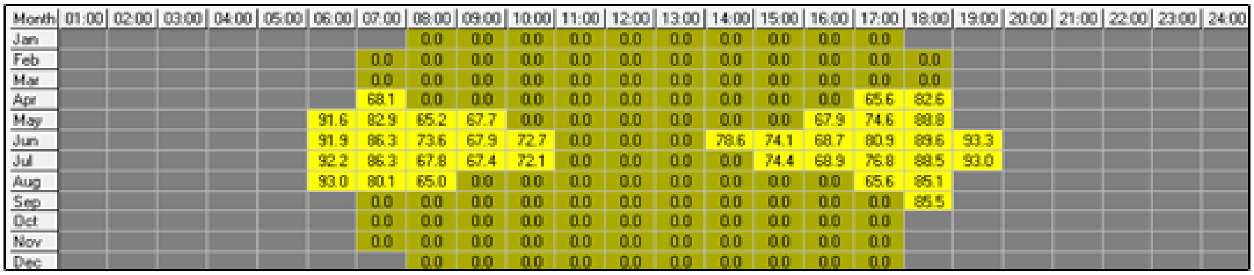
As for overhangs 0.5m depth, Table 5.2 shows that the illuminance intensity is 83% of the base case in summer. As for overhangs 1m depth, Table 5.3 shows that the illuminance intensity is 79% of the base case in summer, which has decreased with a rate of 4.8% from the 0.5m depth. As for overhangs 1.5m depth, Table 5.4 shows that the illuminance intensity is 76% of the base case in summer, which has decreased with a rate of 3.8% from the 1m depth. Meanwhile, Figure 5.25 explains in false color the illuminance levels resulting from integrating overhangs to the north façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.4: Overhangs (0.5m) hourly percentage of illuminance on the north façade



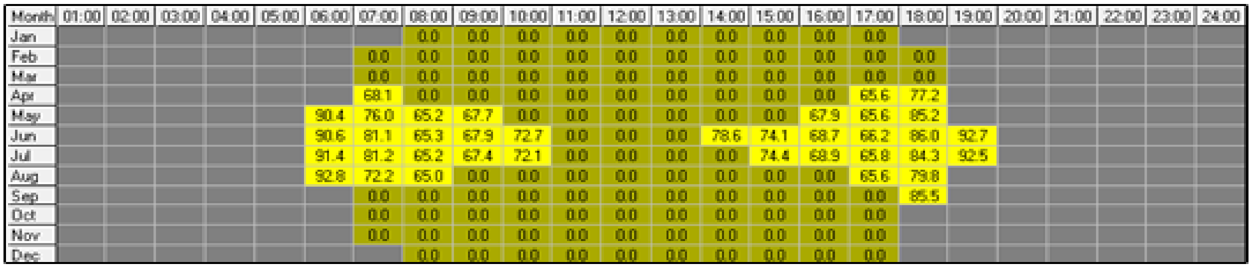
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							80.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.6	88.8						
May						93.1	89.8	77.7	67.7	0.0	0.0	0.0	0.0	0.0	0.0	67.9	87.1	92.3						
Jun						93.2	91.5	86.8	67.9	72.7	0.0	0.0	0.0	78.6	74.1	81.9	90.2	92.7	94.6					
Jul						93.3	91.3	85.4	67.4	72.1	0.0	0.0	0.0	0.0	74.4	68.9	88.6	92.3	94.2					
Aug						94.2	88.0	65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.1	90.5						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.5						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.5: Overhangs (1m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							68.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.6	82.6						
May						91.6	82.9	65.2	67.7	0.0	0.0	0.0	0.0	0.0	0.0	67.9	74.6	88.8						
Jun						91.9	86.3	73.6	67.9	72.7	0.0	0.0	0.0	78.6	74.1	68.7	80.9	89.6	93.3					
Jul						92.2	86.3	67.8	67.4	72.1	0.0	0.0	0.0	0.0	74.4	68.9	76.8	88.5	93.0					
Aug						93.0	80.1	65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.6	85.1						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.5						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.6: Overhangs (1.5m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							68.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.6	77.2						
May						90.4	76.0	65.2	67.7	0.0	0.0	0.0	0.0	0.0	0.0	67.9	65.6	85.2						
Jun						90.6	81.1	65.3	67.9	72.7	0.0	0.0	0.0	78.6	74.1	68.7	66.2	86.0	92.7					
Jul						91.4	81.2	65.2	67.4	72.1	0.0	0.0	0.0	0.0	74.4	68.9	65.8	84.3	92.5					
Aug						92.8	72.2	65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.6	79.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.5						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

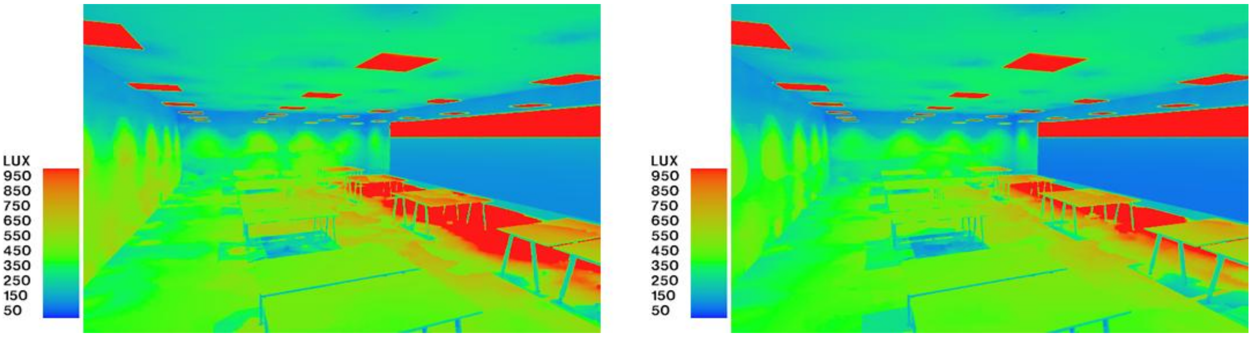
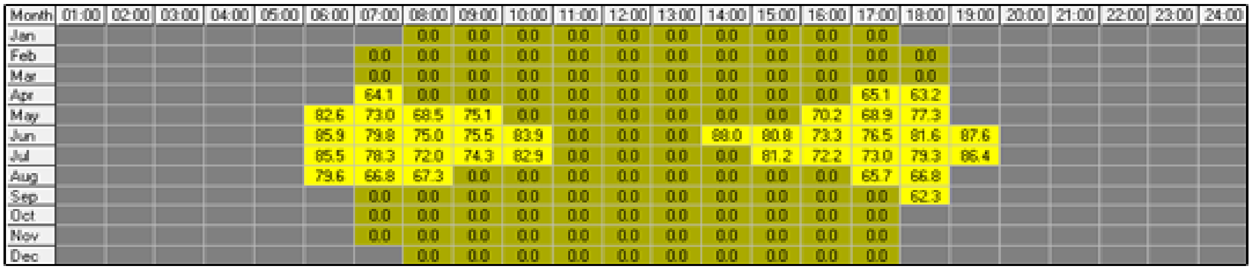


Figure 5.25: Left: North façade false colors lux levels in summer (20th June, 12:00pm), Right: North façade false colors lux levels in winter(20th December, 12:00pm) - Overhangs (Example: 1m)

Side-fins

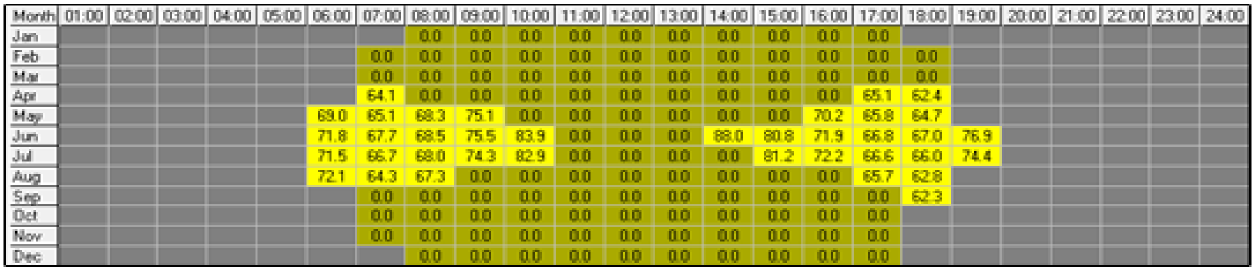
As for side-fins 0.5m depth, Table 5.5 shows that the illuminance intensity is 80% of the base case in summer. As for side-fins 1m depth, Table 5.6 shows that the illuminance intensity is 74.4% of the base case in summer, which has decreased with a rate of 7% from the 0.5m depth. As for side-fins 1.5m depth, Table 5.7 shows that the illuminance intensity is 72.9% of the base case in summer which has decreased with a rate of 2% from the 1m depth. Meanwhile, Figure 5.26 explains in false color the illuminance levels resulting from integrating side-fins to the north façade, which appears to be less effective, compared to overhangs.

Table 5.7: Side-fins (0.5m) hourly percentage of illuminance on the north façade



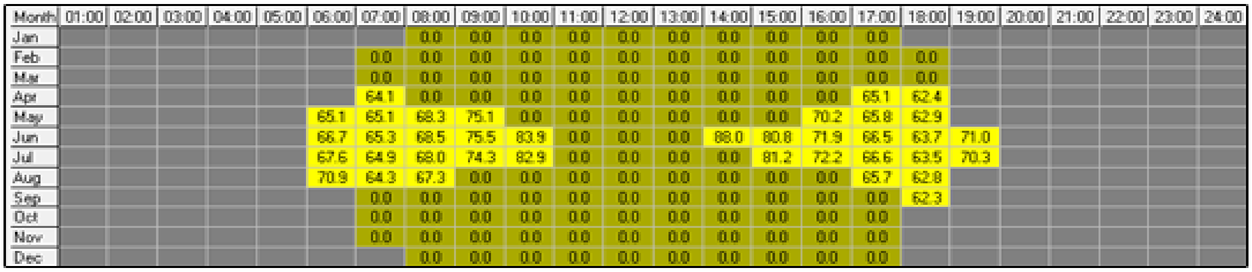
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							64.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.1	63.2						
May						82.6	73.0	68.5	75.1	0.0	0.0	0.0	0.0	0.0	0.0	70.2	68.9	77.3						
Jun						85.9	79.8	75.0	75.5	83.9	0.0	0.0	0.0	88.0	80.8	73.3	76.5	81.6	87.6					
Jul						85.5	78.3	72.0	74.3	82.9	0.0	0.0	0.0	0.0	81.2	72.2	73.0	79.3	86.4					
Aug						79.6	66.8	67.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.7	66.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.3						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.8: Side-fins (1m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							64.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.1	62.4						
May						69.0	65.1	68.3	75.1	0.0	0.0	0.0	0.0	0.0	0.0	70.2	65.8	64.7						
Jun						71.8	67.7	68.5	75.5	83.9	0.0	0.0	0.0	88.0	80.8	71.9	66.8	67.0	76.9					
Jul						71.5	66.7	68.0	74.3	82.9	0.0	0.0	0.0	0.0	81.2	72.2	66.6	66.0	74.4					
Aug						72.1	64.3	67.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.7	62.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.3						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.9: Side-fins (1.5m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							64.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.1	62.4						
May						65.1	65.1	68.3	75.1	0.0	0.0	0.0	0.0	0.0	0.0	70.2	65.8	62.9						
Jun						66.7	65.3	68.5	75.5	83.9	0.0	0.0	0.0	88.0	80.8	71.9	66.5	63.7	71.0					
Jul						67.6	64.9	68.0	74.3	82.9	0.0	0.0	0.0	0.0	81.2	72.2	66.6	63.5	70.3					
Aug						70.9	64.3	67.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.7	62.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.3						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

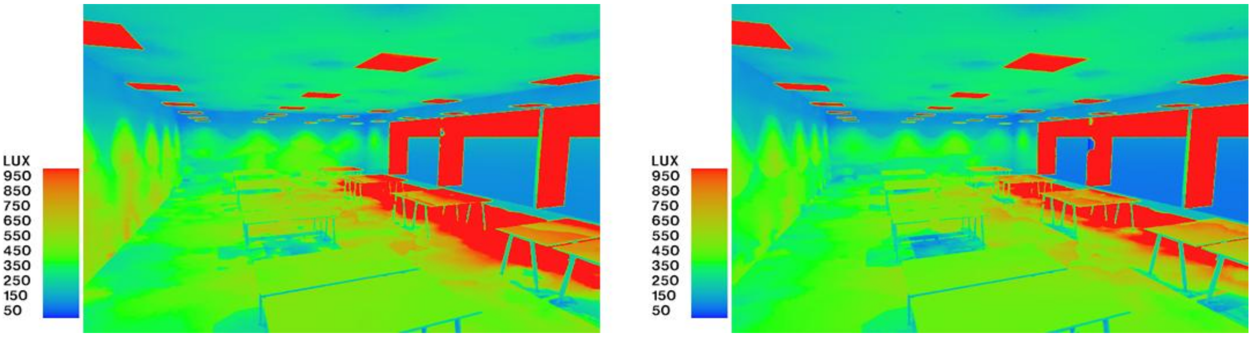
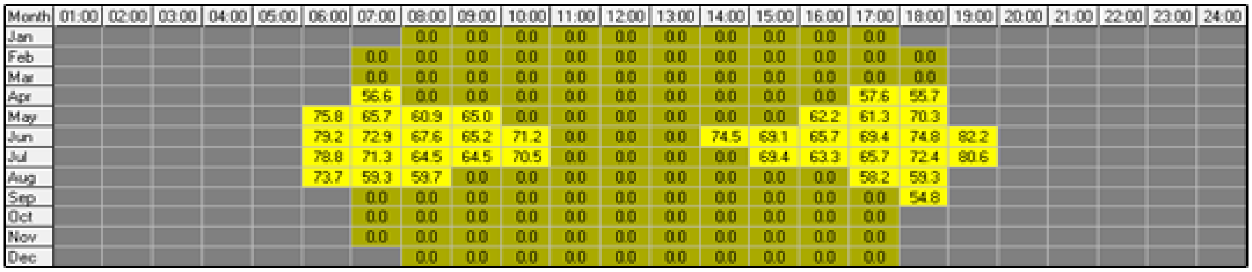


Figure 5.26: Left: North façade false colors lux levels in summer (20th June, 12:00pm), Right: North façade false colors lux levels in winter(20th December, 12:00pm) – Side-fins(Example: 1m)

Combined

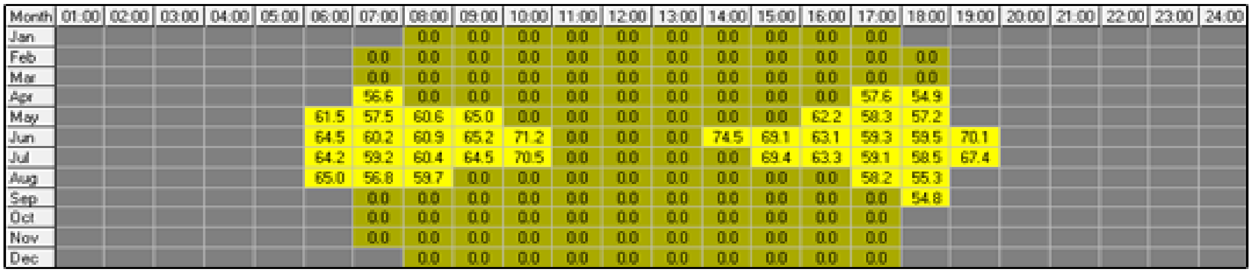
As for combined 0.5m depth, Table 5.8 shows that the illuminance intensity is 72% of the base case in summer. As for combined 1m depth, Table 5.9 shows that the illuminance intensity is 65.2% of the base case in summer, which has decreased with a rate of 9.4% from the 0.5m depth. As for combined 1.5m depth, Table 5.10 shows that the illuminance intensity is 63.6% of the base case in summer, which has decreased with a rate of 2.5% from the 1m depth. Meanwhile, Figure 5.27 explains in false color the illuminance levels resulting from integrating combined overhangs and side-fins to the north façade, which logically seems to be the most effective in terms of the effect of shading compared to either overhangs or side-fins alone.

Table 5.10: Combined (0.5m) hourly percentage of illuminance on the north façade



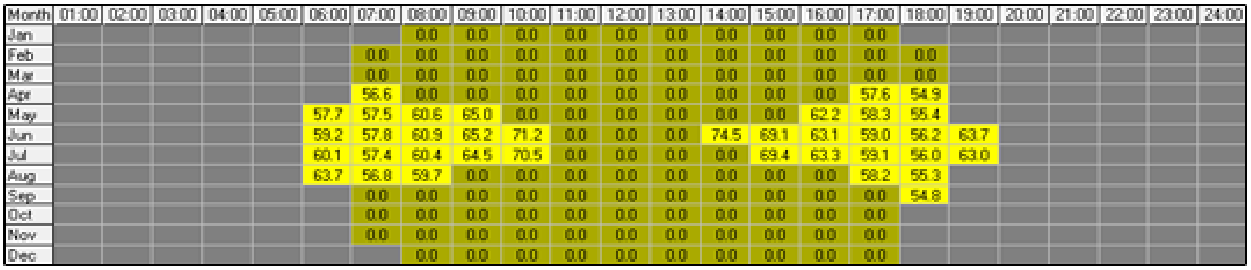
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							56.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.6	55.7						
May						75.8	65.7	60.9	65.0	0.0	0.0	0.0	0.0	0.0	0.0	62.2	61.3	70.3						
Jun						79.2	72.9	67.6	65.2	71.2	0.0	0.0	0.0	74.5	69.1	65.7	69.4	74.8	82.2					
Jul						78.8	71.3	64.5	64.5	70.5	0.0	0.0	0.0	0.0	69.4	63.3	65.7	72.4	80.6					
Aug						73.7	59.3	59.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.2	59.3						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.8						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.11: Combined (1m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							56.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.6	54.9						
May						61.5	57.5	60.6	65.0	0.0	0.0	0.0	0.0	0.0	0.0	62.2	58.3	57.2						
Jun						64.5	60.2	60.9	65.2	71.2	0.0	0.0	0.0	74.5	69.1	63.1	59.3	59.5	70.1					
Jul						64.2	59.2	60.4	64.5	70.5	0.0	0.0	0.0	0.0	69.4	63.3	59.1	58.5	67.4					
Aug						65.0	56.8	59.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.2	55.3						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.8						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

Table 5.12: Combined (1.5m) hourly percentage of illuminance on the north façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							56.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.6	54.9						
May						57.7	57.5	60.6	65.0	0.0	0.0	0.0	0.0	0.0	0.0	62.2	58.3	55.4						
Jun						59.2	57.8	60.9	65.2	71.2	0.0	0.0	0.0	74.5	69.1	63.1	59.0	56.2	63.7					
Jul						60.1	57.4	60.4	64.5	70.5	0.0	0.0	0.0	0.0	69.4	63.3	59.1	56.0	63.0					
Aug						63.7	56.8	59.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.2	55.3						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.8						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Dec								0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							

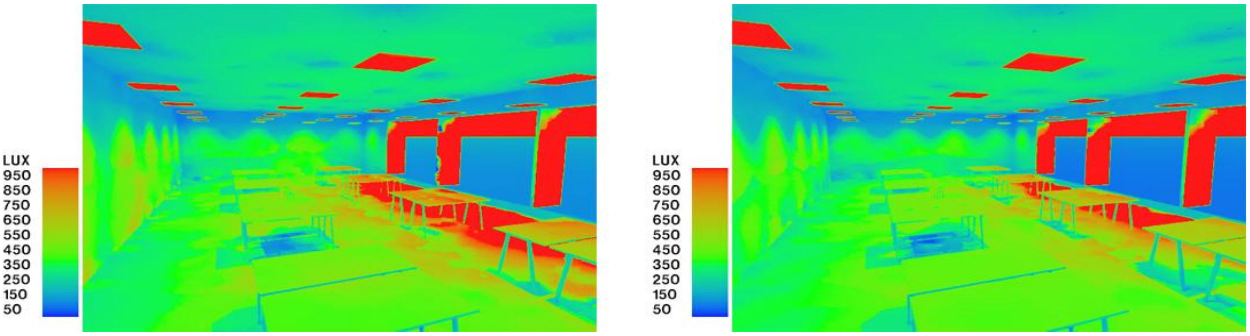


Figure 5.27: Left: North façade false colors lux levels in summer (20th June, 12:00pm), Right: North façade false colors lux levels in winter(20th December, 12:00pm) – Combined(Example: 1m)

South Orientation

The average illuminance on the south oriented façade demonstrates a very small difference between illuminance levels in summer and in winter. Even though, integrating different shading devices does not change the constant percentage relation between the illuminance levels in summer and winter as shown in Figure 5.28.

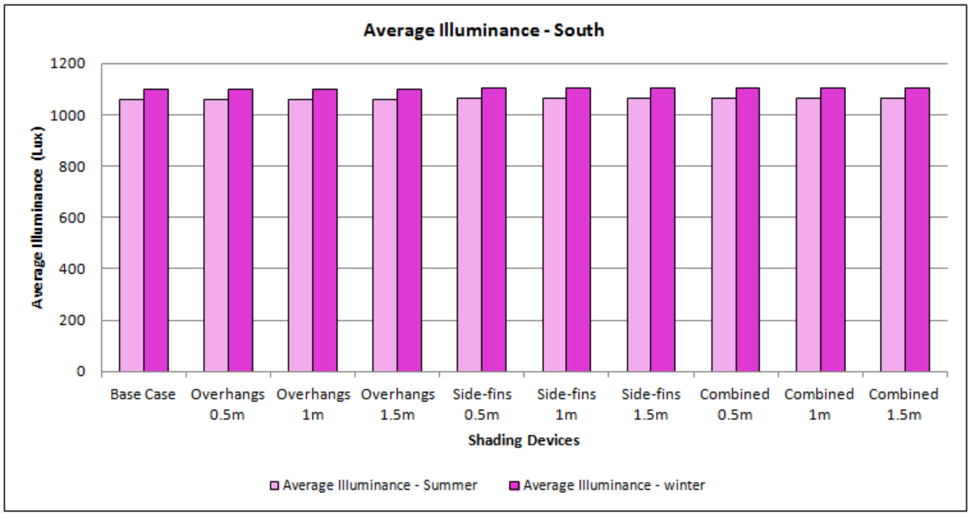


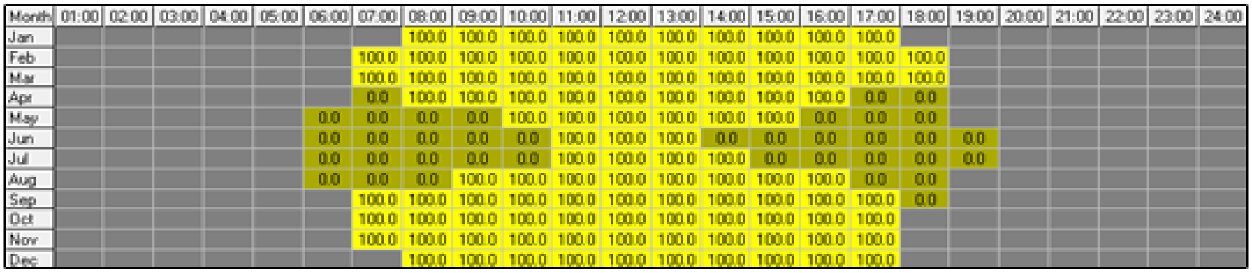
Figure 5.28: A chart showing the average illuminance of all cases on south oriented façades in summer and winter

In general, south façades are completely sunny the whole day in winter during the sunny hours of the day due to the sun position, while, in summer they receive sunlight among 22% of the sunny hours of the day distributed between the periods from 11am to 1, which is different in intensity depending on the shading device and its depth.

Base case

Table 5.11 shows that the illuminance intensity for the base case is 100% in summer as well as in winter. Meanwhile, Figure 5.29 shows the difference between illuminance levels for the base case in summer and in winter, which shows how the first row workstations are more illuminance in summer represented by the red false color, which causes discomfort glare.

Table 5.13: Base case hourly percentage of illuminance on the south façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Feb							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0						
Mar							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0						
Apr							0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0						
May						0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0						
Sep							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0						
Oct							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Nov							100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							
Dec								100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0							

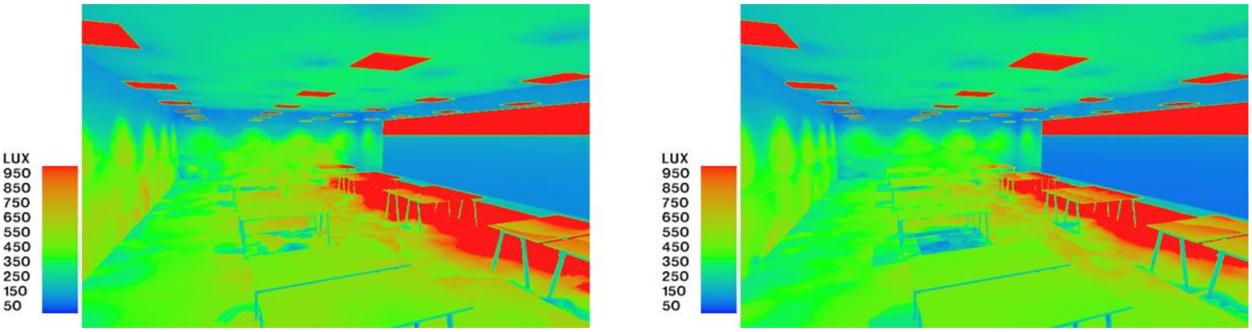
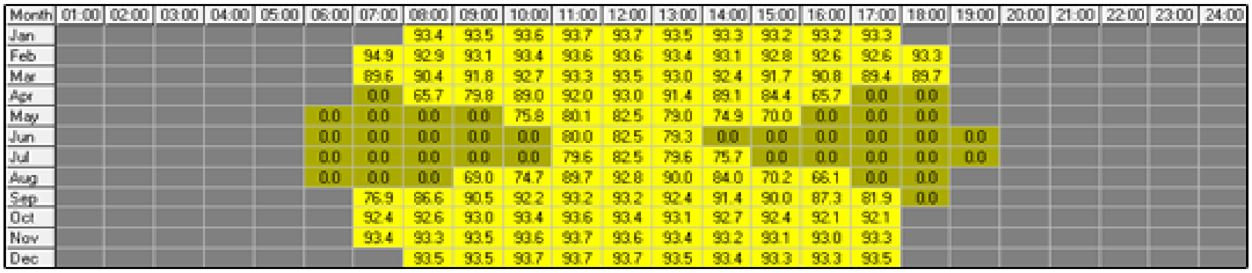


Figure 5.29: Left: South façade false colors lux levels in summer (20th June, 12:00pm), Right: South façade false colors lux levels in winter(20th December, 12:00pm) – Base Case

Overhangs

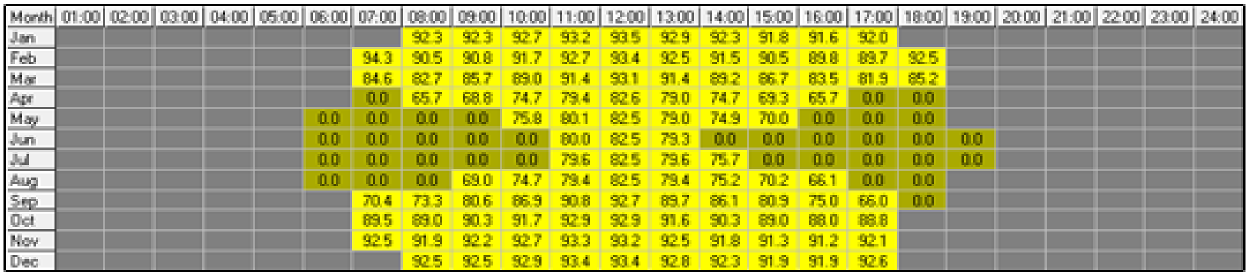
As for overhangs 0.5m depth, Table 5.12 shows that the illuminance intensity is 80.6% of the base case in summer, while, in winter the illuminance intensity is 93.5%. As for overhangs 1m depth, Table 5.13 shows that the illuminance intensity is 80.6% of the base case in summer which has decreased with a rate of 4.8% from the 0.5m depth, while, in winter the illuminance intensity is 92.6% ,which has been reduced by 1% from the 0.5m depth. As for overhangs 1.5m depth, Table 5.14 shows that the illuminance intensity is 80.6% of the base case in summer, which is equal in intensity to the 1m depth, while, in winter the illuminance intensity is 91.4% ,which has been reduced by 1.3% from the 1m depth. Meanwhile, Figure 5.30 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.14: Overhangs (0.5m) hourly percentage of illuminance on the south façade



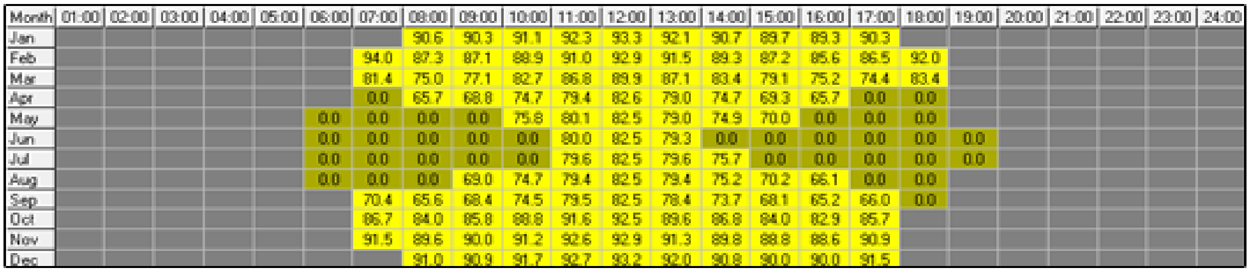
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								93.4	93.5	93.6	93.7	93.7	93.5	93.3	93.2	93.2	93.3							
Feb							94.9	92.9	93.1	93.4	93.6	93.6	93.4	93.1	92.8	92.6	92.6	93.3						
Mar							89.6	90.4	91.8	92.7	93.3	93.5	93.0	92.4	91.7	90.8	89.4	89.7						
Apr							0.0	65.7	79.8	89.0	92.0	93.0	91.4	89.1	84.4	65.7	0.0	0.0						
May						0.0	0.0	0.0	0.0	75.8	80.1	82.5	79.0	74.9	70.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	80.0	82.5	79.3	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	79.6	82.5	79.6	75.7	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	69.0	74.7	89.7	92.8	90.0	84.0	70.2	66.1	0.0	0.0						
Sep							76.9	86.6	90.5	92.2	93.2	93.2	92.4	91.4	90.0	87.3	81.9	0.0						
Oct							92.4	92.6	93.0	93.4	93.6	93.4	93.1	92.7	92.4	92.1	92.1							
Nov							93.4	93.3	93.5	93.6	93.7	93.6	93.4	93.2	93.1	93.0	93.3							
Dec								93.5	93.5	93.7	93.7	93.7	93.5	93.4	93.3	93.3	93.5							

Table 5.15: Overhangs (1m) hourly percentage of illuminance on the south façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								92.3	92.3	92.7	93.2	93.5	92.9	92.3	91.8	91.6	92.0							
Feb							94.3	90.5	90.8	91.7	92.7	93.4	92.5	91.5	90.5	89.8	89.7	92.5						
Mar							84.6	82.7	85.7	89.0	91.4	93.1	91.4	89.2	86.7	83.5	81.9	85.2						
Apr							0.0	65.7	68.8	74.7	79.4	82.6	79.0	74.7	69.3	65.7	0.0	0.0						
May						0.0	0.0	0.0	0.0	75.8	80.1	82.5	79.0	74.9	70.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	80.0	82.5	79.3	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	79.6	82.5	79.6	75.7	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	69.0	74.7	79.4	82.5	79.4	75.2	70.2	66.1	0.0	0.0						
Sep							70.4	73.3	80.6	86.9	90.8	92.7	89.7	86.1	80.9	75.0	66.0	0.0						
Oct							89.5	89.0	90.3	91.7	92.9	92.9	91.6	90.3	89.0	88.0	88.8							
Nov							92.5	91.9	92.2	92.7	93.3	93.2	92.5	91.8	91.3	91.2	92.1							
Dec								92.5	92.5	92.9	93.4	93.4	92.8	92.3	91.9	91.9	92.6							

Table 5.16: Overhangs (1.5m) hourly percentage of illuminance on the South façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								90.6	90.3	91.1	92.3	93.3	92.1	90.7	89.7	89.3	90.3							
Feb							94.0	87.3	87.1	88.9	91.0	92.9	91.5	89.3	87.2	85.6	86.5	92.0						
Mar							81.4	75.0	77.1	82.7	86.8	89.9	87.1	83.4	79.1	75.2	74.4	83.4						
Apr							0.0	65.7	68.8	74.7	79.4	82.6	79.0	74.7	69.3	65.7	0.0	0.0						
May						0.0	0.0	0.0	0.0	75.8	80.1	82.5	79.0	74.9	70.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	80.0	82.5	79.3	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	79.6	82.5	79.6	75.7	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	69.0	74.7	79.4	82.5	79.4	75.2	70.2	66.1	0.0	0.0						
Sep							70.4	65.6	68.4	74.5	79.5	82.5	78.4	73.7	68.1	65.2	66.0	0.0						
Oct							86.7	84.0	85.8	88.8	91.6	92.5	89.6	86.8	84.0	82.9	85.7							
Nov							91.5	89.6	90.0	91.2	92.6	92.9	91.3	89.8	88.8	88.6	90.9							
Dec								91.0	90.9	91.7	92.7	93.2	92.0	90.8	90.0	90.0	91.5							

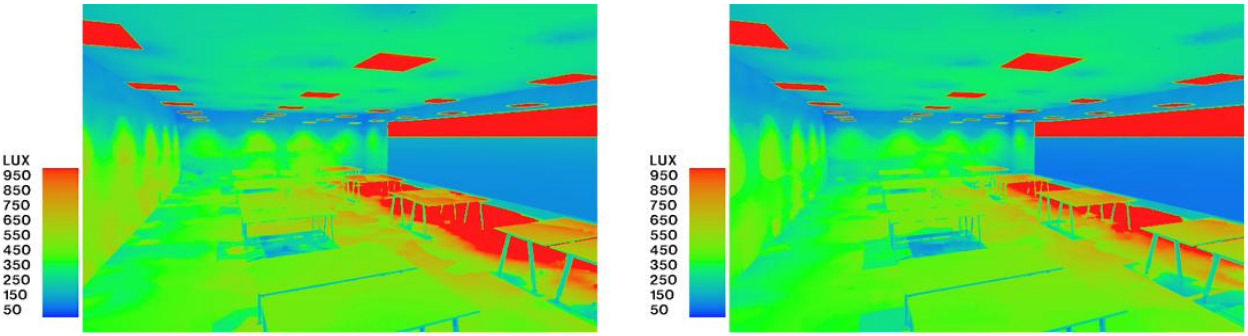


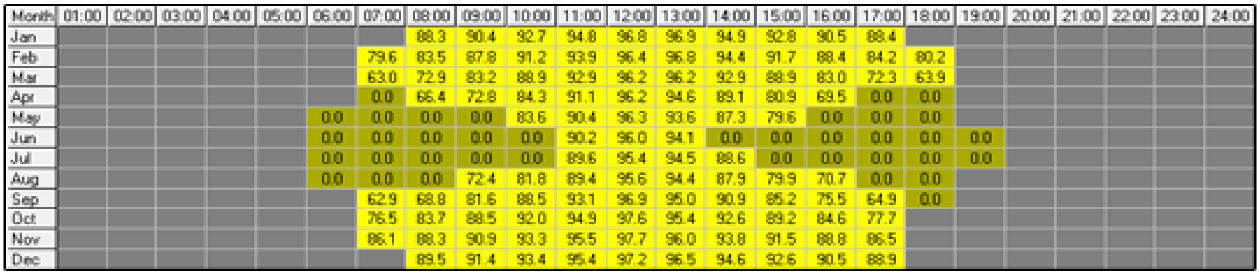
Figure 5.30: Left: South façade false colors lux levels in summer (20th June, 12:00pm), Right: South façade false colors lux levels in winter(20th December, 12:00pm) - Overhangs (Example: 1m)

Side-fins

As for side-fins 0.5m depth, Table 5.15 shows that the illuminance intensity is 93.4% of the base case in summer, while, in winter the illuminance intensity is 93%. As for side-fins 1m depth,

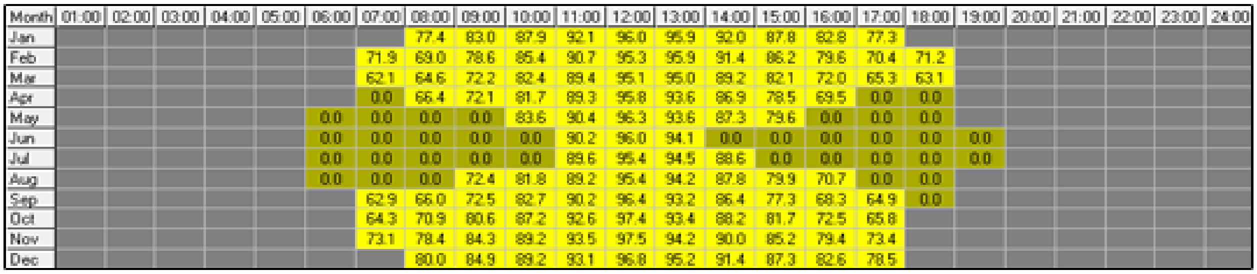
Table 5.16 shows that the illuminance intensity is 93% of the base case in summer which is equal in intensity to the 0.5m depth, while, in winter the illuminance intensity is 87.9% ,which has been reduced by 5.5% from the 0.5m depth. As for side-fins 1.5m depth, Table 5.17 shows that the illuminance intensity is 93.4% of the base case in summer which is equal in intensity to the 1m depth, while, in winter the illuminance intensity is 83.3% ,which has been reduced by 5.2% from the 1m depth. Meanwhile, Figure 5.31 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.17: Side-fins (0.5m) hourly percentage of illuminance on the south façade



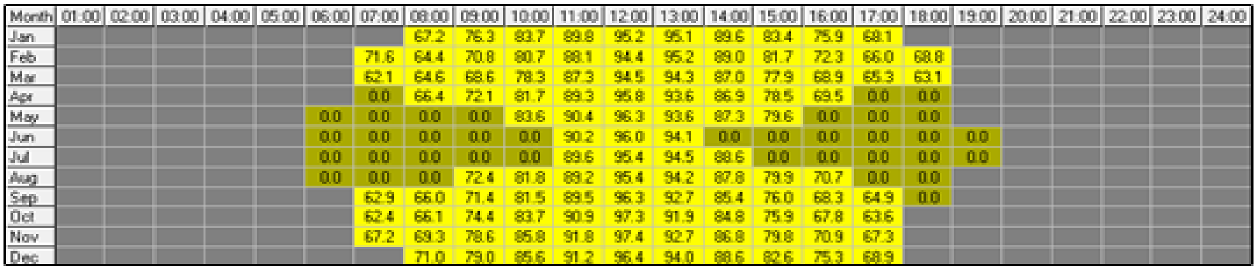
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								88.3	90.4	92.7	94.8	96.8	96.9	94.9	92.8	90.5	88.4							
Feb							79.6	83.5	87.8	91.2	93.9	96.4	96.8	94.4	91.7	88.4	84.2	80.2						
Mar							63.0	72.9	83.2	88.9	92.9	96.2	96.2	92.9	88.9	83.0	72.3	63.9						
Apr							0.0	66.4	72.8	84.3	91.1	96.2	94.6	89.1	80.9	69.5	0.0	0.0						
May						0.0	0.0	0.0	0.0	83.6	90.4	96.3	93.6	87.3	79.6	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	90.2	96.0	94.1	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	89.6	95.4	94.5	88.6	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	72.4	81.8	89.4	95.6	94.4	87.9	79.9	70.7	0.0	0.0						
Sep							62.9	68.8	81.6	88.5	93.1	96.9	95.0	90.9	85.2	75.5	64.9	0.0						
Oct							76.5	83.7	88.5	92.0	94.9	97.6	95.4	92.6	89.2	84.6	77.7							
Nov							86.1	88.3	90.9	93.3	95.5	97.7	96.0	93.8	91.5	88.8	86.5							
Dec								89.5	91.4	93.4	95.4	97.2	96.5	94.6	92.6	90.5	88.9							

Table 5.18: Side-fins (1m) hourly percentage of illuminance on the South façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								77.4	83.0	87.9	92.1	96.0	95.9	92.0	87.8	82.8	77.3							
Feb							71.9	69.0	78.6	85.4	90.7	95.3	95.9	91.4	86.2	79.6	70.4	71.2						
Mar							62.1	64.6	72.2	82.4	89.4	95.1	95.0	89.2	82.1	72.0	65.3	63.1						
Apr							0.0	66.4	72.1	81.7	89.3	95.8	93.6	86.9	78.5	69.5	0.0	0.0						
May						0.0	0.0	0.0	0.0	83.6	90.4	96.3	93.6	87.3	79.6	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	90.2	96.0	94.1	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	89.6	95.4	94.5	88.6	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	72.4	81.8	89.2	95.4	94.2	87.8	79.9	70.7	0.0	0.0						
Sep							62.9	66.0	72.5	82.7	90.2	96.4	93.2	86.4	77.3	68.3	64.9	0.0						
Oct							64.3	70.9	80.6	87.2	92.6	97.4	93.4	88.2	81.7	72.5	65.8							
Nov							73.1	78.4	84.3	89.2	93.5	97.5	94.2	90.0	85.2	79.4	73.4							
Dec								80.0	84.9	89.2	93.1	96.8	95.2	91.4	87.3	82.6	78.5							

Table 5.19: Side-fins (1.5m) hourly percentage of illuminance on the south façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								67.2	76.3	83.7	89.8	95.2	95.1	89.6	83.4	75.9	68.1							
Feb							71.6	64.4	70.8	80.7	88.1	94.4	95.2	89.0	81.7	72.3	66.0	68.8						
Mar							62.1	64.6	68.6	78.3	87.3	94.5	94.3	87.0	77.9	68.9	65.3	63.1						
Apr							0.0	66.4	72.1	81.7	89.3	95.8	93.6	86.9	78.5	69.5	0.0	0.0						
May						0.0	0.0	0.0	0.0	83.6	90.4	96.3	93.6	87.3	79.6	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	90.2	96.0	94.1	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	89.6	95.4	94.5	88.6	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	72.4	81.8	89.2	95.4	94.2	87.8	79.9	70.7	0.0	0.0						
Sep							62.9	66.0	71.4	81.5	89.5	96.3	92.7	85.4	76.0	68.3	64.9	0.0						
Oct							62.4	66.1	74.4	83.7	90.9	97.3	91.9	84.8	75.9	67.8	63.6							
Nov							67.2	69.3	78.6	85.8	91.8	97.4	92.7	86.8	79.8	70.9	67.3							
Dec								71.0	79.0	85.6	91.2	96.4	94.0	88.6	82.6	75.3	68.9							

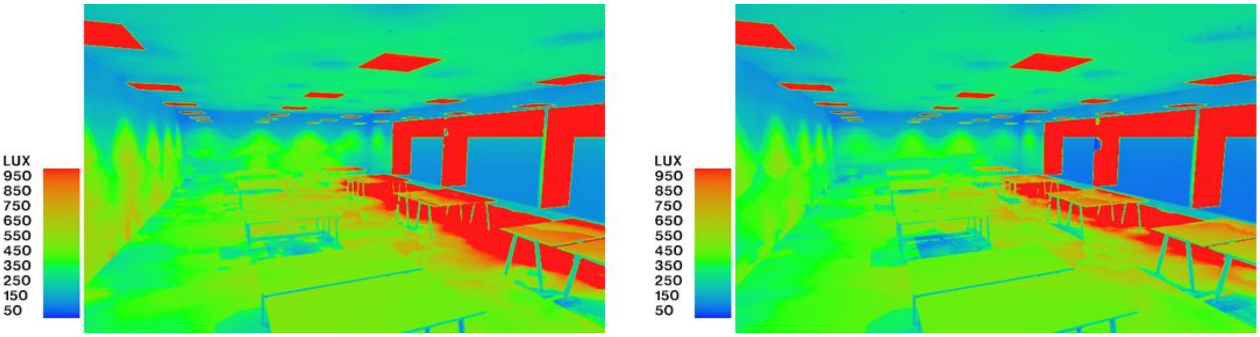
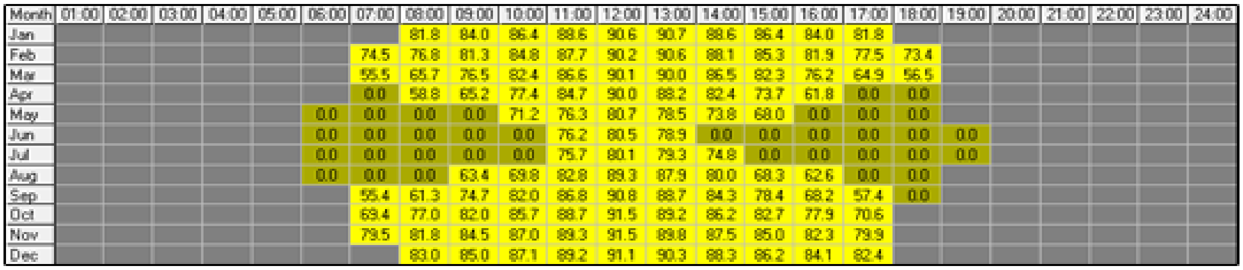


Figure 5.31: Left: South façade false colors lux levels in summer (20th June, 12:00pm), Right: South façade false colors lux levels in winter(20th December, 12:00pm) – Side-fins(Example: 1m)

Combined

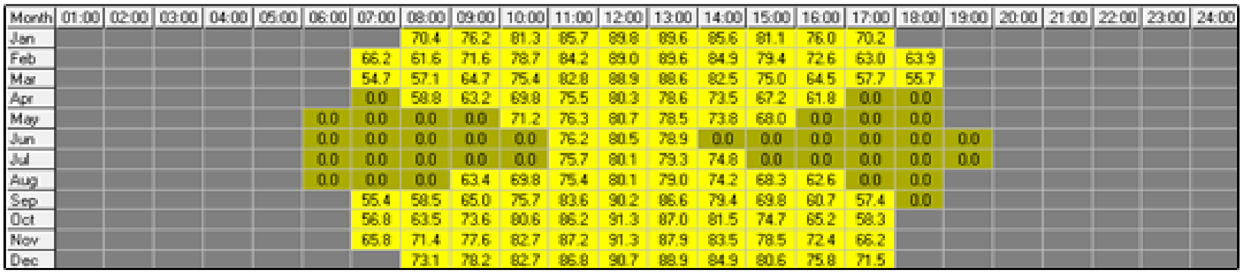
As for combined 0.5m depth, Table 5.18 shows that the illuminance intensity is 78.5% of the base case in summer, while, in winter the illuminance intensity is 86.7%. As for combined 1m depth, Table 5.19 shows that the illuminance intensity is 78.5% of the base case in summer, which is equal in intensity to the 0.5m depth, while, in winter the illuminance intensity is 81.3%, which has been reduced by 6.2% from the 0.5m depth. As for combined 1.5m depth, Table 5.20 shows that the illuminance intensity is 78.5% of the base case in summer, which is equal in intensity to the 1m depth, while, in winter the illuminance intensity is 76.4%, which has been reduced by 6% from the 1m depth. Meanwhile, Figure 5.32 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.20: Combined (0.5m) hourly percentage of illuminance on the south façade



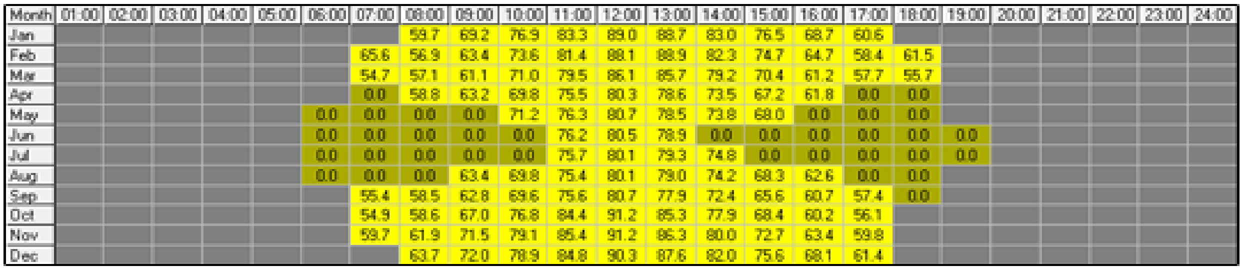
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								81.8	84.0	86.4	88.6	90.6	90.7	88.6	86.4	84.0	81.8							
Feb							74.5	76.8	81.3	84.8	87.7	90.2	90.6	88.1	85.3	81.9	77.5	73.4						
Mar							55.5	65.7	76.5	82.4	86.6	90.1	90.0	86.5	82.3	76.2	64.9	56.5						
Apr							0.0	58.8	65.2	77.4	84.7	90.0	88.2	82.4	73.7	61.8	0.0	0.0						
May						0.0	0.0	0.0	0.0	71.2	76.3	80.7	78.5	73.8	68.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	76.2	80.5	78.9	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	75.7	80.1	79.3	74.8	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	63.4	69.8	82.8	89.3	87.9	80.0	68.3	62.6	0.0	0.0						
Sep							55.4	61.3	74.7	82.0	86.8	90.8	88.7	84.3	78.4	68.2	57.4	0.0						
Oct							69.4	77.0	82.0	85.7	88.7	91.5	89.2	86.2	82.7	77.9	70.6							
Nov							79.5	81.8	84.5	87.0	89.3	91.5	89.8	87.5	85.0	82.3	79.9							
Dec								83.0	85.0	87.1	89.2	91.1	90.3	88.3	86.2	84.1	82.4							

Table 5.21: Combined (1m) hourly percentage of illuminance on the south façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								70.4	76.2	81.3	85.7	89.8	89.6	85.6	81.1	76.0	70.2							
Feb							66.2	61.6	71.6	78.7	84.2	89.0	89.6	84.9	79.4	72.6	63.0	63.9						
Mar							54.7	57.1	64.7	75.4	82.8	88.9	88.6	82.5	75.0	64.5	57.7	55.7						
Apr							0.0	58.8	63.2	69.8	75.5	80.3	78.6	73.5	67.2	61.8	0.0	0.0						
May						0.0	0.0	0.0	0.0	71.2	76.3	80.7	78.5	73.8	68.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	76.2	80.5	78.9	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	75.7	80.1	79.3	74.8	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	63.4	69.8	75.4	80.1	79.0	74.2	68.3	62.6	0.0	0.0						
Sep							55.4	58.5	65.0	75.7	83.6	90.2	86.6	79.4	69.8	60.7	57.4	0.0						
Oct							56.8	63.5	73.6	80.6	86.2	91.3	87.0	81.5	74.7	65.2	58.3							
Nov							65.8	71.4	77.6	82.7	87.2	91.3	87.9	83.5	78.5	72.4	66.2							
Dec								73.1	78.2	82.7	86.8	90.7	88.9	84.9	80.6	75.8	71.5							

Table 5.22: Combined (1.5m) hourly percentage of illuminance on the south façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								59.7	69.2	76.9	83.3	89.0	88.7	83.0	76.5	68.7	60.6							
Feb							65.6	56.9	63.4	73.6	81.4	88.1	88.9	82.3	74.7	64.7	58.4	61.5						
Mar							54.7	57.1	61.1	71.0	79.5	86.1	85.7	79.2	70.4	61.2	57.7	55.7						
Apr							0.0	58.8	63.2	69.8	75.5	80.3	78.6	73.5	67.2	61.8	0.0	0.0						
May						0.0	0.0	0.0	0.0	71.2	76.3	80.7	78.5	73.8	68.0	0.0	0.0	0.0						
Jun						0.0	0.0	0.0	0.0	0.0	76.2	80.5	78.9	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						0.0	0.0	0.0	0.0	0.0	75.7	80.1	79.3	74.8	0.0	0.0	0.0	0.0	0.0					
Aug						0.0	0.0	0.0	63.4	69.8	75.4	80.1	79.0	74.2	68.3	62.6	0.0	0.0						
Sep							55.4	58.5	62.8	69.6	75.6	80.7	77.9	72.4	65.6	60.7	57.4	0.0						
Oct							54.9	58.6	67.0	76.8	84.4	91.2	85.3	77.9	68.4	60.2	56.1							
Nov							59.7	61.9	71.5	79.1	85.4	91.2	86.3	80.0	72.7	63.4	59.8							
Dec								63.7	72.0	78.9	84.8	90.3	87.6	82.0	75.6	68.1	61.4							

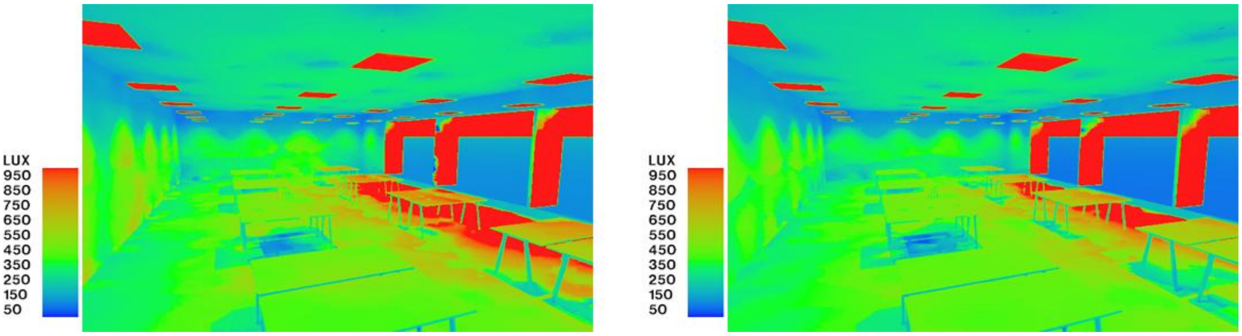


Figure 5.32: Left: South façade false colors lux levels in summer (20th June, 12:00pm), Right: South façade false colors lux levels in winter(20th December, 12:00pm) – Combined(Example: 1m)

East Orientation

The average illuminance on the east oriented façade demonstrates a large difference between illuminance levels in summer and in winter. In addition, integrating different shading devices in summer does not seem to contribute much to the illuminance levels, however, in winter side-fins seem to contribute more to reduction in illuminance levels as shown in Figure 5.33.

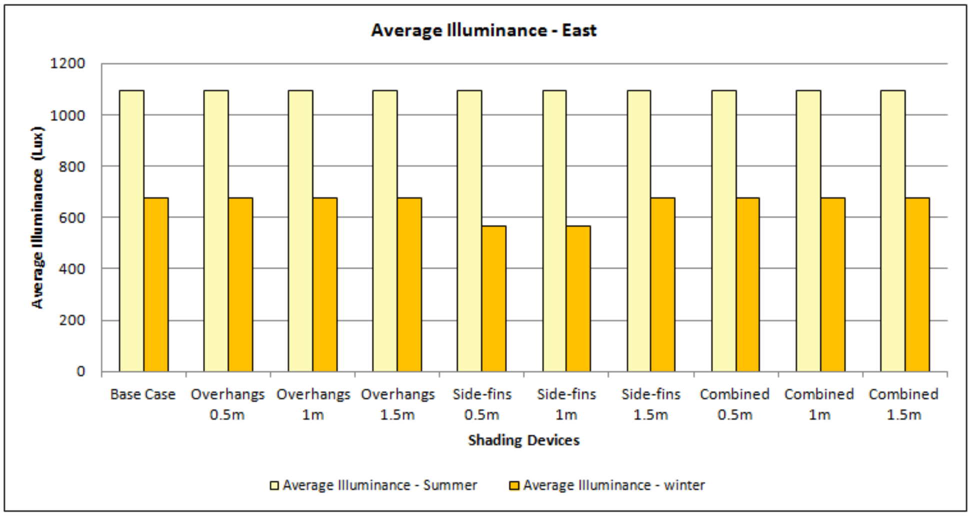


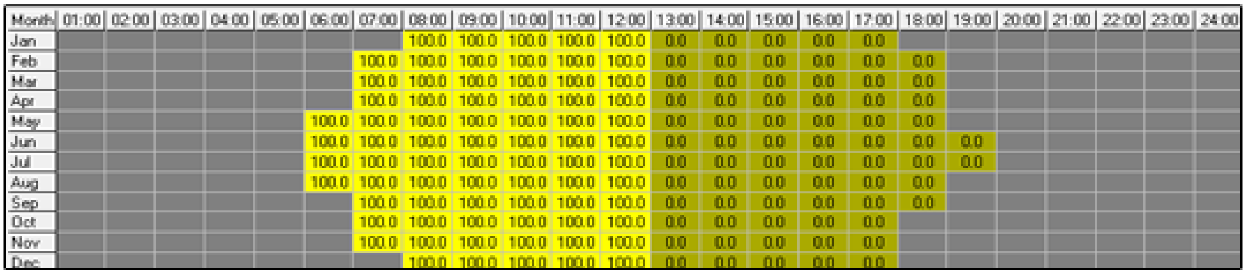
Figure 5.33: A chart showing the average illuminance of all cases on East oriented façades in summer and winter

In general, east façades receive direct illumination 50% of the daily sunny hours due to the solar altitude in summer and in winter during the period from 6am to 12pm, which is different in intensity depending on the shading device and its depth.

Base case

Table 5.21 shows that the illuminance intensity for the base case is 100% in summer as well as in winter. Meanwhile, Figure 5.34 shows the difference between illuminance levels for the base case in summer and in winter, which shows how the first row workstations are more illuminance in summer represented by the red false color, which causes discomfort glare.

Table 5.23: Base case hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Feb							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
May						100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Nov							100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							
Dec								100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0							

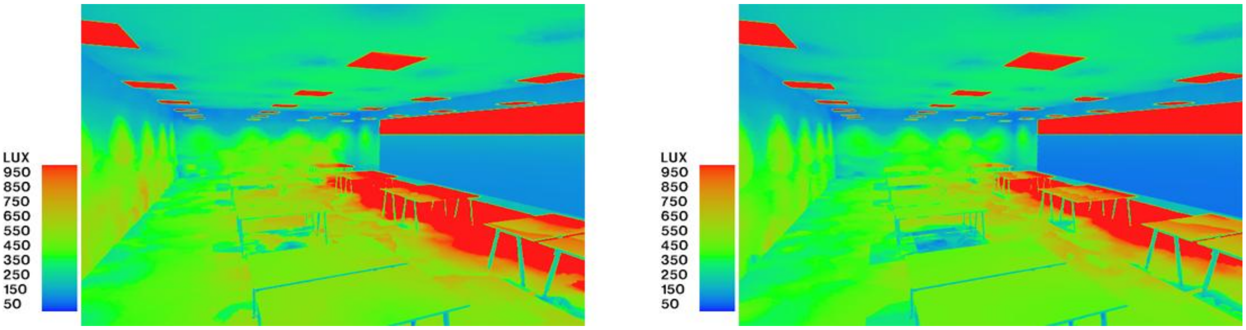
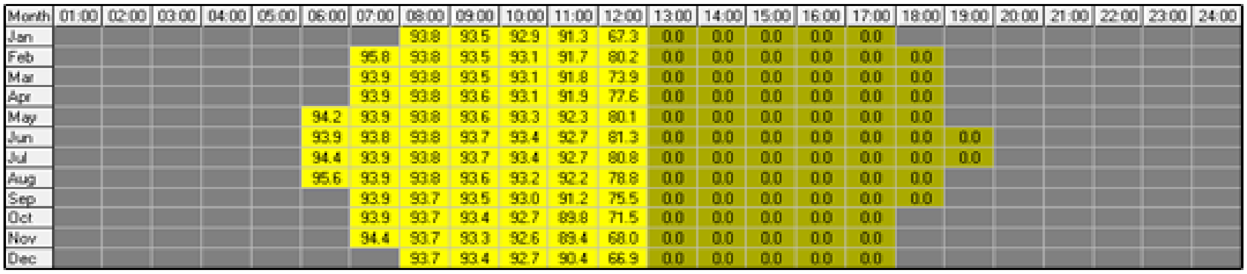


Figure 5.34: Left: East façade false colors lux levels in summer (20th June, 12:00pm), Right: East façade false colors lux levels in winter(20th December, 12:00pm) – Base Case

Overhangs

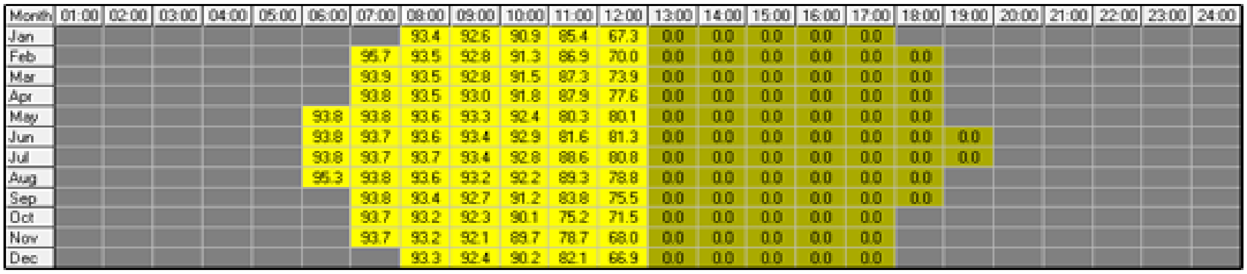
As for overhangs 0.5m depth, Table 5.22 shows that the illuminance intensity is 91.8% of the base case in summer, while, in winter the illuminance intensity is 87.4%. As for overhangs 1m depth, Table 5.23 shows that the illuminance intensity is 90% of the base case in summer, which is reduced by 1% from the 0.5m depth, while, in winter the illuminance intensity is 85% ,which has been reduced by 2.7% from the 0.5m depth. As for overhangs 1.5m depth, Table 5.24 shows that the illuminance intensity is 89.9% of the base case in summer, which is almost equal in intensity to the 1m depth, while, in winter the illuminance intensity is 80.7% ,which has been reduced by 5.1% from the 1m depth. Meanwhile, Figure 5.35 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.24: Overhangs (0.5m) hourly percentage of illuminance on the east façade



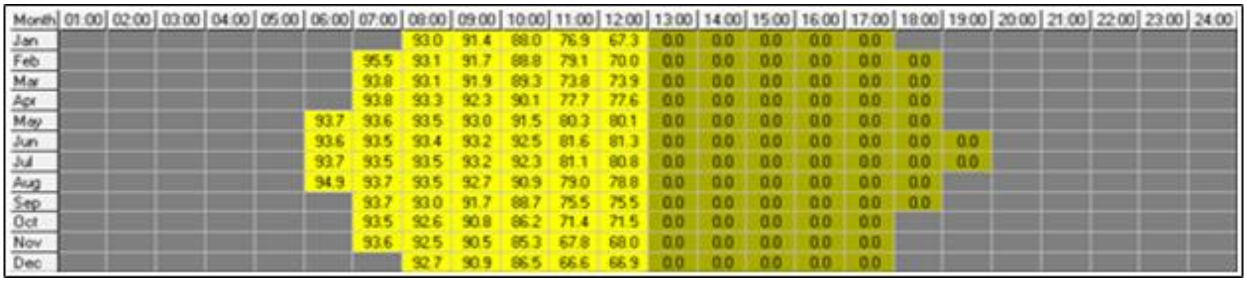
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								93.8	93.5	92.9	91.3	67.3	0.0	0.0	0.0	0.0	0.0							
Feb							95.8	93.8	93.5	93.1	91.7	80.2	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							93.9	93.8	93.5	93.1	91.8	73.9	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							93.9	93.8	93.6	93.1	91.9	77.6	0.0	0.0	0.0	0.0	0.0	0.0						
May						94.2	93.9	93.8	93.6	93.3	92.3	80.1	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						93.9	93.8	93.8	93.7	93.4	92.7	81.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						94.4	93.9	93.8	93.7	93.4	92.7	80.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						95.6	93.9	93.8	93.6	93.2	92.2	78.8	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							93.9	93.7	93.5	93.0	91.2	75.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							93.9	93.7	93.4	92.7	89.8	71.5	0.0	0.0	0.0	0.0	0.0							
Nov							94.4	93.7	93.3	92.6	89.4	68.0	0.0	0.0	0.0	0.0	0.0							
Dec								93.7	93.4	92.7	90.4	66.9	0.0	0.0	0.0	0.0	0.0							

Table 5.25: Overhangs (1m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								93.4	92.6	90.9	85.4	67.3	0.0	0.0	0.0	0.0	0.0							
Feb							95.7	93.5	92.8	91.3	86.9	70.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							93.9	93.5	92.8	91.5	87.3	73.9	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							93.8	93.5	93.0	91.8	87.9	77.6	0.0	0.0	0.0	0.0	0.0	0.0						
May						93.8	93.8	93.6	93.3	92.4	80.3	80.1	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						93.8	93.7	93.6	93.4	92.9	81.6	81.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						93.8	93.7	93.7	93.4	92.8	88.6	80.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						95.3	93.8	93.6	93.2	92.2	89.3	78.8	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							93.8	93.4	92.7	91.2	83.8	75.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							93.7	93.2	92.3	90.1	75.2	71.5	0.0	0.0	0.0	0.0	0.0							
Nov							93.7	93.2	92.1	89.7	78.7	68.0	0.0	0.0	0.0	0.0	0.0							
Dec								93.3	92.4	90.2	82.1	66.9	0.0	0.0	0.0	0.0	0.0							

Table 5.26: Overhangs (1.5m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								93.0	91.4	88.0	76.9	67.3	0.0	0.0	0.0	0.0	0.0							
Feb							95.5	93.1	91.7	88.8	79.1	70.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							93.8	93.1	91.9	89.3	73.8	73.9	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							93.8	93.3	92.3	90.1	77.7	77.6	0.0	0.0	0.0	0.0	0.0	0.0						
May						93.7	93.6	93.5	93.0	91.5	80.3	80.1	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						93.6	93.5	93.4	93.2	92.5	81.6	81.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						93.7	93.5	93.5	93.2	92.3	81.1	80.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						94.9	93.7	93.5	92.7	90.9	79.0	78.8	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							93.7	93.0	91.7	88.7	75.5	75.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							93.5	92.6	90.8	86.2	71.4	71.5	0.0	0.0	0.0	0.0	0.0							
Nov							93.6	92.5	90.5	85.3	67.8	68.0	0.0	0.0	0.0	0.0	0.0							
Dec								92.7	90.9	86.5	66.6	66.9	0.0	0.0	0.0	0.0	0.0							

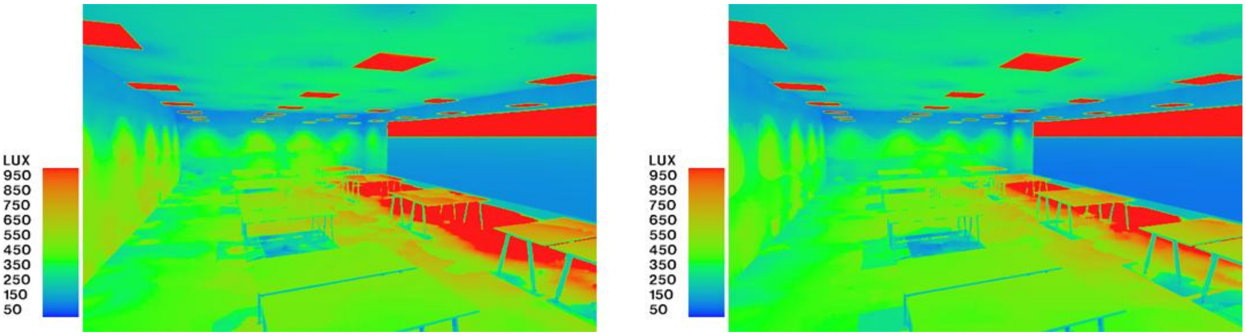


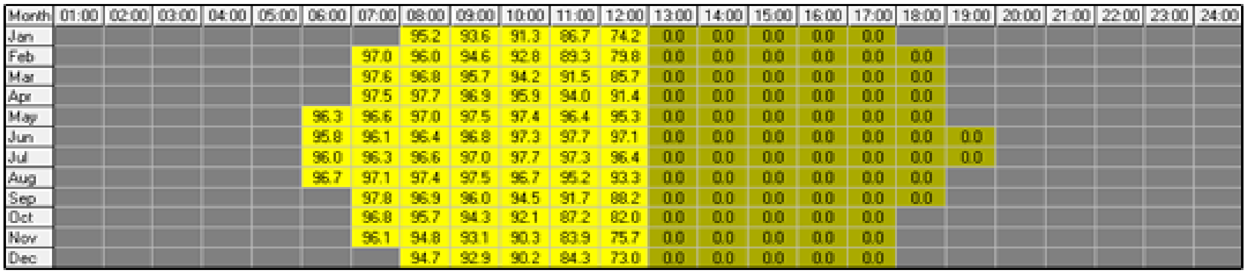
Figure 5.35: Left: East façade false colors lux levels in summer (20th June, 12:00pm), Right: East façade false colors lux levels in winter(20th December, 12:00pm) - Overhangs (Example: 1m)

Side-fins

As for side-fins 0.5m depth, Table 5.25 shows that the illuminance intensity is 96.7% of the base case in summer, while, in winter the illuminance intensity is 87%. As for side-fins 1m depth, Table 5.26 shows that the illuminance intensity is 95.8% of the base case in summer, which has a very slight difference in intensity than the 0.5m depth, while, in winter the illuminance intensity is 81.9% ,which has been reduced by 5.9% from the 0.5m depth. As for side-fins 1.5m depth, Table 5.27 shows that the illuminance intensity is 94.9% of the base case in summer, which has a very slight difference in intensity than the 1m depth, while, in winter the illuminance intensity is

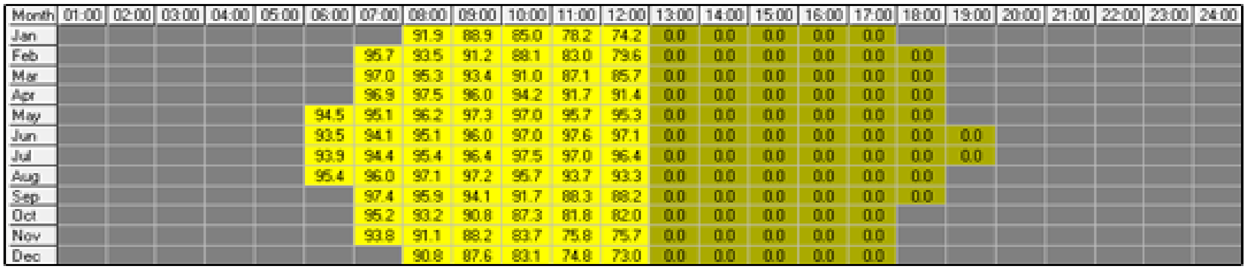
78.4% ,which has been reduced by 4.3% from the 1m depth. Meanwhile, Figure 5.36 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.27: Side-fins (0.5m) hourly percentage of illuminance on the east façade



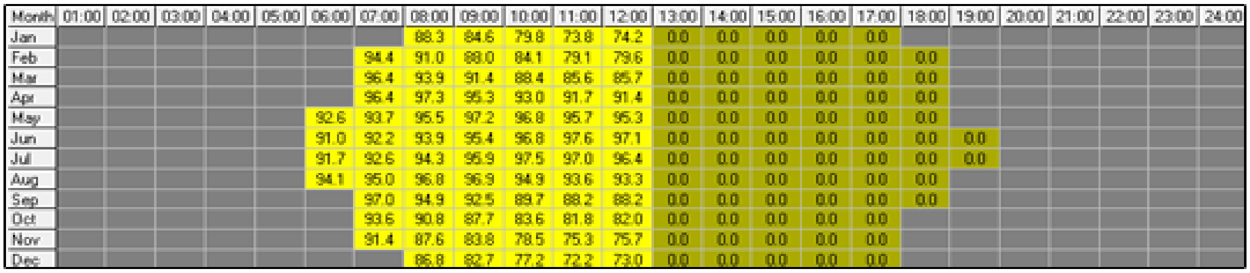
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								95.2	93.6	91.3	86.7	74.2	0.0	0.0	0.0	0.0	0.0							
Feb							97.0	96.0	94.6	92.8	89.3	79.8	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							97.6	96.8	95.7	94.2	91.5	85.7	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							97.5	97.7	96.9	95.9	94.0	91.4	0.0	0.0	0.0	0.0	0.0	0.0						
May						96.3	96.6	97.0	97.5	97.4	96.4	95.3	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						95.8	96.1	96.4	96.8	97.3	97.7	97.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						96.0	96.3	96.6	97.0	97.7	97.3	96.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						96.7	97.1	97.4	97.5	96.7	95.2	93.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							97.8	96.9	96.0	94.5	91.7	88.2	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							96.8	95.7	94.3	92.1	87.2	82.0	0.0	0.0	0.0	0.0	0.0							
Nov							96.1	94.8	93.1	90.3	83.9	75.7	0.0	0.0	0.0	0.0	0.0							
Dec								94.7	92.9	90.2	84.3	73.0	0.0	0.0	0.0	0.0	0.0							

Table 5.28: Side-fins (1m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								91.9	88.9	85.0	78.2	74.2	0.0	0.0	0.0	0.0	0.0							
Feb							95.7	93.5	91.2	88.1	83.0	79.6	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							97.0	95.3	93.4	91.0	87.1	85.7	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							96.9	97.5	96.0	94.2	91.7	91.4	0.0	0.0	0.0	0.0	0.0	0.0						
May						94.5	95.1	96.2	97.3	97.0	95.7	95.3	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						93.5	94.1	95.1	96.0	97.0	97.6	97.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						93.9	94.4	95.4	96.4	97.5	97.0	96.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						95.4	96.0	97.1	97.2	95.7	93.7	93.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							97.4	95.9	94.1	91.7	88.3	88.2	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							95.2	93.2	90.8	87.3	81.8	82.0	0.0	0.0	0.0	0.0	0.0							
Nov							93.8	91.1	88.2	83.7	75.8	75.7	0.0	0.0	0.0	0.0	0.0							
Dec								90.8	87.6	83.1	74.8	73.0	0.0	0.0	0.0	0.0	0.0							

Table 5.29: Side-fins (1.5m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								88.3	84.6	79.8	73.8	74.2	0.0	0.0	0.0	0.0	0.0							
Feb							94.4	91.0	88.0	84.1	79.1	79.6	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							96.4	93.9	91.4	88.4	85.6	85.7	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							96.4	97.3	95.3	93.0	91.7	91.4	0.0	0.0	0.0	0.0	0.0	0.0						
May						92.6	93.7	95.5	97.2	96.8	95.7	95.3	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						91.0	92.2	93.9	95.4	96.8	97.6	97.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						91.7	92.6	94.3	95.9	97.5	97.0	96.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						94.1	95.0	96.8	96.9	94.9	93.6	93.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							97.0	94.9	92.5	89.7	88.2	88.2	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							93.6	90.8	87.7	83.6	81.8	82.0	0.0	0.0	0.0	0.0	0.0							
Nov							91.4	87.6	83.8	78.5	75.3	75.7	0.0	0.0	0.0	0.0	0.0							
Dec								86.8	82.7	77.2	72.2	73.0	0.0	0.0	0.0	0.0	0.0							

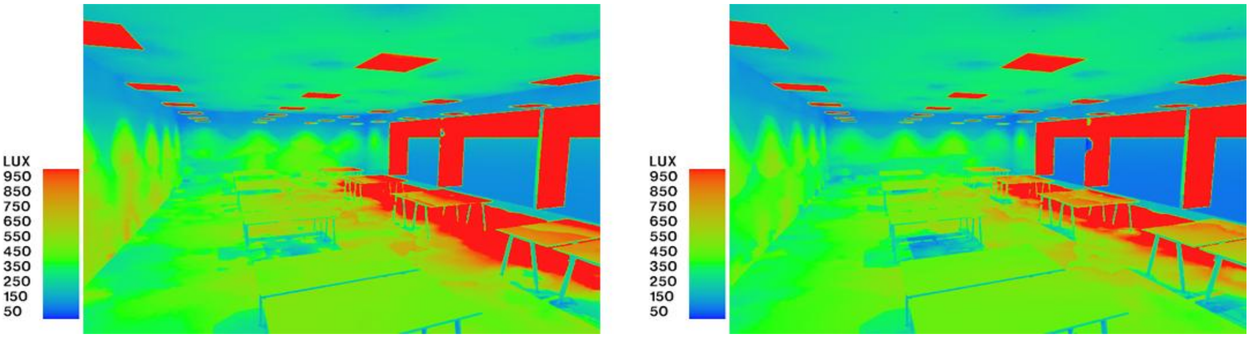
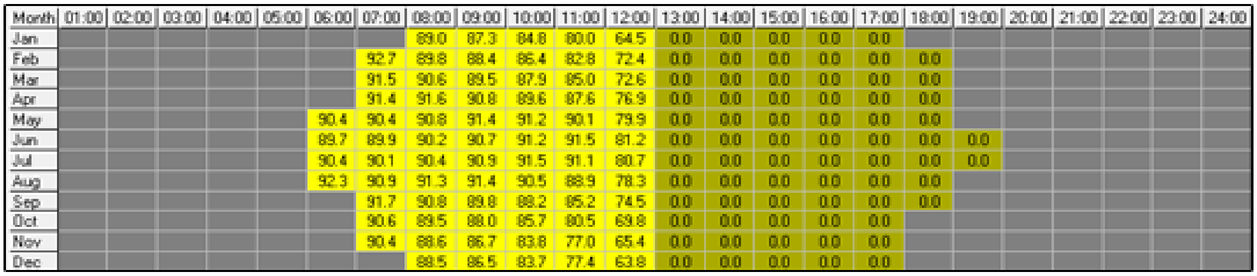


Figure 5.36: Left: East façade false colors lux levels in summer (20th June, 12:00pm), Right: East façade false colors lux levels in winter(20th December, 12:00pm) – Side-fins(Example: 1m)

Combined

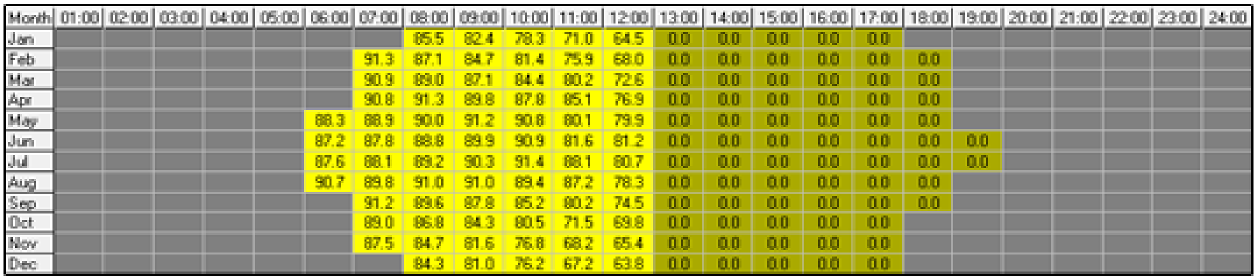
As for combined 0.5m depth, Table 5.28 shows that the illuminance intensity is 89.2% of the base case in summer, while, in winter the illuminance intensity is 80%. As for combined 1m depth, Table 5.29 shows that the illuminance intensity is 86.8% of the base case in summer, which has decreased with a rate of 2.7% from the 0.5m depth, while, in winter the illuminance intensity is 74.5%, which has been reduced by 6.9% from the 0.5m depth. As for combined 1.5m depth, Table 5.30 shows that the illuminance intensity is 85.8% of the base case in summer which has decreased with a rate of 1.2% from the 1m depth, while, in winter the illuminance intensity is 70.6% , which has been reduced by 5.2% from the 1m depth. Meanwhile, Figure 5.37 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.30: Combined (0.5m) hourly percentage of illuminance on the east façade



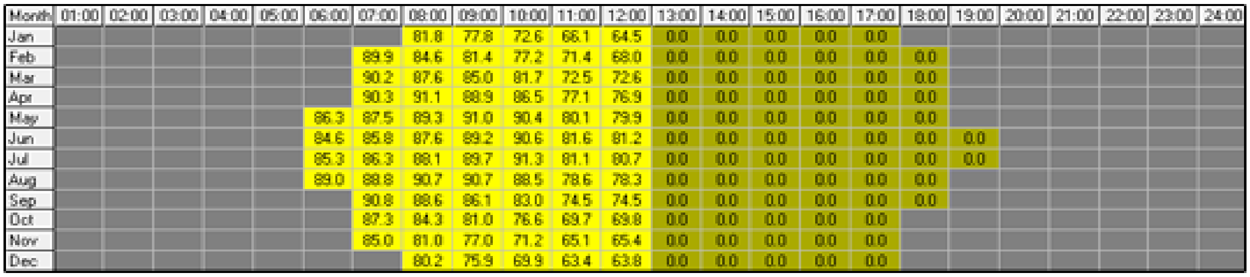
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								89.0	87.3	84.8	80.0	64.5	0.0	0.0	0.0	0.0	0.0							
Feb							92.7	89.8	88.4	86.4	82.8	72.4	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							91.5	90.6	89.5	87.9	85.0	72.6	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							91.4	91.6	90.8	89.6	87.6	76.9	0.0	0.0	0.0	0.0	0.0	0.0						
May						90.4	90.4	90.8	91.4	91.2	90.1	79.9	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						89.7	89.9	90.2	90.7	91.2	91.5	81.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						90.4	90.1	90.4	90.9	91.5	91.1	80.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						92.3	90.9	91.3	91.4	90.5	88.9	78.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							91.7	90.8	89.8	88.2	85.2	74.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							90.6	89.5	88.0	85.7	80.5	69.8	0.0	0.0	0.0	0.0	0.0							
Nov							90.4	88.6	86.7	83.8	77.0	65.4	0.0	0.0	0.0	0.0	0.0							
Dec								88.5	86.5	83.7	77.4	63.8	0.0	0.0	0.0	0.0	0.0							

Table 5.31: Combined (1m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								85.5	82.4	78.3	71.0	64.5	0.0	0.0	0.0	0.0	0.0							
Feb							91.3	87.1	84.7	81.4	75.9	68.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							90.9	89.0	87.1	84.4	80.2	72.6	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							90.8	91.3	89.8	87.8	85.1	76.9	0.0	0.0	0.0	0.0	0.0	0.0						
May						88.3	88.9	90.0	91.2	90.8	80.1	79.9	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						87.2	87.8	88.8	89.9	90.9	81.6	81.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						87.6	88.1	89.2	90.3	91.4	88.1	80.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						90.7	89.8	91.0	91.0	89.4	87.2	78.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							91.2	89.6	87.8	85.2	80.2	74.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							89.0	86.8	84.3	80.5	71.5	69.8	0.0	0.0	0.0	0.0	0.0							
Nov							87.5	84.7	81.6	76.8	68.2	65.4	0.0	0.0	0.0	0.0	0.0							
Dec								84.3	81.0	76.2	67.2	63.8	0.0	0.0	0.0	0.0	0.0							

Table 5.32: Combined (1.5m) hourly percentage of illuminance on the east façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								81.8	77.8	72.6	66.1	64.5	0.0	0.0	0.0	0.0	0.0							
Feb							89.9	84.6	81.4	77.2	71.4	68.0	0.0	0.0	0.0	0.0	0.0	0.0						
Mar							90.2	87.6	85.0	81.7	72.5	72.6	0.0	0.0	0.0	0.0	0.0	0.0						
Apr							90.3	91.1	88.9	86.5	77.1	76.9	0.0	0.0	0.0	0.0	0.0	0.0						
May						86.3	87.5	89.3	91.0	90.4	80.1	79.9	0.0	0.0	0.0	0.0	0.0	0.0						
Jun						84.6	85.8	87.6	89.2	90.6	81.6	81.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Jul						85.3	86.3	88.1	89.7	91.3	81.1	80.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
Aug						89.0	88.8	90.7	90.7	88.5	78.6	78.3	0.0	0.0	0.0	0.0	0.0	0.0						
Sep							90.8	88.6	86.1	83.0	74.5	74.5	0.0	0.0	0.0	0.0	0.0	0.0						
Oct							87.3	84.3	81.0	76.6	69.7	69.8	0.0	0.0	0.0	0.0	0.0							
Nov							85.0	81.0	77.0	71.2	65.1	65.4	0.0	0.0	0.0	0.0	0.0							
Dec								80.2	75.9	69.9	63.4	63.8	0.0	0.0	0.0	0.0	0.0							

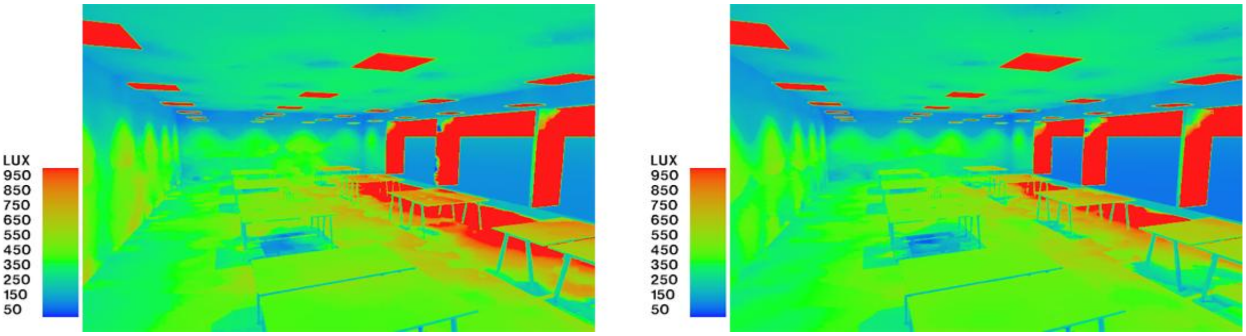


Figure 5.37: Left: East façade false colors lux levels in summer (20th June, 12:00pm), Right: East façade false colors lux levels in winter(20th December, 12:00pm) – Combined(Example: 1m)

West Orientation

The average illuminance on the west oriented façade demonstrates a large difference between illuminance levels in summer and in winter. In addition, integrating different shading devices in winter doesn't seem to contribute much to the illuminance levels, however, in summer side-fins seem to contribute more to reduction in illuminance levels as shown in Figure 5.38.

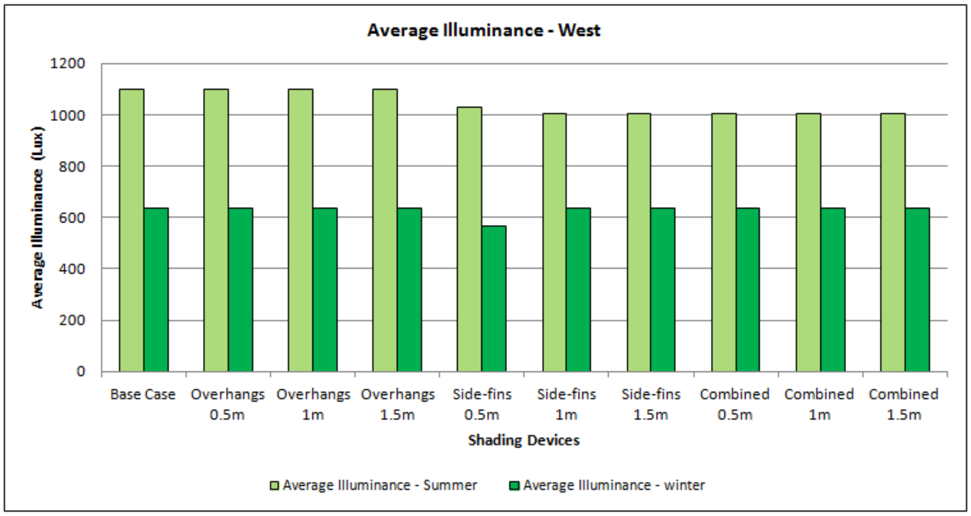


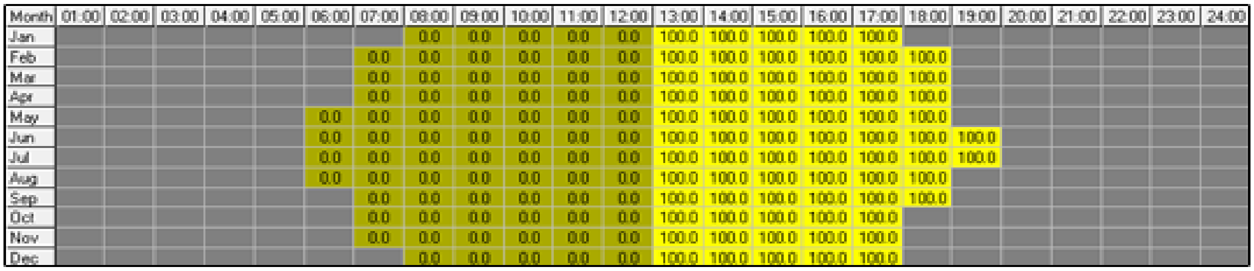
Figure 5.38: A chart showing the average illuminance of all cases on west oriented façades in summer and winter

In general, west façades receive direct illumination 50% of the daily sunny hours due to the solar altitude in summer and in winter during the period from 1pm to 7pm, which is different in intensity depending on the shading device and its depth.

Base case

Table 5.31 shows that the illuminance intensity for the base case is 100% in summer as well as in winter. Meanwhile, Figure 5.39 shows the difference between illuminance levels for the base case in summer and in winter, which shows how the first row workstations are more illuminance in summer represented by the red false color, which causes discomfort glare.

Table 5.33: Base case hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0							
Dec								0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0							

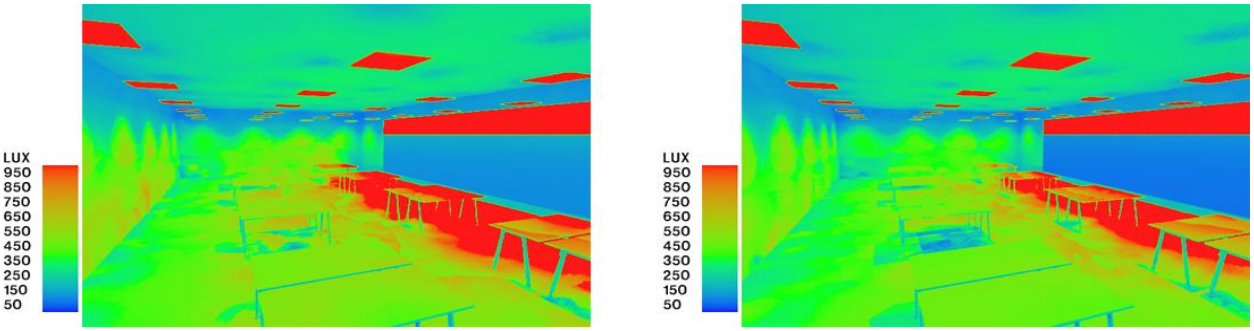
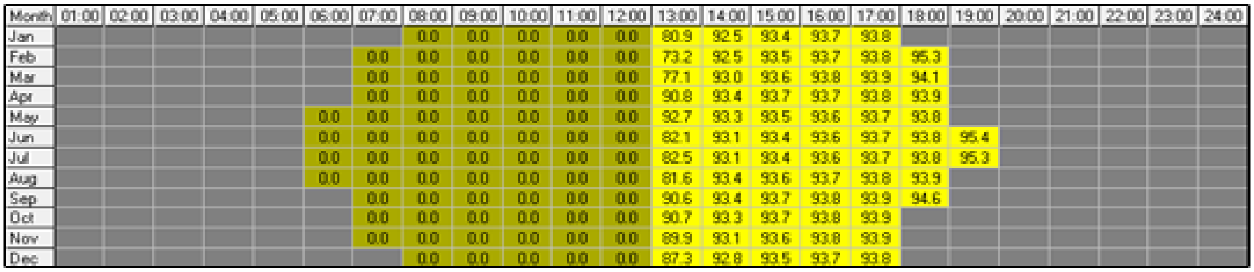


Figure 5.39: Left: West façade false colors lux levels in summer (20th June, 12:00pm), Right: West façade false colors lux levels in winter(20th December, 12:00pm) – Base Case

Overhangs

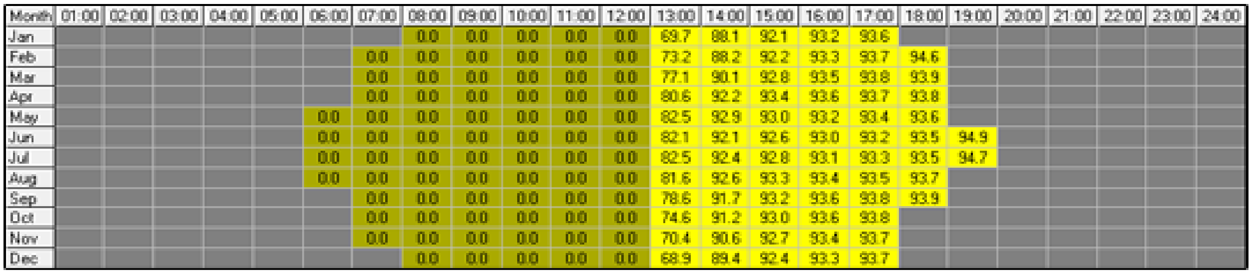
As for overhangs 0.5m depth, Table 5.32 shows that the illuminance intensity is 92.2% of the base case in summer as well as in winter. As for overhangs 1m depth, Table 5.33 shows that the illuminance intensity is 91.6% of the base case in summer, which is reduced by 1% from the 0.5m depth, while, in winter the illuminance intensity is 87.5% ,which has been reduced by 5.1% from the 0.5m depth. As for overhangs 1.5m depth, Table 5.34 shows that the illuminance intensity is 89.7% of the base case in summer which has decreased with a rate of 2.1% from the 1m depth, while, in winter the illuminance intensity is 85.9% ,which has been reduced by 1.8% from the 1m depth. Meanwhile, Figure 5.40 explains in false color the illuminance levels resulting from integrating overhangs to the west façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.34: Overhangs (0.5m) hourly percentage of illuminance on the west façade



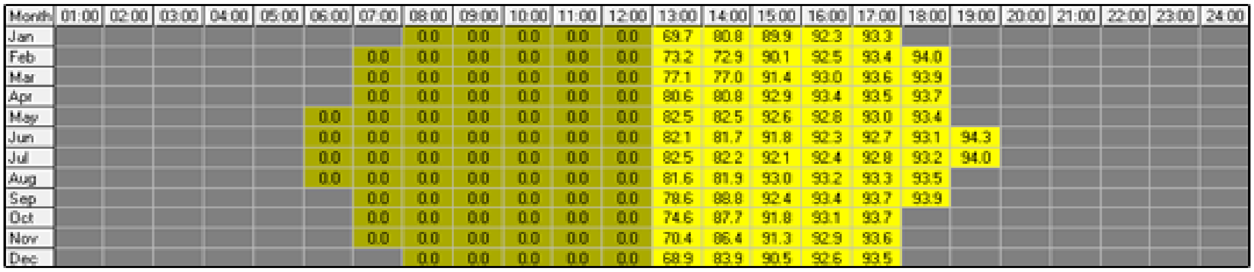
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	80.9	92.5	93.4	93.7	93.8							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	73.2	92.5	93.5	93.7	93.8	95.3						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	77.1	93.0	93.6	93.8	93.9	94.1						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	90.8	93.4	93.7	93.7	93.8	93.9						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.7	93.3	93.5	93.6	93.7	93.8						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.1	93.1	93.4	93.6	93.7	93.8	95.4					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.5	93.1	93.4	93.6	93.7	93.8	95.3					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.6	93.4	93.6	93.7	93.8	93.9						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	90.6	93.4	93.7	93.8	93.9	94.6						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	90.7	93.3	93.7	93.8	93.9							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	89.9	93.1	93.6	93.8	93.9							
Dec								0.0	0.0	0.0	0.0	0.0	87.3	92.8	93.5	93.7	93.8							

Table 5.35: Overhangs (1m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	69.7	88.1	92.1	93.2	93.6							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	73.2	88.2	92.2	93.3	93.7	94.6						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	77.1	90.1	92.8	93.5	93.8	93.9						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	80.6	92.2	93.4	93.6	93.7	93.8						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.5	92.9	93.0	93.2	93.4	93.6						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.1	92.1	92.6	93.0	93.2	93.5	94.9					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.5	92.4	92.8	93.1	93.3	93.5	94.7					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.6	92.6	93.3	93.4	93.5	93.7						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	78.6	91.7	93.2	93.6	93.8	93.9						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	74.6	91.2	93.0	93.6	93.8							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	70.4	90.6	92.7	93.4	93.7							
Dec								0.0	0.0	0.0	0.0	0.0	68.9	89.4	92.4	93.3	93.7							

Table 5.36: Overhangs (1.5m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	69.7	80.8	89.9	92.3	93.3							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	73.2	72.9	90.1	92.5	93.4	94.0						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	77.1	77.0	91.4	93.0	93.6	93.9						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	80.6	80.8	92.9	93.4	93.5	93.7						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.5	82.5	92.6	92.8	93.0	93.4						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.1	81.7	91.8	92.3	92.7	93.1	94.3					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.5	82.2	92.1	92.4	92.8	93.2	94.0					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.6	81.9	93.0	93.2	93.3	93.5						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	78.6	88.8	92.4	93.4	93.7	93.9						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	74.6	87.7	91.8	93.1	93.7							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	70.4	86.4	91.3	92.9	93.6							
Dec								0.0	0.0	0.0	0.0	0.0	68.9	83.9	90.5	92.6	93.5							

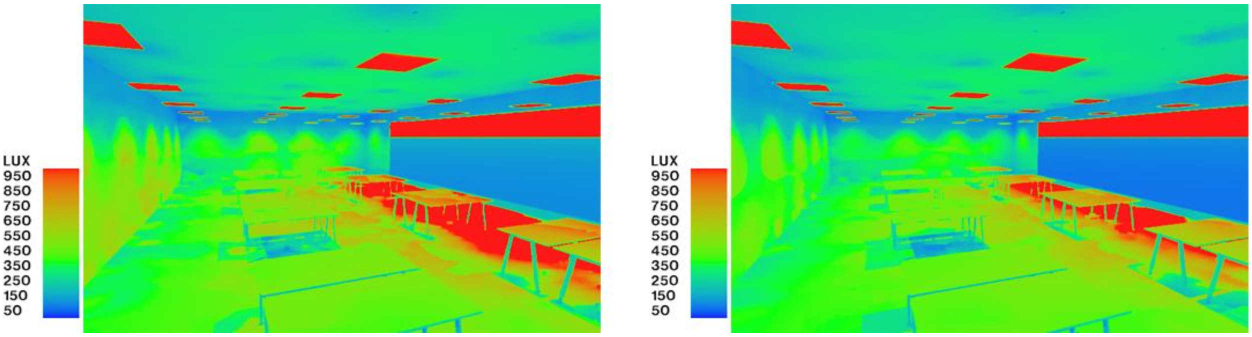
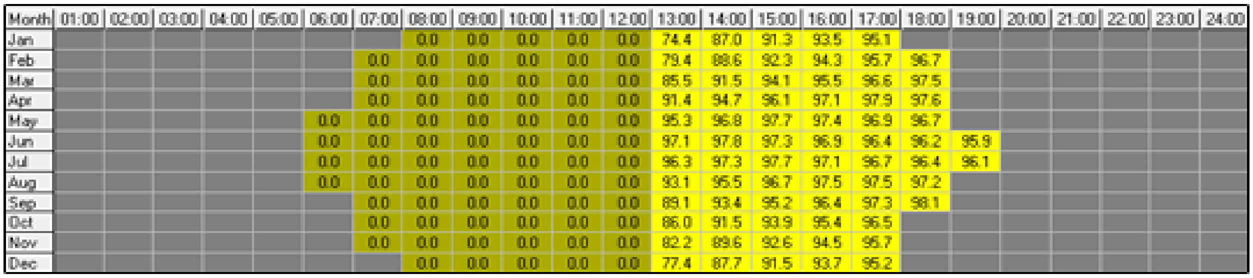


Figure 5.40: Left: West façade false colors lux levels in summer (20th June, 12:00pm), Right: West façade false colors lux levels in winter(20th December, 12:00pm) - Overhangs (Example: 1m)

Side-fins

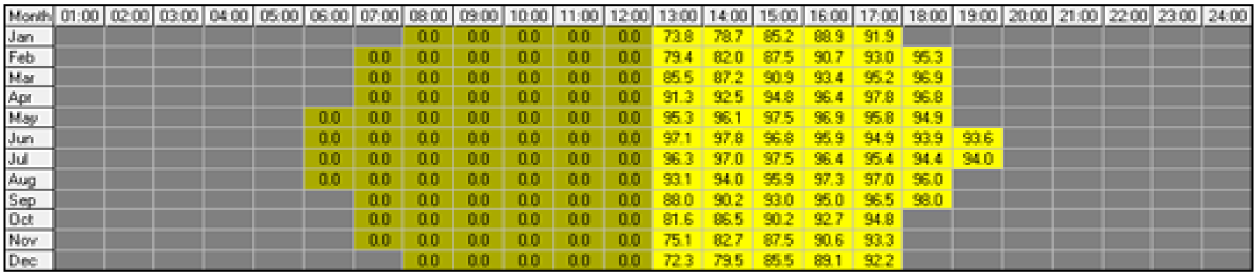
As for side-fins 0.5m depth, Table 5.35 shows that the illuminance intensity is 96.8% of the base case in summer, while, in winter the illuminance intensity is 89.1%. As for side-fins 1m depth, Table 5.36 shows that the illuminance intensity is 95.7% of the base case in summer which has decreased with a rate of 1.1% from the 0.5m depth, while, in winter the illuminance intensity is 83.7% ,which has been reduced by 6% from the 0.5m depth. As for side-fins 1.5m depth, Table 5.37 shows that the illuminance intensity is 94.7% of the base case in summer which has decreased with a rate of 1% from the 1m depth, while, in winter the illuminance intensity is 79.9% ,which has been reduced by 4.5% from the 1m depth. Meanwhile, Figure 5.41 explains in false color the illuminance levels resulting from integrating overhangs to the west façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.37: Side-fins (0.5m) hourly percentage of illuminance on the west façade



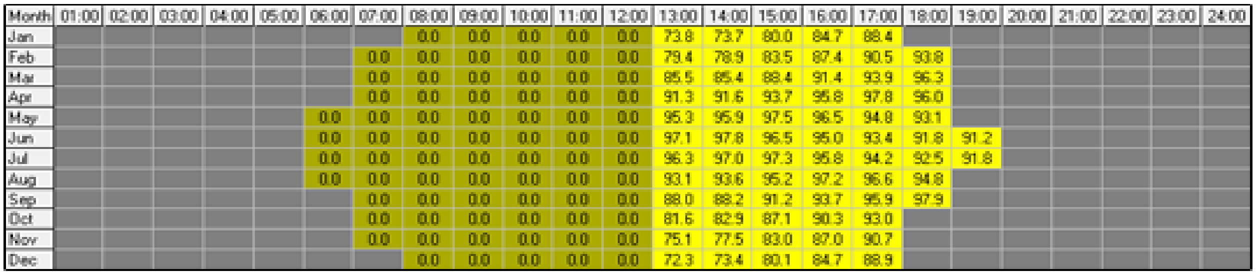
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	74.4	87.0	91.3	93.5	95.1							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	79.4	88.6	92.3	94.3	95.7	96.7						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	85.5	91.5	94.1	95.5	96.6	97.5						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	91.4	94.7	96.1	97.1	97.9	97.6						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.3	96.8	97.7	97.4	96.9	96.7						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.1	97.8	97.3	96.9	96.4	96.2	95.9					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.3	97.3	97.7	97.1	96.7	96.4	96.1					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	93.1	95.5	96.7	97.5	97.5	97.2						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	89.1	93.4	95.2	96.4	97.3	98.1						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	86.0	91.5	93.9	95.4	96.5							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	82.2	89.6	92.6	94.5	95.7							
Dec								0.0	0.0	0.0	0.0	0.0	77.4	87.7	91.5	93.7	95.2							

Table 5.38: Side-fins (1m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	73.8	78.7	85.2	88.9	91.9							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	79.4	82.0	87.5	90.7	93.0	95.3						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	85.5	87.2	90.9	93.4	95.2	96.9						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	91.3	92.5	94.8	96.4	97.8	96.8						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.3	96.1	97.5	96.9	95.8	94.9						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.1	97.8	96.8	95.9	94.9	93.9	93.6					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.3	97.0	97.5	96.4	95.4	94.4	94.0					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	93.1	94.0	95.9	97.3	97.0	96.0						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	88.0	90.2	93.0	95.0	96.5	98.0						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	81.6	86.5	90.2	92.7	94.8							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	75.1	82.7	87.5	90.6	93.3							
Dec								0.0	0.0	0.0	0.0	0.0	72.3	79.5	85.5	89.1	92.2							

Table 5.39: Side-fins (1.5m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	73.8	73.7	80.0	84.7	88.4							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	79.4	78.9	83.5	87.4	90.5	93.8						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	85.5	85.4	88.4	91.4	93.9	96.3						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	91.3	91.6	93.7	95.8	97.8	96.0						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.3	95.9	97.5	96.5	94.8	93.1						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.1	97.8	96.5	95.0	93.4	91.8	91.2					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.3	97.0	97.3	95.8	94.2	92.5	91.8					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	93.1	93.6	95.2	97.2	96.6	94.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	88.0	88.2	91.2	93.7	95.9	97.9						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	81.6	82.9	87.1	90.3	93.0							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	75.1	77.5	83.0	87.0	90.7							
Dec								0.0	0.0	0.0	0.0	0.0	72.3	73.4	80.1	84.7	88.9							

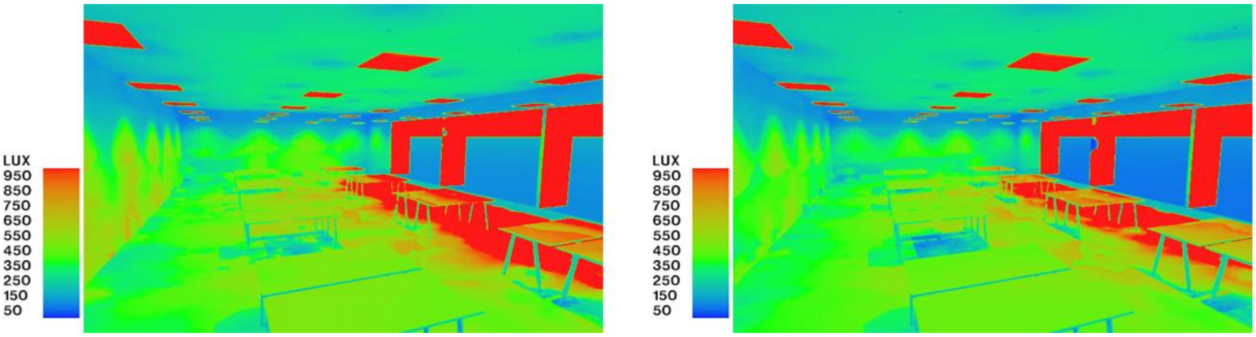
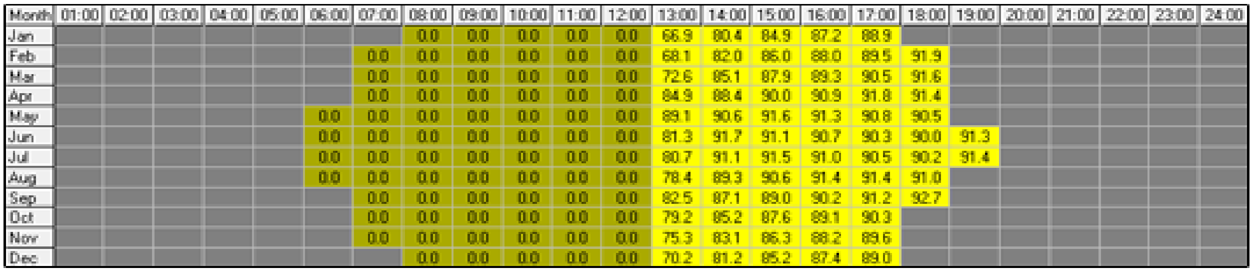


Figure 5.41: Left: West façade false colors lux levels in summer (20th June, 12:00pm), Right: West façade false colors lux levels in winter(20th December, 12:00pm) – Side-fins(Example: 1m)

Combined

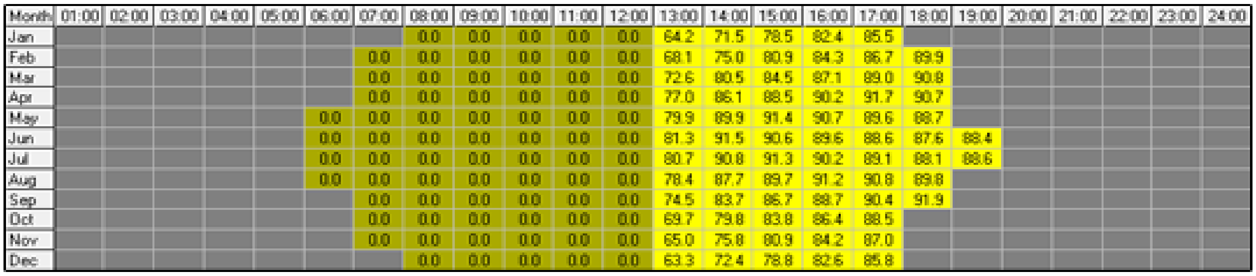
As for combined 0.5m depth, Table 5.38 shows that the illuminance intensity is 89.5% of the base case in summer, while, in winter the illuminance intensity is 82.6%. As for combined 1m depth, Table 5.39 shows that the illuminance intensity is 88.2% of the base case in summer, which has decreased with a rate of 1.5% from the 0.5m depth, while, in winter the illuminance intensity is 76.4%, which has been reduced by 7.5% from the 0.5m depth. As for combined 1.5m depth, Table 5.40 shows that the illuminance intensity is 85.7% of the base case in summer which has decreased with a rate of 2.8% from the 1m depth, while, in winter the illuminance intensity is 72.5% , which has been reduced by 5.1% from the 1m depth. Meanwhile, Figure 5.42 explains in false color the illuminance levels resulting from integrating overhangs to the south façade, which shows less red color illuminance in the space next to the façade compared to the base case.

Table 5.40: Combined (0.5m) hourly percentage of illuminance on the west façade



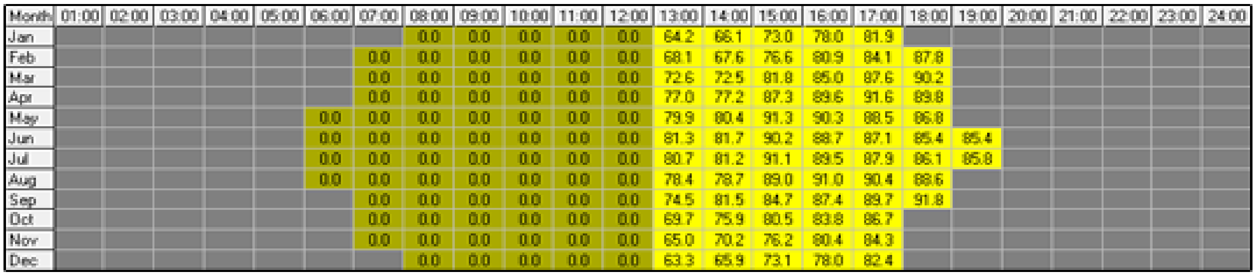
Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	66.9	80.4	84.9	87.2	88.9							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	68.1	82.0	86.0	88.0	89.5	91.9						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	72.6	85.1	87.9	89.3	90.5	91.6						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	84.9	88.4	90.0	90.9	91.8	91.4						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.1	90.6	91.6	91.3	90.8	90.5						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.3	91.7	91.1	90.7	90.3	90.0	91.3					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.7	91.1	91.5	91.0	90.5	90.2	91.4					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.4	89.3	90.6	91.4	91.4	91.0						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	82.5	87.1	89.0	90.2	91.2	92.7						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	79.2	85.2	87.6	89.1	90.3							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	75.3	83.1	86.3	88.2	89.6							
Dec								0.0	0.0	0.0	0.0	0.0	70.2	81.2	85.2	87.4	89.0							

Table 5.41: Combined (1m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	64.2	71.5	78.5	82.4	85.5							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	68.1	75.0	80.9	84.3	86.7	89.9						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	72.6	80.5	84.5	87.1	89.0	90.8						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	77.0	86.1	88.5	90.2	91.7	90.7						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.9	89.9	91.4	90.7	89.6	88.7						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.3	91.5	90.6	89.6	88.6	87.6	88.4					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.7	90.8	91.3	90.2	89.1	88.1	88.6					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.4	87.7	89.7	91.2	90.8	89.8						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	74.5	83.7	86.7	88.7	90.4	91.9						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	69.7	79.8	83.8	86.4	88.5							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	65.0	75.8	80.9	84.2	87.0							
Dec								0.0	0.0	0.0	0.0	0.0	63.3	72.4	78.8	82.6	85.8							

Table 5.42: Combined (1.5m) hourly percentage of illuminance on the west façade



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan								0.0	0.0	0.0	0.0	0.0	64.2	66.1	73.0	78.0	81.9							
Feb							0.0	0.0	0.0	0.0	0.0	0.0	68.1	67.6	76.6	80.9	84.1	87.8						
Mar							0.0	0.0	0.0	0.0	0.0	0.0	72.6	72.5	81.8	85.0	87.6	90.2						
Apr							0.0	0.0	0.0	0.0	0.0	0.0	77.0	77.2	87.3	89.6	91.6	89.8						
May						0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.9	80.4	91.3	90.3	88.5	86.8						
Jun						0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.3	81.7	90.2	88.7	87.1	85.4	85.4					
Jul						0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.7	81.2	91.1	89.5	87.9	86.1	85.8					
Aug						0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.4	78.7	89.0	91.0	90.4	88.6						
Sep							0.0	0.0	0.0	0.0	0.0	0.0	74.5	81.5	84.7	87.4	89.7	91.8						
Oct							0.0	0.0	0.0	0.0	0.0	0.0	69.7	75.9	80.5	83.8	86.7							
Nov							0.0	0.0	0.0	0.0	0.0	0.0	65.0	70.2	76.2	80.4	84.3							
Dec								0.0	0.0	0.0	0.0	0.0	63.3	65.9	73.1	78.0	82.4							

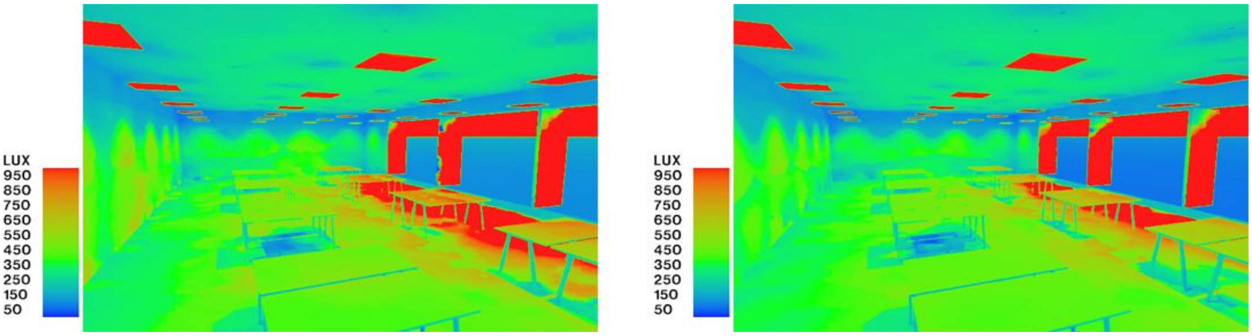


Figure 5.42: Left: West façade false colors lux levels in summer (20th June, 12:00pm), Right: West façade false colors lux levels in winter(20th December, 12:00pm) – Combined(Example: 1m)

B. Glare Threshold

North Orientation

Figure 5.43 shows more glare in summer inside the space in case of the north oriented façades; however, it was reduced by an average of 5.5% in winter due to the smaller amount of solar radiation in winter on these façades. The percentage of reduction in glare differs from one type of shading devices to another as well as further small variations in value due to the depth of shading device. In general, as the depth increases, the glare decreases.

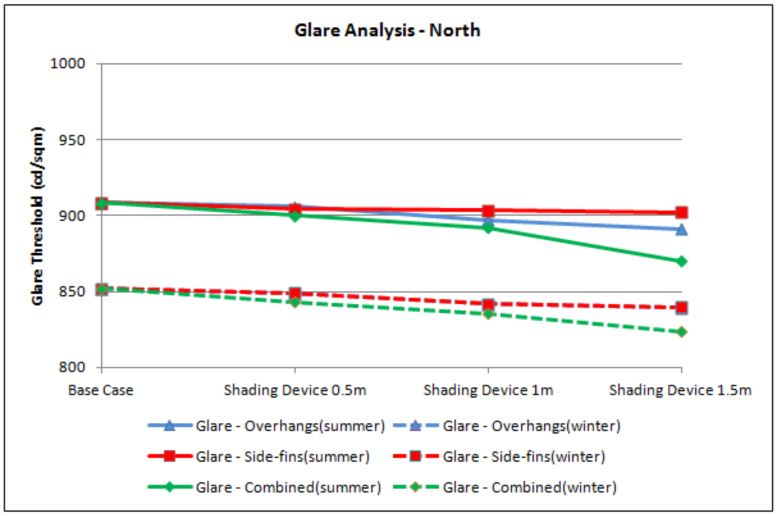


Figure 5.43: A graph showing the glare reduction in both summer and winter in all cases (North)

Base case

As for the base case, the glare threshold in summer is 908.5 cd/m^2, while, in winter its value is 851.8 cd/m^2, which has been reduced by 6.2% between the two seasons as shown in Figure 5.44.

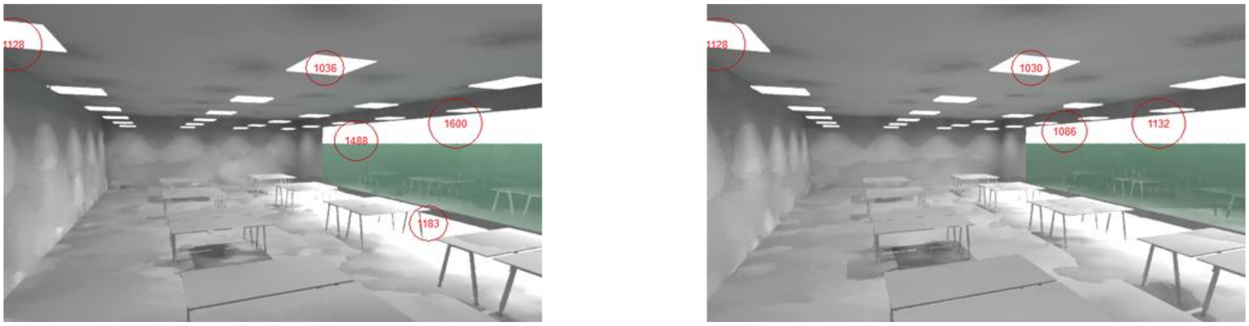


Figure 5.44: Left: North façade glare analysis in summer (20th June, 12:00pm), Right: North façade glare analysis in winter (20th December, 12:00pm), – Base case

Overhangs

As for overhangs (example: 1m depth), the glare threshold in summer is 897 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.2% between the two seasons as shown in Figure 5.45. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 1.3% and 1.2% in summer and winter respectively.

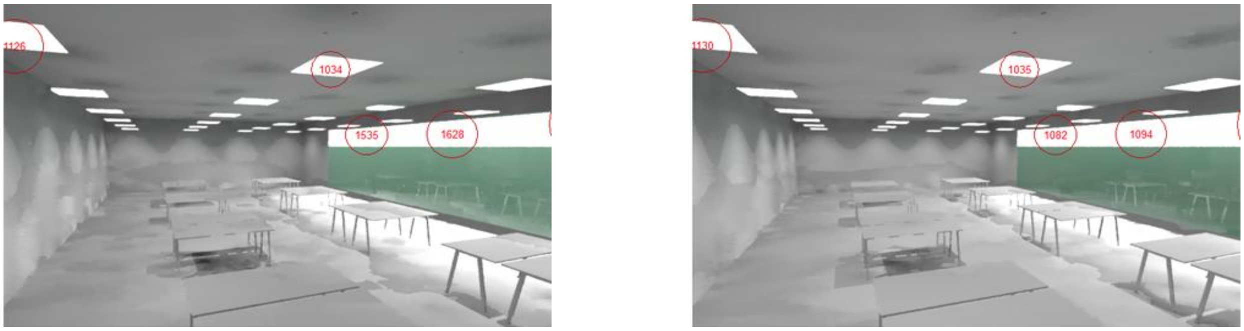


Figure 5.45: Left: North façade glare analysis in summer (20th June, 12:00pm), Right: North façade glare analysis in winter (20th December, 12:00pm), – Overhangs (Example: 1m)

Side-fins

As for side-fins (example: 1m depth), the glare threshold in summer is 903.5 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.8% between the two seasons as shown in Figure 5.46. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 0.6% and 1.9% in summer and winter respectively.

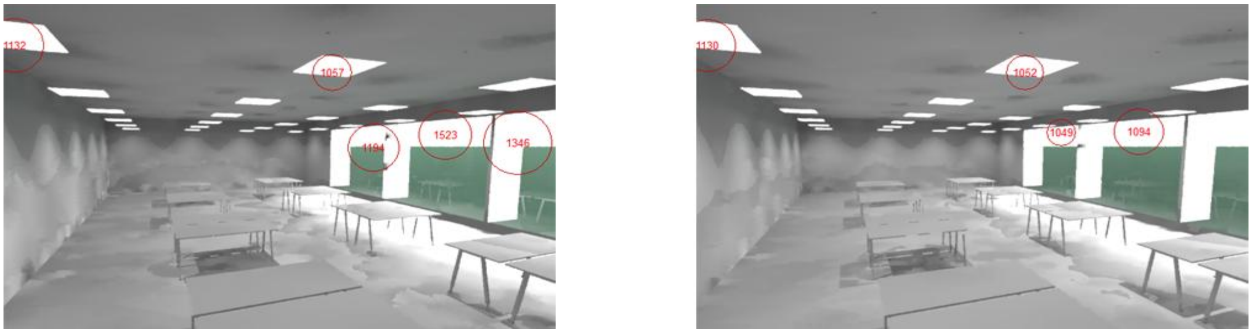


Figure 5.46: Left: North façade glare analysis in summer (20th June, 12:00pm), Right: North façade glare analysis in winter (20th December, 12:00pm), – Side-fins (Example: 1m)

Combined

As for combined (example: 1m depth), the glare threshold in summer is 892.2 cd/m^2, while, in winter its value is 835.5 cd/m^2, which has been reduced by 6.4% between the two seasons as shown in Figure 5.47. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 1.8% and 1.9% in summer and winter respectively.

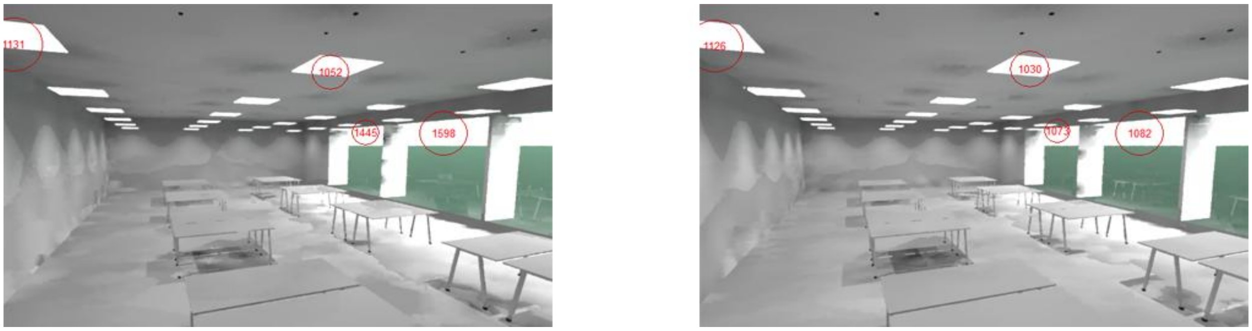


Figure 5.47: Left: North façade glare analysis in summer (20th June, 12:00pm), Right: North façade glare analysis in winter (20th December, 12:00pm), – Combined (Example: 1m)

South Orientation

Figure 5.48 shows a high glare intensity in both summer and winter seasons inside the space in case of the south oriented façades, due to the large amount of solar radiation falling on the façade especially in winter. The percentage of reduction in glare differs from one type of shading devices to another as well as further small variations in value due to the depth of shading device.

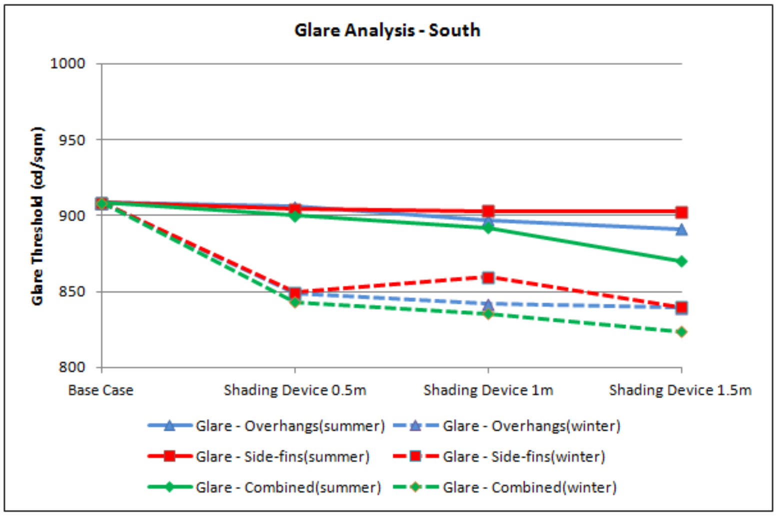


Figure 5.48: A graph showing the glare reduction in both summer and winter in all cases (South)

Base case

As for the base case, the glare threshold in both summer and winter seasons is 908.5 cd/m^2, which indicates high glare intensity throughout the year as shown in Figure 5.49.

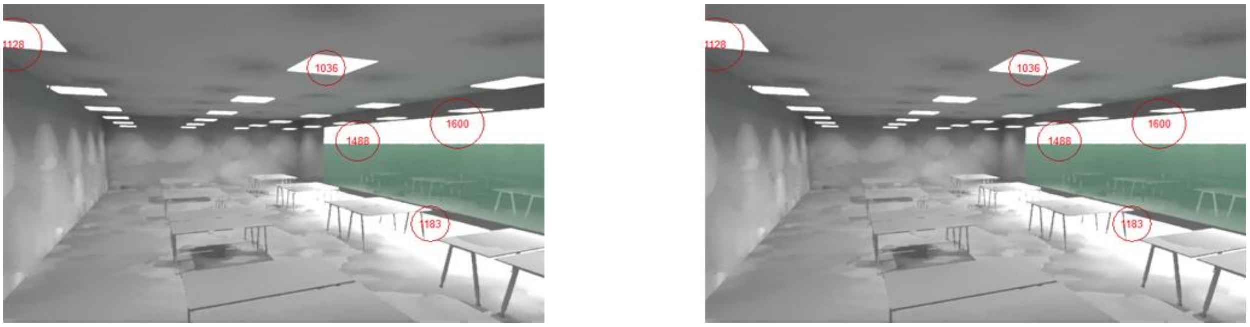


Figure 5.49: Left: South façade glare analysis in summer (20th June, 12:00pm), Right: South façade glare analysis in winter (20th December, 12:00pm), – Base case

Overhangs

As for overhangs (example: 1m depth), the glare threshold in summer is 897 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.2% between the two seasons as shown in Figure 5.50. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 7.4% and 1.3% in summer and winter respectively.

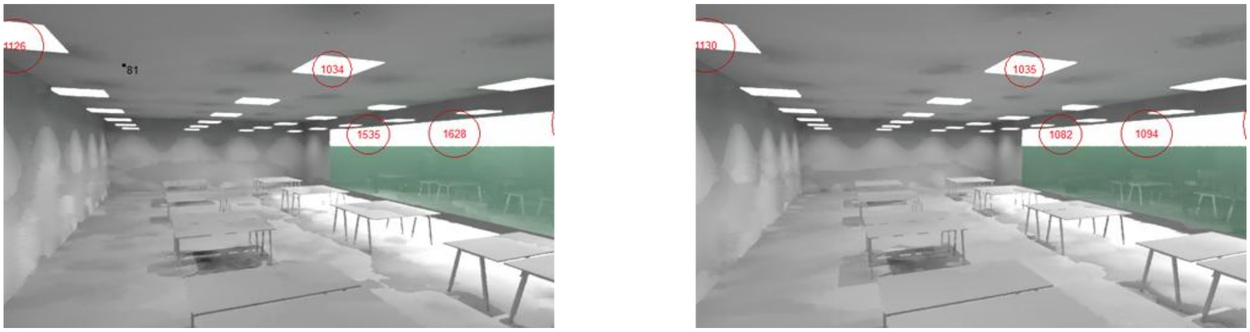


Figure 5.50: Left: South façade glare analysis in summer (20th June, 12:00pm), Right: South façade glare analysis in winter (20th December, 12:00pm), – Overhangs (Example: 1m)

Side-fins

As for side-fins (example: 1m depth), the glare threshold in summer is 903 cd/m^2, while, in winter its value is 859.6 cd/m^2, which has been reduced by 4.8% between the two seasons as shown in Figure 5.51. Meanwhile, the impact of integrating side-fins to the base case reduces the glare by 0.6% and 5.4% in summer and winter respectively.

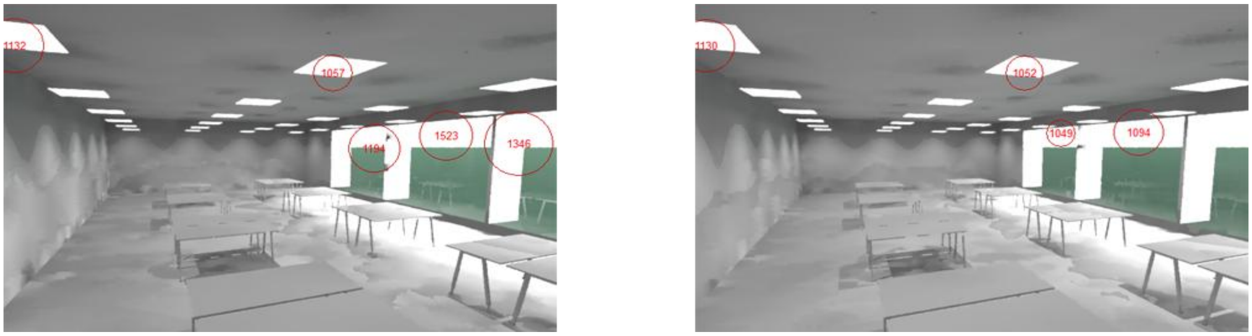


Figure 5.51: Left: South façade glare analysis in summer (20th June, 12:00pm), Right: South façade glare analysis in winter (20th December, 12:00pm), – Side-fins (Example: 1m)

Combined

As for combined (example: 1m depth), the glare threshold in summer is 892.2 cd/m^2, while, in winter its value is 835.5 cd/m^2, which has been reduced by 6.4% between the two seasons as shown in Figure 5.52. Meanwhile, the impact of integrating combined to the base case reduces the glare by 1.8% and 1.9% in summer and winter respectively.

Figure 5.52: Left: South façade glare analysis in summer (20th June, 12:00pm), Right: South façade glare analysis in winter (20th December, 12:00pm), – Combined (Example: 1m)

East Orientation

Figure 5.53 shows higher glare intensity in summer than in winter inside the space in case of the east oriented façades, due to the large amount of solar radiation falling on the façade especially in winter. The percentage of reduction in glare differs from one type of shading devices to another as well as further small variations in value due to the depth of shading device.

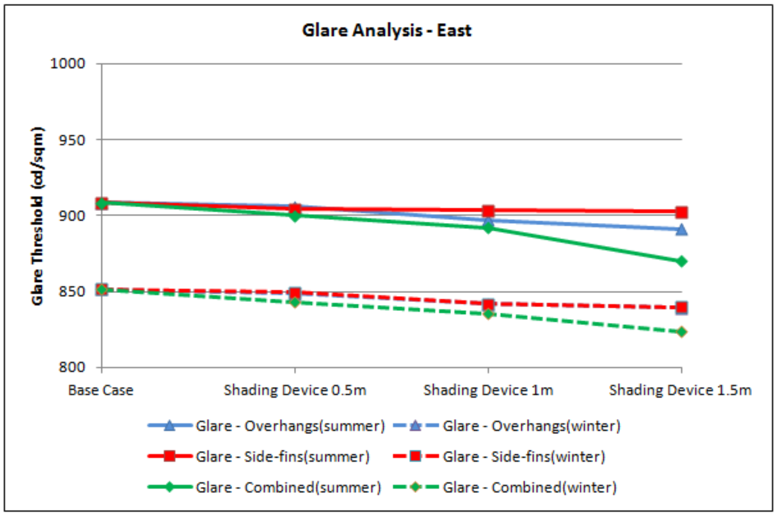


Figure 5.53: A graph showing the glare reduction in both summer and winter in all cases (East)

Base case

As for the base case, the glare threshold in summer is 908.5 cd/m^2, while, in winter its 851.6 cd/m^2, which has been reduced by 6.3% between the two seasons as shown in Figure 5.54.

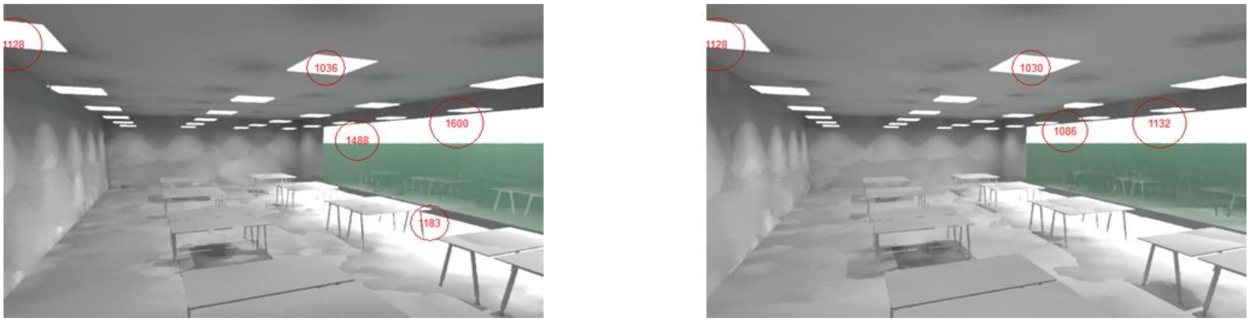


Figure 5.54: Left: East façade glare analysis in summer (20th June, 12:00pm), Right: East façade glare analysis in winter (20th December, 12:00pm), – Base case

Overhangs

As for overhangs (example: 1m depth), the glare threshold in summer is 897 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.2% between the two seasons as shown in Figure 5.55. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 1.3% and 1.2% in summer and winter respectively.

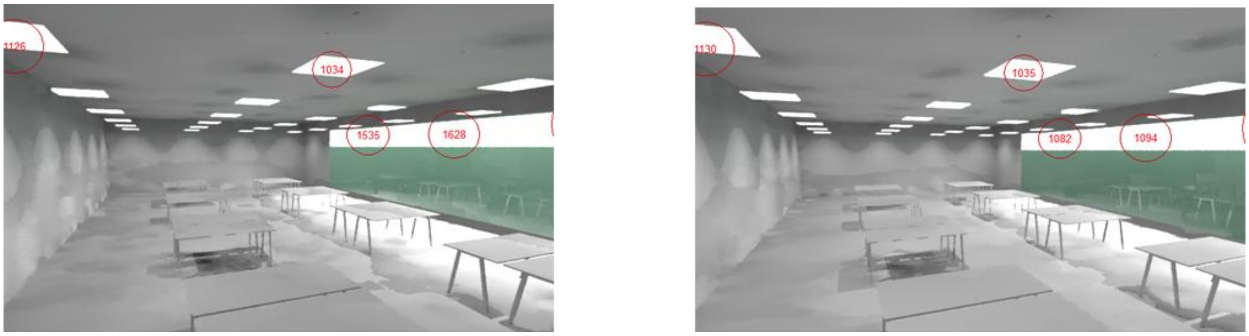


Figure 5.55: Left: East façade glare analysis in summer (20th June, 12:00pm), Right: East façade glare analysis in winter (20th December, 12:00pm), – Overhangs (Example: 1m)

Side-fins

As for side-fins (example: 1m depth), the glare threshold in summer is 903.5 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.8% between the two seasons as shown in Figure 5.56. Meanwhile, the impact of integrating side-fins to the base case reduces the glare by 0.6% and 1.2% in summer and winter respectively.

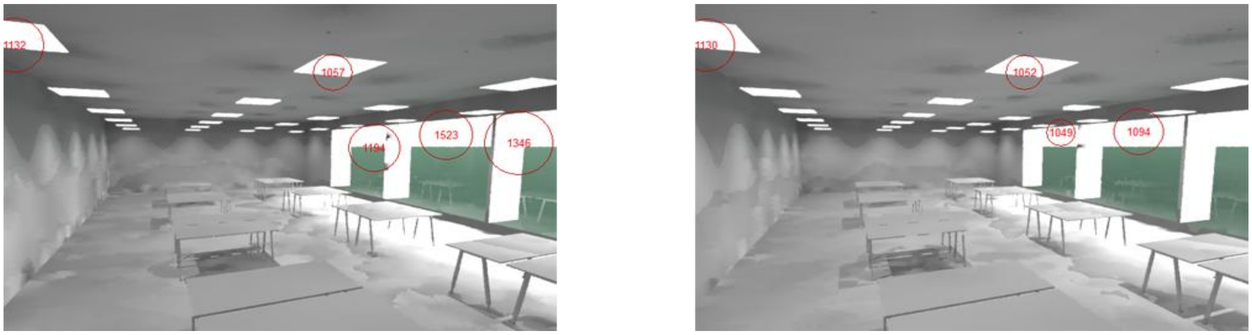


Figure 5.56: Left: East façade glare analysis in summer (20th June, 12:00pm), Right: East façade glare analysis in winter (20th December, 12:00pm), – Side-fins (Example: 1m)

Combined

As for combined (example: 1m depth), the glare threshold in summer is 892.2 cd/m^2, while, in winter its value is 835.5 cd/m^2, which has been reduced by 6.4% between the two seasons as shown in Figure 5.57. Meanwhile, the impact of integrating combined to the base case reduces the glare by 1.8% and 1.9% in summer and winter respectively.

Figure 5.57: Left: East façade glare analysis in summer (20th June, 12:00pm), Right: East façade glare analysis in winter (20th December, 12:00pm), – Combined (Example: 1m)

West Orientation

Figure 5.58 shows higher glare intensity in summer than in winter inside the space in case of the west oriented façades, due to the large amount of solar radiation falling on the façade. The percentage of reduction in glare differs from one type of shading devices to another as well as further small variations in value due to the depth of shading device.

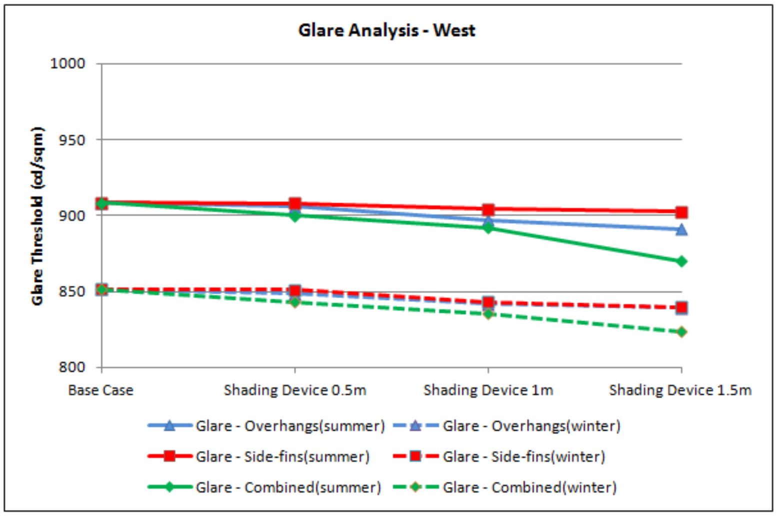


Figure 5.58: A graph showing the glare reduction in both summer and winter in all cases (West)

Base case

As for the base case, the glare threshold in summer is 908.5 cd/m^2, while, in winter its 851.6 cd/m^2, which has been reduced by 6.3% between the two seasons as shown in Figure 5.59.

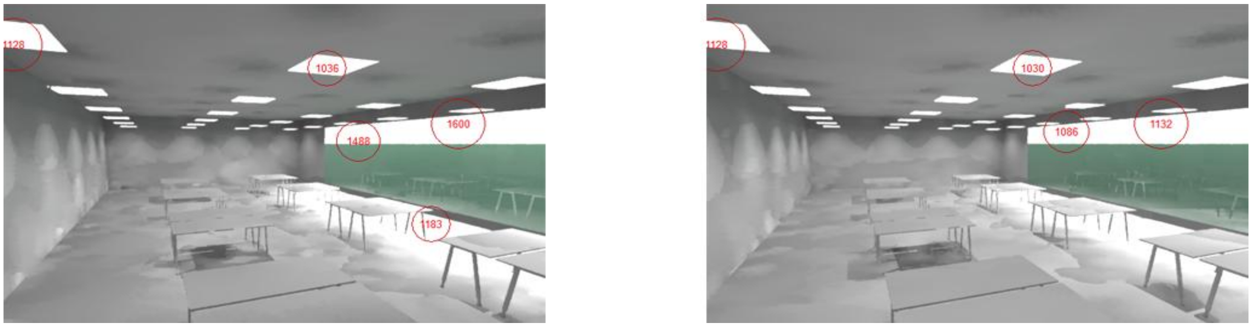


Figure 5.59: Left: West façade glare analysis in summer (20th June, 12:00pm), Right: West façade glare analysis in winter (20th December, 12:00pm), – Base case

Overhangs

As for overhangs (example: 1m depth), the glare threshold in summer is 897 cd/m^2, while, in winter its value is 841.7 cd/m^2, which has been reduced by 6.2% between the two seasons as shown in Figure 5.60. Meanwhile, the impact of integrating overhangs to the base case reduces the glare by 1.3% and 1.2% in summer and winter respectively.

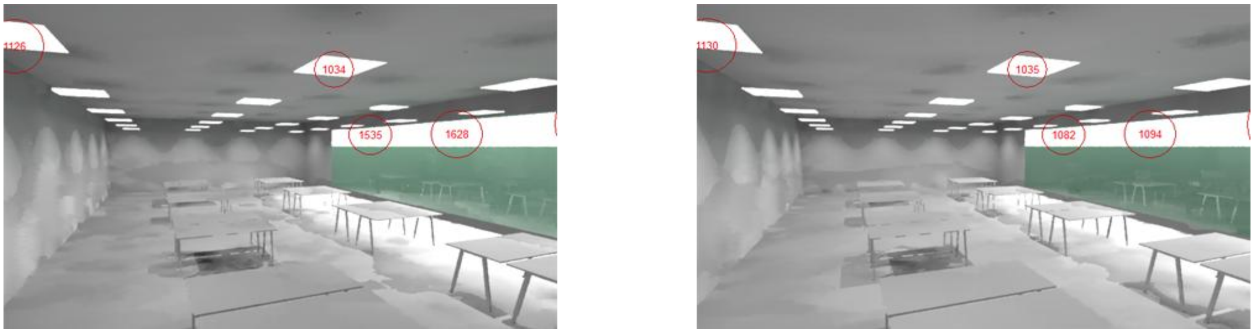


Figure 5.60: Left: West façade glare analysis in summer (20th June, 12:00pm), Right: West façade glare analysis in winter (20th December, 12:00pm), – Overhangs (Example: 1m)

Side-fins

As for side-fins (example: 1m depth), the glare threshold in summer is 904.1 cd/m^2, while, in winter its value is 843 cd/m^2, which has been reduced by 6.8% between the two seasons as shown in Figure 5.61. Meanwhile, the impact of integrating side-fins to the base case reduces the glare by 0.5% and 1% in summer and winter respectively.

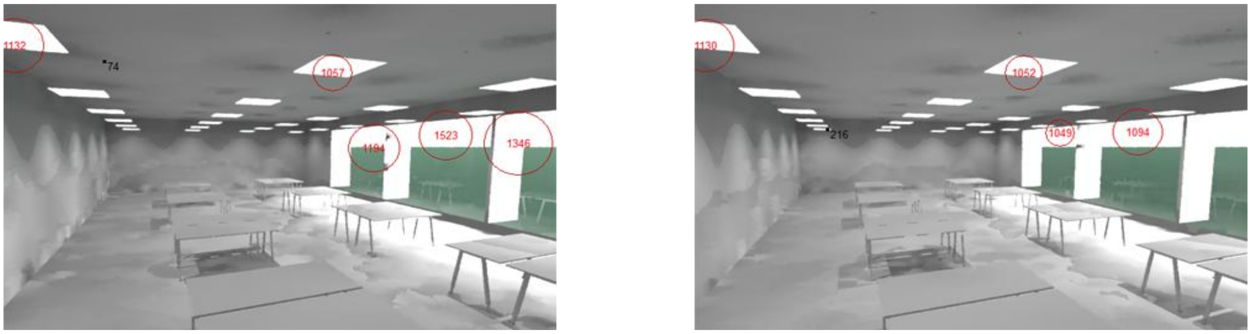


Figure 5.61: Left: West façade glare analysis in summer (20th June, 12:00pm), Right: West façade glare analysis in winter (20th December, 12:00pm), – Side-fins (Example: 1m)

Combined

As for combined (example: 1m depth), the glare threshold in summer is 892.2 cd/m^2, while, in winter its value is 835.5 cd/m^2, which has been reduced by 6.4% between the two seasons as shown in Figure 5.62. Meanwhile, the impact of integrating combined to the base case reduces the glare by 1.8% and 1.9% in summer and winter respectively.

Figure 5.62: Left: West façade glare analysis in summer (20th June, 12:00pm), Right: West façade glare analysis in winter (20th December, 12:00pm), – Combined (Example: 1m)

5.2.3 Energy Consumption

A. Annual Cooling Plant Load

North Orientation

North oriented façades contribute to a very small reduction in energy consumption compared to the other orientations throughout all the cases either base case or overhangs or side fins. As shown in Figure 5.63, the integration of the largest depth combined shading device provides a reduction of 8.3% from the base case, while, the largest depth overhang provides a reduction of 2.8% and the largest depth side-fin provides a reduction of 6.4%.

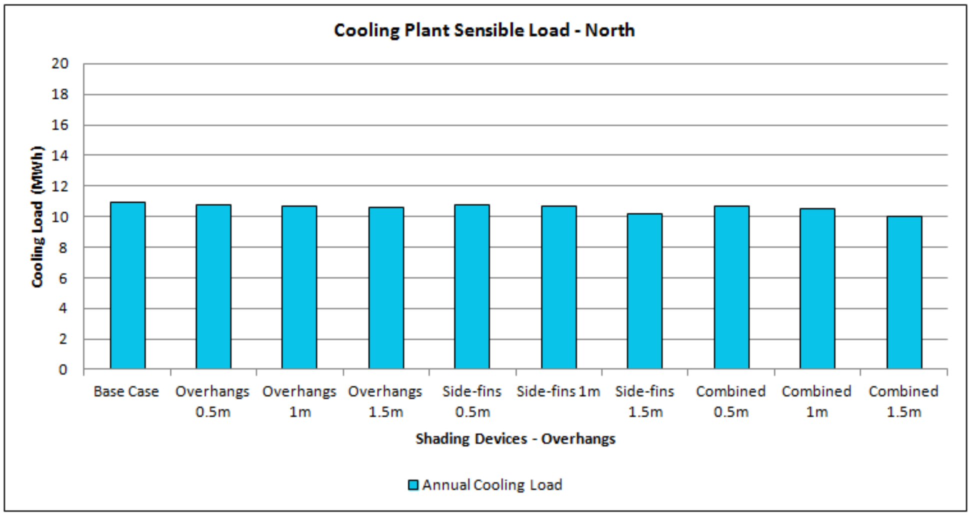


Figure 5.63: A chart showing the annual cooling load for all cases on north oriented façades

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 0.9%. Meanwhile, increasing the depth to 1m provides a further reduction of 0.9% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 0.9% from the 1m depth. Figure 5.64 presents the daily energy profile in summer and in winter of different overhangs performance. It is shown that summer achieves the peak ranges of the annual energy usage, meanwhile, the variation in overhangs' depths provides a very small contribution to the energy consumption results.

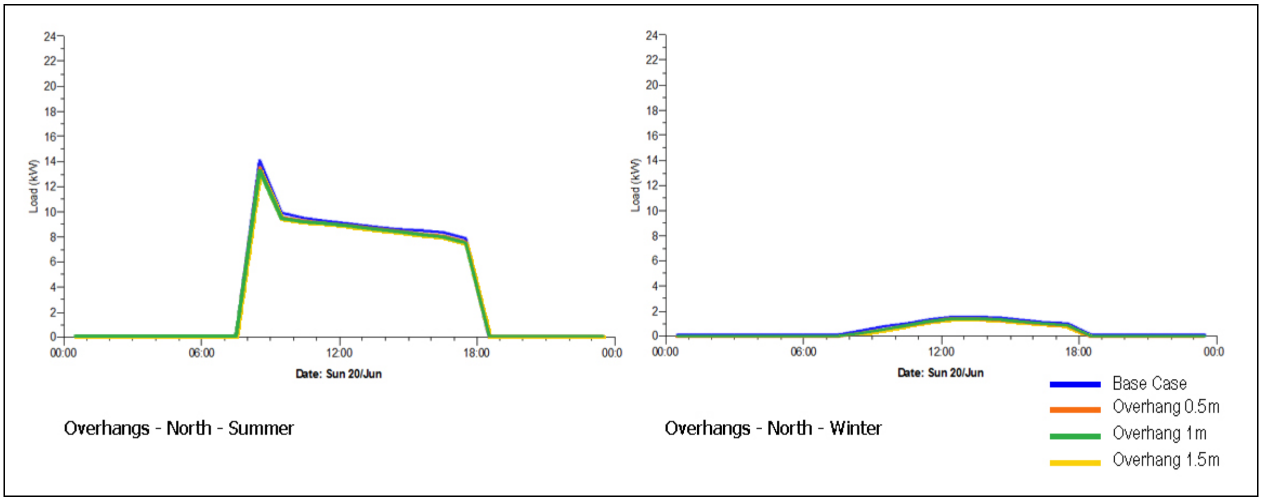


Figure 5.64: A graph showing the daily cooling load profile of overhangs 1m in summer and winter for north oriented façades

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 0.9%. Meanwhile, increasing the depth to 1m provides a further reduction of 0.9% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 4.7% from the 1m depth. Figure 5.65 presents the daily energy profile in summer and in winter of different overhangs performance. It is shown that summer achieves the peak ranges of the annual energy usage, meanwhile, the variation in side-fins' depths provides a very small contribution to the energy consumption results.

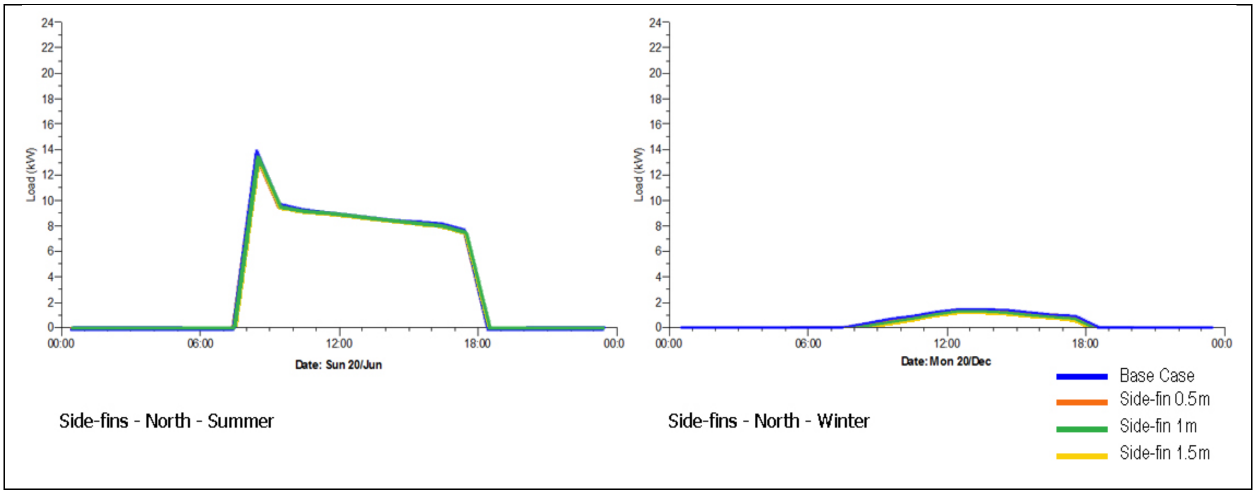


Figure 5.65: A graph showing the daily cooling load profile of side-fins 1m in summer and winter for north oriented façades

South Orientation

South oriented façades contribute to the largest reduction in energy consumption compared to the other orientations throughout all the cases either base case or overhangs or side fins. As shown in Figure 5.66, the integration of the largest depth combined shading device provides a reduction of 27.5% from the base case, while, the largest depth overhang provides a reduction of 17% and the largest depth side-fin provides a reduction of 12.9%.

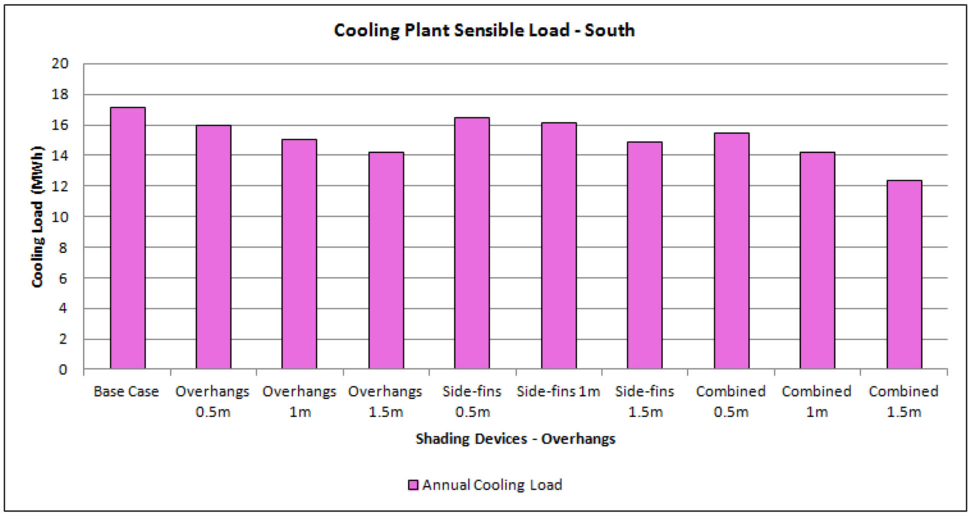


Figure 5.66: A chart showing the annual cooling load for all cases on south oriented façades

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 6.4%. Meanwhile, increasing the depth to 1m provides a further reduction of 6.3% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 5.4% from the 1m depth. Figure 5.67 presents the daily energy profile in summer and in winter of different overhangs performance. It is shown that summer and winter profiles achieve the high ranges of the energy consumption, meanwhile, the variation in overhangs' depths seems to be more effective in winter.

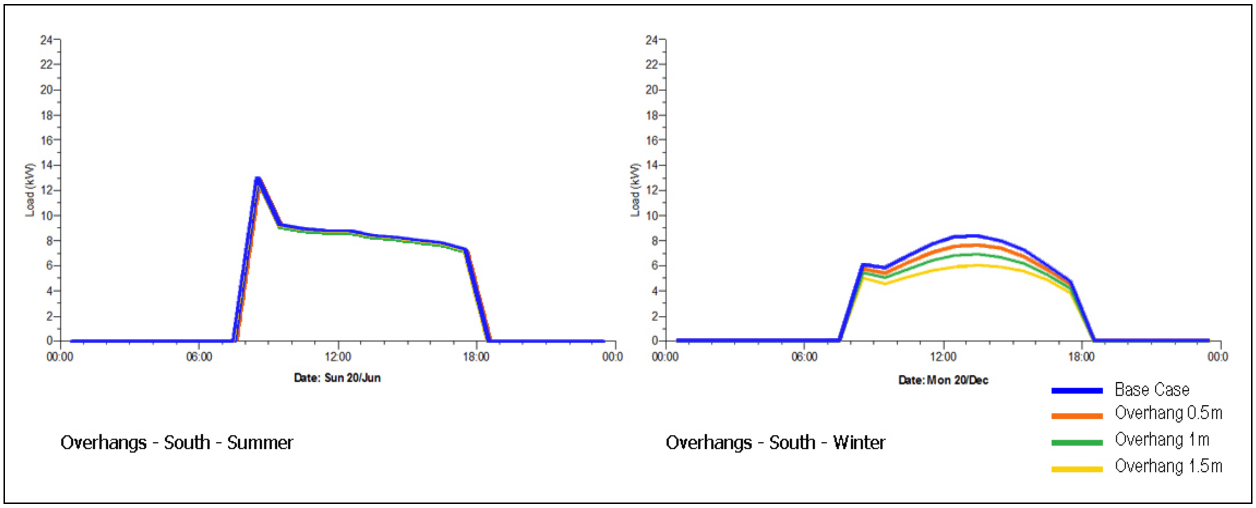


Figure 5.67: A graph showing the daily cooling load profile of overhangs 1m in summer and winter for south oriented façades

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 3.5%. Meanwhile, increasing the depth to 1m provides a further reduction of 2.4% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 7.1% from the 1m depth. Figure 5.68 presents the daily energy profile in summer and in winter of different side-fins performance. It is shown that summer and winter profiles achieve the high ranges of the energy consumption, meanwhile, the variation in overhangs' depths seems to be more effective in winter.

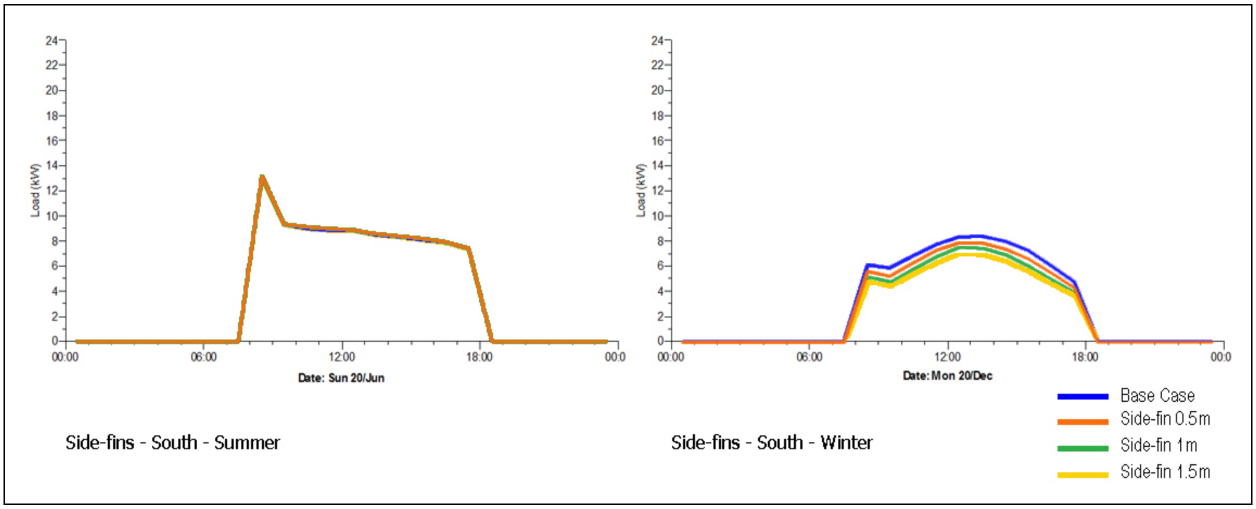


Figure 5.68: A graph showing the daily cooling load profile of Side-fins 1m in summer and winter for south oriented façades

East Orientation

East oriented façades contribute to moderate reductions in energy consumption compared to the other orientations throughout all the cases either base case or overhangs or side fins. As shown in Figure 5.69, the integration of the largest depth combined shading device provides a reduction of 22.6% from the base case, while, the largest depth overhang provides a reduction of 13.4% and the largest depth side-fin provides a reduction of 10.4%.

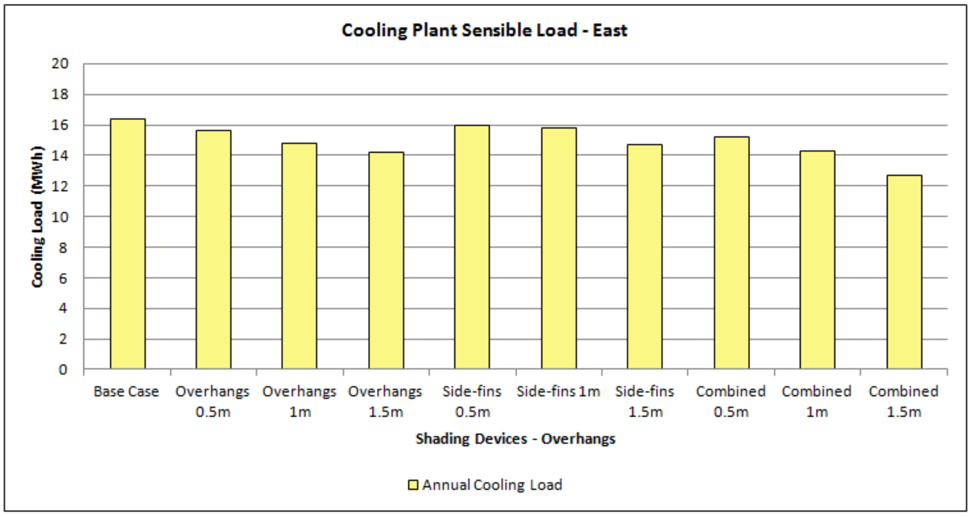


Figure 5.69: A chart showing the annual cooling load for all cases on east oriented façades

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 4.9%. Meanwhile, increasing the depth to 1m provides a further reduction of 5.1% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 4.1% from the 1m depth. Figure 5.70 presents the daily energy profile in summer and in winter of different overhangs performance. It is shown that summer achieves the peak ranges of the annual energy usage, meanwhile, the variation in overhangs' depths contributes to the energy consumption results in winter slightly higher than in summer.

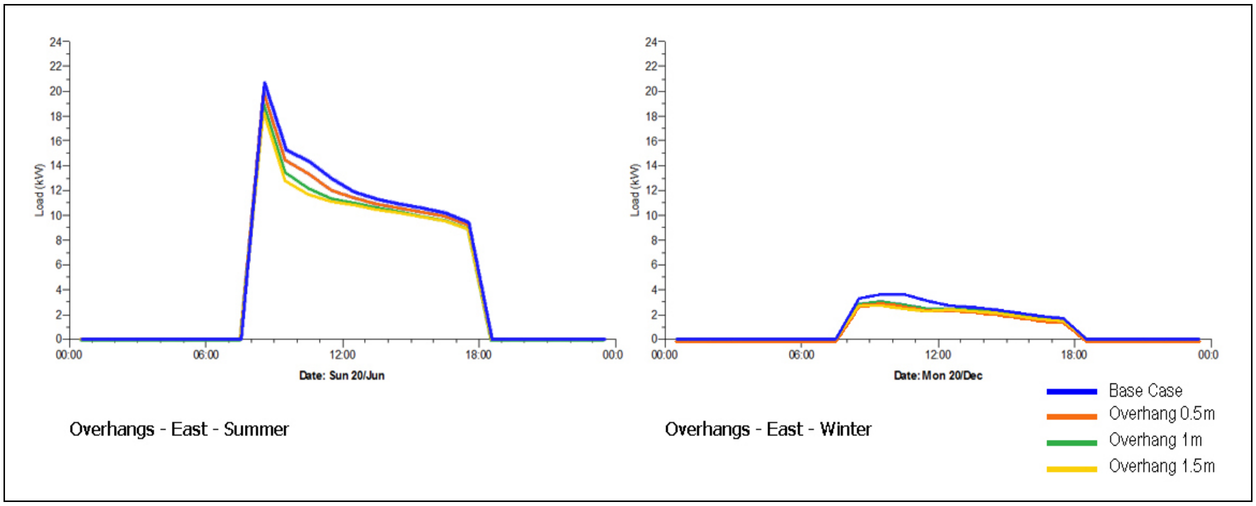


Figure 5.70: A graph showing the daily cooling load profile of overhangs 1m in summer and winter for east oriented façades

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 2.4%. Meanwhile, increasing the depth to 1m provides a further reduction of 1.3% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 7% from the 1m depth. Figure 5.71 presents the daily energy profile in summer and in winter of different side-fins' performance. It is shown that summer achieves the peak ranges of the annual energy usage; meanwhile, the variation in overhangs' depths contributes to the energy consumption results in winter slightly higher than in summer.

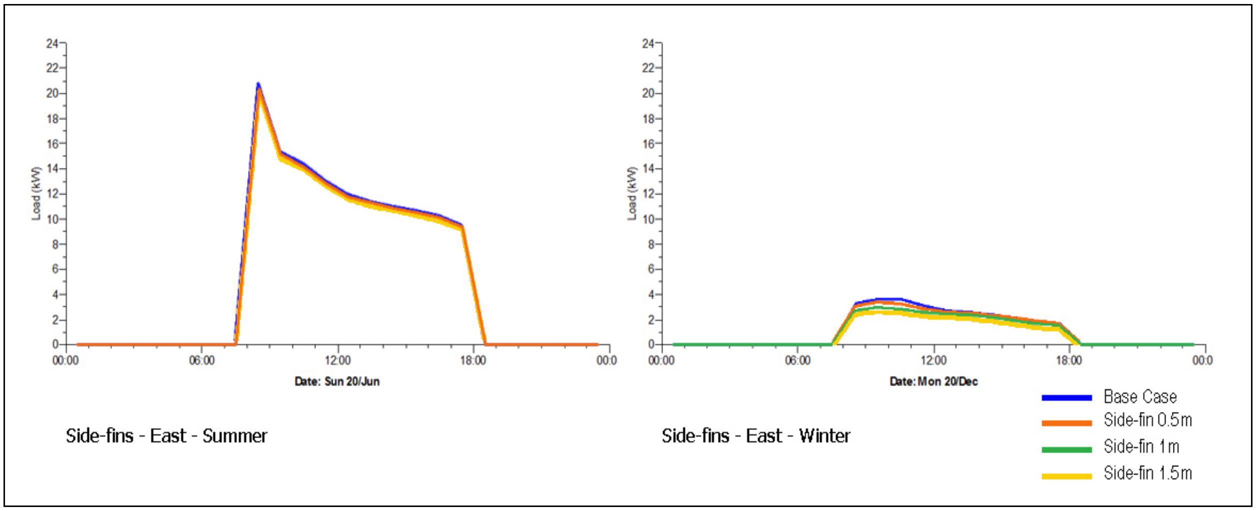


Figure 5.71: A graph showing the daily cooling load profile of Side-fins 1m in summer and winter for east oriented façades

West Orientation

West oriented façades contribute to moderate reductions in energy consumption compared to the other orientations throughout all the cases either base case or overhangs or side fins. As shown in Figure 5.72, the integration of the largest depth combined shading device provides a reduction of 21.2% from the base case, while, the largest depth overhang provides a reduction of 12.1% and the largest depth side-fin provides a reduction of 10.3%.

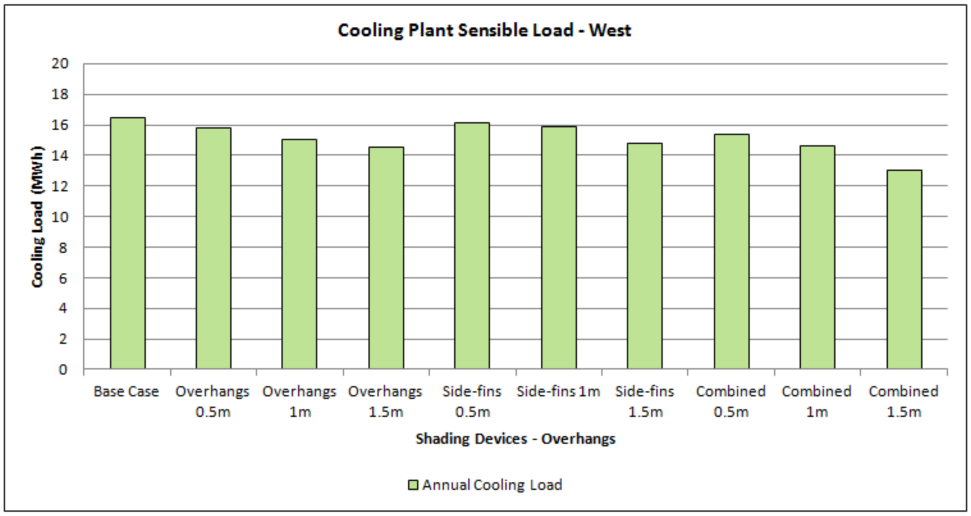


Figure 5.72: A chart showing the annual cooling load for all cases on west oriented façades

When comparing overhangs according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 4.2%. Meanwhile, increasing the depth to 1m provides a further reduction of 5.1% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 3.3% from the 1m depth. Figure 5.73 presents the daily energy profile in summer and in winter of different overhangs performance. It is shown that summer achieves the peak ranges of the annual energy usage.

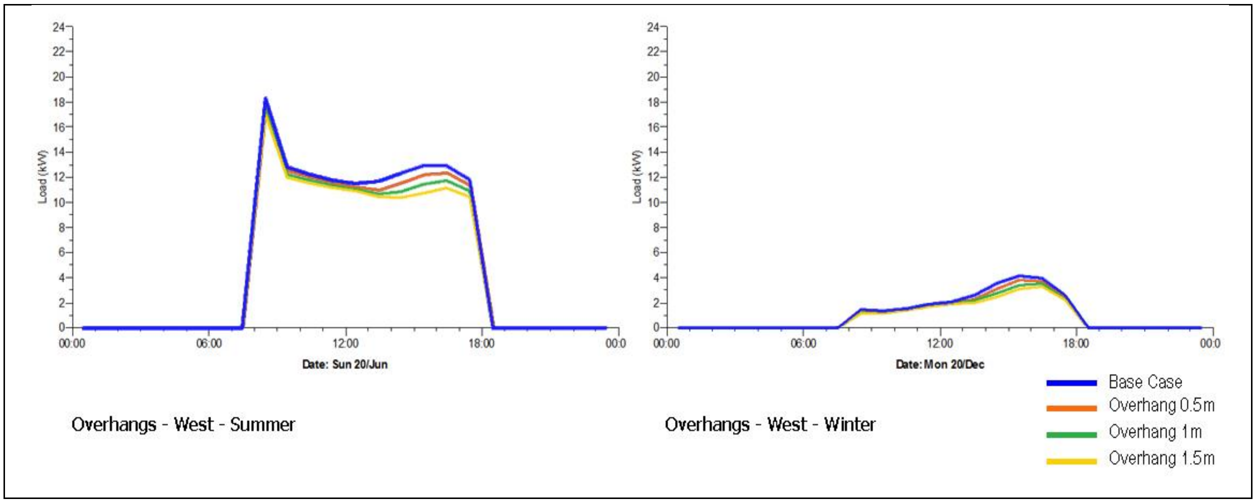


Figure 5.73: A graph showing the daily cooling load profile of overhangs 1m in summer and winter for west oriented façades

When comparing side-fins according to their different depths (0.5m, 1m and 1.5m), energy consumption reduction between the base case and the 0.5m depths turns out to be 2.4%. Meanwhile, increasing the depth to 1m provides a further reduction of 1.2% only from the 0.5m depth, while, increasing the depth to 1.5m provides a reduction of 7% from the 1m depth. Figure 5.74 presents the daily energy profile in summer and in winter of different side-fins' performance. It is shown that summer achieves the peak ranges of the annual energy usage.

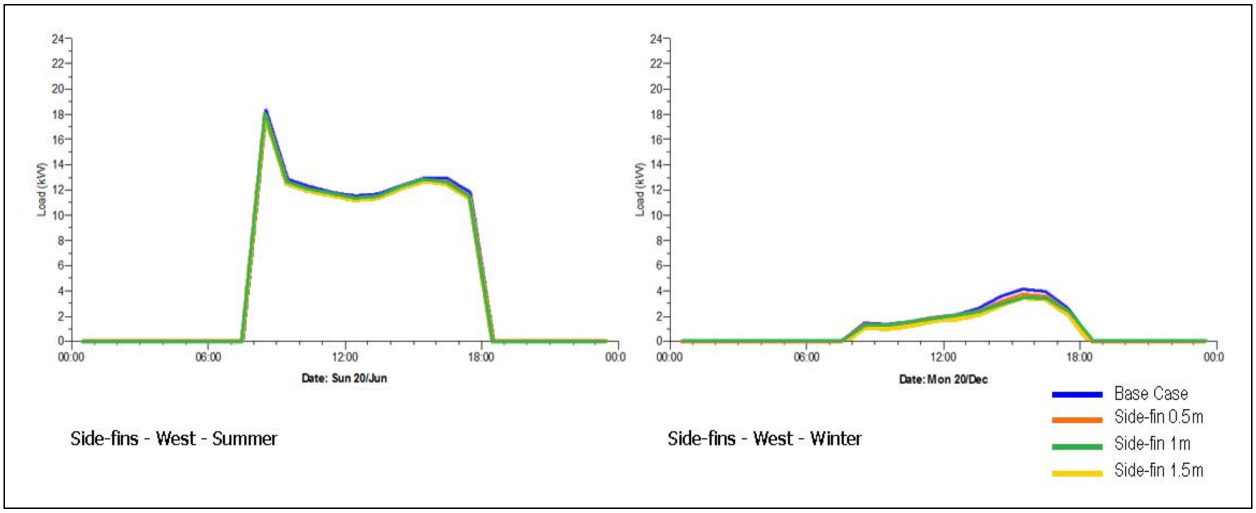


Figure 5.74: A graph showing the daily cooling load profile of side-fins 1m in summer and winter for west oriented façades

Comparing North and South Orientations

When comparing annual cooling loads for north and south orientations, Figure 5.75 shows that there is a very significant difference between north and south energy consumption, since the south orientation cooling loads exceeds the north orientation ones by 36% which is a major amount of energy. Meanwhile, the figure illustrates the large variation in energy consumption when integrating shading elements to the south façade, which reflects its significant effectiveness. However, the variation in cooling load is very small in case of the north façade.

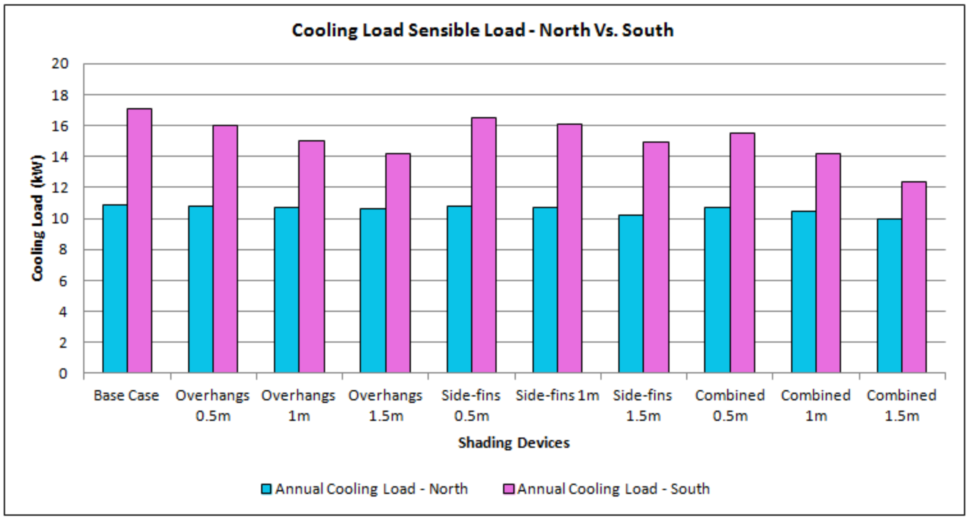
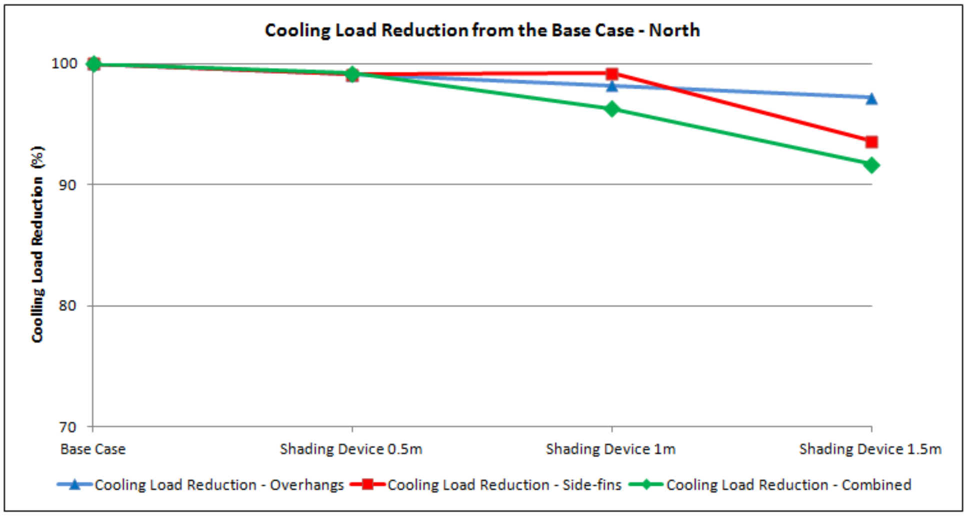


Figure 5.75: A chart comparing north and south orientations in terms of annual cooling load

Figure 5.76 shows the percentage of reduction of each of the shading device cases from the base case in the north and south façades. It illustrates that in the north, the largest depth overhangs, side-fins and combined contribute to reductions of 2.8%, 6.4% and 8.3% respectively, however, in case of the south oriented façades, the largest depth overhangs, side-fins and combined contribute to reductions of 17%, 12.9% and 27.5% respectively.



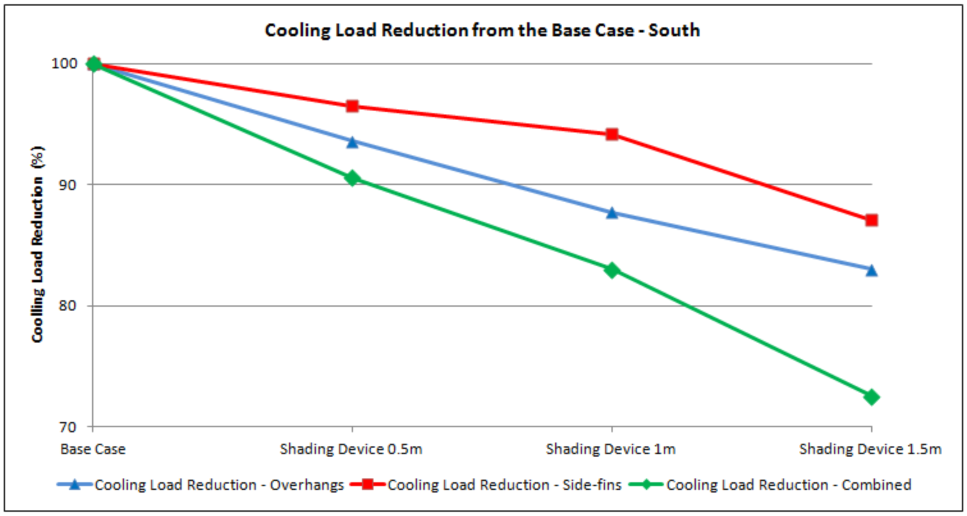


Figure 5.76: A graph showing annual cooling load reductions for north (top) and south (bottom) orientations

Comparing East and West Orientations

When comparing annual cooling loads for east and west orientations, Figure 5.77 shows that there is a very slight difference between east and west energy consumption, since the west orientation cooling loads exceeds the east orientation ones by 0.6% which is a major amount of energy. Meanwhile, the figure illustrates a moderate variation in energy consumption when integrating shading elements to the east and west façades.

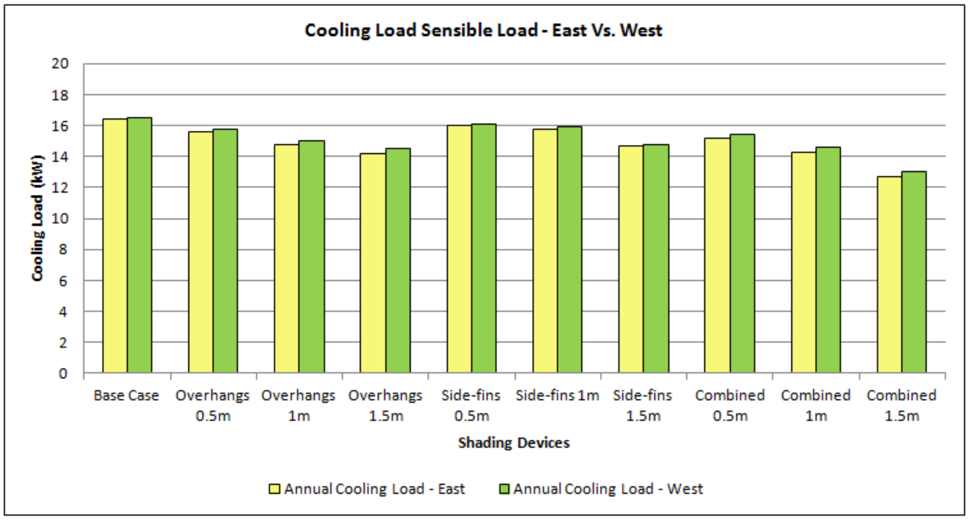
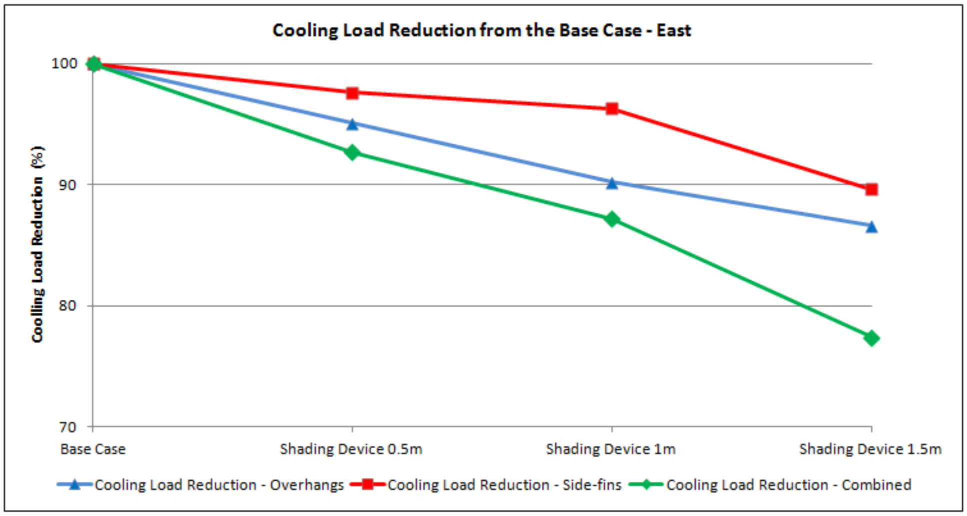


Figure 5.77: A chart comparing east and west orientations in terms of annual cooling load

Figure 5.78 shows the percentage of reduction of each of the shading device cases from the base case in the east and west façades. It illustrates that in the east, the largest depth overhangs, side-fins and combined contribute to reductions of 13.4%, 10.4% and 22.6% respectively, however, in case of the west oriented façades, the largest depth overhangs, side-fins and combined contribute to reductions of 21.1%, 10.3% and 21.2% respectively.



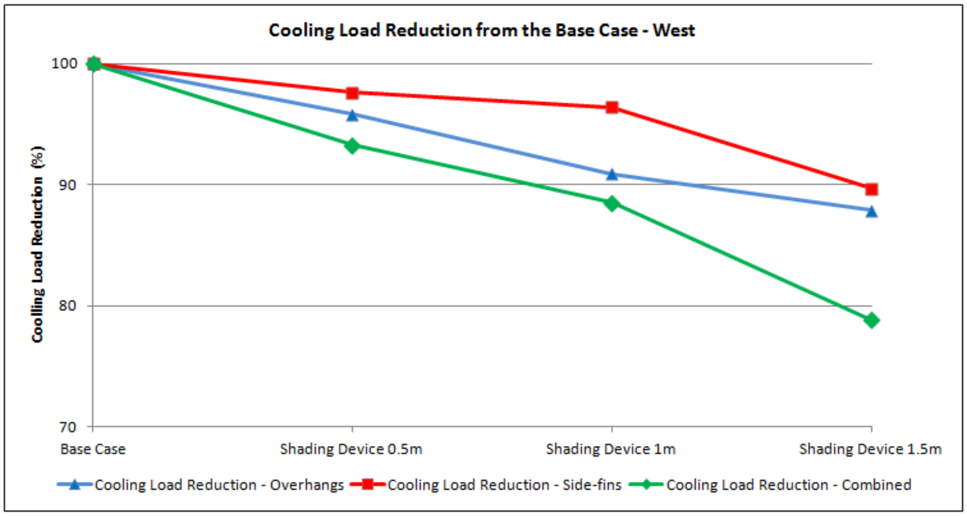


Figure 5.78: A graph showing annual cooling load reductions for East (top) and West (bottom) orientations

CHAPTER 6: DISCUSSION

6.1 Introduction

Using building performance simulation tools, this study asses the impact of different shading scenarios (overhangs, side-fins and combined) on the occupant’s thermal and visual comfort, in addition to the system’s energy consumption. The study is utilized to seek the balance between the three aspects in respect to the building orientations as well as the season variation. The base case was first assessed, then followed by the different cases, which are; overhangs of depths 0.5m, 1m and 1.5m, side-fins of depths 0.5m, 1m and 1.5m and combined cases of overhangs and side-fins with depths 0.5m, 1m and 1.5m. Meanwhile, all other parameters such as; the design data, the materials, occupants and heat gains where kept constant. Then further analysis was conducted to give estimation calculated output values reflecting measures related to thermal comfort, visual comfort and energy consumption.

The performed literature review clearly shows that most buildings in UAE were designed irrespective to occupants’ comfort criteria due to the lack of integrating shading elements to the fully glazed façades located in a very hot and humid climate, which consequently higher the rate of energy usage as explained by AboulNaga referring to data obtained from Dubai Electricity and Water Department (2001).

A study performed by Young Yan (2012) looked at the relation between illuminance levels in open plan offices in Korea and the building’s energy profile, Young Yan recognized how human perception affect their visual comfort rates depending on the illuminance levels they are used to. Meanwhile, the workstations set up in relation to the glazed façade directly influence the illuminance levels and intensity of the occupant, besides, their attitude of using artificial lighting strongly impact the energy consumed in the space. Another research performed by Datta (2001) investigated the relation between louver shading devices integrated to different façades and occupants’ thermal comfort. The results obtained ensured the variation of the shading coefficient between different times of the day as well as between the different seasons, meanwhile, taking into consideration the occupants’ clothing, the cooling system set point and shading device properties in terms of the position of the louvers and the slats width and location. Generally, many studies addressed buildings’ energy consumption, one of which, Palmero-Marrero (2010), clarified that a significant reduction in energy could be specified in different countries located at various latitudes and climates and yet maintaining adequate thermal comfort levels for occupants.

6.2 Discussion

6.2.1 Thermal Comfort

In terms of thermal comfort criteria, the shading element selection depends majorly on the outdoor climate as well as the opening sizes. As explained by Tzempelikos (2007), in order to trace the sunlight transmittance an hourly basis simulation should be performed in respect to the sunrays' angle of incidence to get a feeling of the amount of solar radiation penetrating into the space. In general, Baker (2002) mentioned how important shading is to the users' comfort, since it could lower the indoor temperature ranging from 3C° to 7C°. For this study, it was observed that shading devices notable reduce the amount of solar gains penetrating the glazing ranging between 13.5% and 55%.

For this study, values of annual and peak solar gain were recorded. The results indicated that north façades are known to receive the least amount of solar radiation (base case: 5.2 MWh) in comparison to the east, west and south orientations, since annual solar gain could be ultimately reduced from the base case by 26.9%, 17.3% and 13.5% respectively for combined, overhangs and side-fins. Meanwhile, south façades is the most affected by shading devices integration due to its largest amount of solar gain (base case: 12.5 MWh), since the maximum reductions achieved are 55% in case of combined overhangs and side-fins, 41.1% in case of overhangs and 18.6% in case of side-fins.

As for east and west orientations, they tend to receive close values of annual solar gain (base case: east façade 11.8 MWh and west façade 12.2 MWh). As mentioned by Lovell (2010), due to the low sun position at east and west orientations, in addition to the sun's frequently changing position, it creates a challenge to control the amount of solar gain entering the space. However, Alzoubi (2010) noticed the benefit of integrating vertical shading devices to such façades, which provides adequate daylighting levels and at the same time preventing excessive solar gain. On the east façade, combined overhangs and side-fins resulted in a 44.9% reduction in terms of annual amount of solar radiation, whereas overhangs and side-fins achieve ultimate reductions of

10.2% and 13.6% respectively. However, the west oriented façades, combined overhangs and side-fins resulted in a 55% reduction in terms of annual amount of solar radiation, whereas overhangs and side-fins achieve ultimate reductions of 41.1% and 18.6% respectively. In general, Datta (2001) ensured the positive effect of implementing shading elements to any building envelope, which could lead to reducing the solar gain in 70% and 40% in summer and winter respectively.

As for the base case, the seasonal variation of peak value solar gain penetrating indicated that north orientation have the minimum difference between the peak solar gain in summer (1.8 MWh) and in winter (1.1 MWh). While, the south façade tend to own the optimum variation between the two seasons (1.8 MWh and 9.9 MWh) due to the difference in sun position. Meanwhile, east and west façades record the same peak value in summer (7.7MWh). However, in winter, the west orientation peak value (6.5 MWh) is slightly higher than that of the east (5.9 MWh). The amount of annual solar gain also proves the recorded rates percentage of people dissatisfied (PPD), which reflects occupants' thermal comfort. In summer, people feel discomfort when seated next to east and west façades, which recorded values of 27% and 26% respectively, which is the highest percentage, followed by the north and south façade, which encountered a led PPD of 21% and 20% respectively. However, in winter the south orientation experiences the largest PPD of 19% due to the sun's altitude, followed by the east and west façades, which recorded a similar percentage of 14%, while the least percentage of 12% belongs to the north façade.

Overhangs

Concerning horizontal overhangs, there is a variation between the effectiveness of overhangs depth increase on the four orientations. As for the overhang 0.5m depth, it is most effective on south and west façades achieving a similar reduction in annual solar gain of 15.5%, while, it seems to have a reduction of only 7.7% on the north façade, which is considered the least. Meanwhile, they are moderately effective on the east façade, which recorded a reduction of 8.7% from the base case. When expanding the overhang depth to 1m, the south façade recorded the ultimate reduction of solar radiation from the 0.5m depth, which is 17.4%, followed by the east orientation, which has achieved a reduction of 14.6%, while the north and west façades tend to have a similar moderate solar gain behavior of 6.2% and 6% respectively. Meanwhile, a further increase in the overhang depth to 1.5m results in a 15.6% reduction in case of the south oriented façades, followed by a 12.5% reduction on the east façade, then a 10.4% reduction on the north façade, while the least reduction of 4.5% was recorded on the west façade.

In general, the thermal comfort scenario resulting from integrating overhangs shows that in summer, it seemed to be most effective on south façades, which recorded a PPD of 18%, followed by the north orientation, which indicated a PPD of 20%. While, it seemed to be the least effective on east and west orientations, which accounted for the highest levels of discomfort as 23% and 24% respectively. However, in winter, north orientation accounted for the least PPD, followed by the east and west orientations, which provided a similar PPD of 13%, on the other hand, south façades accounted for the highest PPD (16%) because of the solar altitude.

Side-fins

As for vertical side-fins 0.5m depth, integrating it to the south, east and west façades recorded a similar values of 9.3%, while, the north orientation scored a less reduction percentage of 7.7%. Side-fins of depth 1m seems to be highly efficient on east façades decreasing the solar gain by 9.6% from the 0.5m depth, followed by the south and west façades, which are almost equal in value since the south is reduced by 5.9% and the west by 6%. However, the north orientation is the least affected by increasing the side-fin depth to 1m as it records a reduction of 2.2% only. Meanwhile, a further expansion of the side-fin depth to 1.5m results that south façades experiences the largest solar gain value reduction of 13.6%, followed by the east and west façades, which recorded reductions of 10.4% and 4.5% reductions from the 1m depth side-fins. Meanwhile, enlarging the side-fin depth on the north orientation did not progress any reduction in solar radiation levels.

As for the thermal comfort indicators resulting from the integration of side-fins to the façade, in summer, north and south façades, which recorded a similar PPD of 20%, however, it could have negative visual implications, followed by the east and west orientations, which recorded very close PPD of 26% and 25% respectively. However, in winter, side-fins seemed to be the most effective on the north orientation with a PPD of 11%, followed by the east and west orientations, which accounted for similar discomfort levels of 13%. Meanwhile, they achieved the highest discomfort level of 16% on the south façade.

Combined overhangs and side-fins

Regarding integrating combined overhangs and side-fins to different façades, which could be interpreted into a balcony or a recessed window, 0.5m depth results in a reduction of 24% from the base case on the south and west façades, which is considered the highest compromise. While, the east façade solar gain is reduced by 19.5%, however, the north orientation is reduced by 13.5%. Expanding the shading device depth to 1.5m results in a reduction of 23.5% from the 1m depth on the south and west façades, which is considered the largest reduction, while, the east façade solar gain is reduced by 18.9%, on the other hand, the north orientation records the least reduction of is 8.9%. A further increase in the shading device depth provides a reduction of 22.7% from the 1m depth on the south and west façades, while, the east façade solar gain is reduced by 15.6% and the north orientation records a 7.3% decrease, which is the least affected by enlarging the depth to 1.5m.

Concerning occupants' thermal comfort indicators resulting from the integration of combined overhangs and side-fins to the façade, in summer, north and south façades seemed more efficient, which recorded a similar PPD of 20%, followed by east and west orientations, which recorded close PPD of 24% and 25% respectively. However, in winter, combined shading elements seemed to be the most effective on the north orientation, followed by the east and west orientations, which accounted for 12% and 13% respectively. Meanwhile, they achieved the highest discomfort level of 15% on the south façade.

6.2.2 Visual Comfort

Speaking about occupants' visual comfort, values for office average illuminance and glare were recorded. To get exact position of the sun we need latitude, longitude, date and time (Baker, 2002). As for the base case, in summer, north façade account for 78% among 9 daytime hours which results in a low intensity illumination, on the other hand south façades are completely receive direct sunlight among 2 hours of the daytime, which indicates a very high illumination intensity. As stated by Tzempelikos (2007), since the sunlight incidence on the south façades is the largest among all orientations, designers should set this as criteria when designing the façade apertures. In winter, north façades are completely shaded throughout the whole day, which indicates the minimum illumination levels inside the space, on the contrary, south façades receives continuous direct sunlight through the whole daytime. However, east and west orientations receive average direct sunlight on 50% of the façade area among daytime hours. As for the glare threshold, in summer all orientations recorded a similar value (908.5 cd/m^2), while in winter, south façades are subjected to the highest glare levels (908.5 cd/m^2), followed by the north, east and west orientations which achieved almost the same values of 851.8 cd/m2, 851.6 cd/m^2, 851.6 cd/m^2 respectively.

Meanwhile, east and west orientations account moderate intensity direct sunlight on 50% of the façade area among daytime hours. Harriman (2009) advised to lessen the windows on the east and west façade in tropical countries due to the sun position. Meanwhile, Lovell (2010) strongly recommended implementing shading elements to west oriented façades to avoid accumulated thermal gain among the whole day as well as the visually uncomfortable direct afternoon sun rays. Also, Palmero-Marrero (2010) ensured that vertical shading elements are more appropriate for east and west directed façades, however horizontal ones are more suitable for the south orientation.

Overhangs

As for horizontal overhangs, there is a variation between the space's average illuminations resulting from the increase in the overhang depth on the four orientations. As for the north orientation, in summer, integrating overhangs of 0.5m depth account for reduction in the illuminance intensity by 83% from the base case, which is highly effective, while increasing the depth to 1m provide a further reduction of 4.8%, meanwhile, a further increase in the depth resulted in a 3.8% reduction for the 1.5m depth. In addition, the percentage of glare possibility is reduced by 1.3%. In winter, the façade does not receive any direct sunlight, while the percentage of glare is reduced by 1.2%, which is considered a very minute reduction.

As for the south orientation, in summer, integrating overhangs of 0.5m depth account for reduction in the illuminance intensity by 80.6% from the base case, while increasing the depth to

1m provide a further reduction of 4.8%, meanwhile any further increase in the overhang depth does not contribute to the reduction of illuminance intensity. In addition, the percentage of glare possibility is reduced by 7.4%. In winter, implementing overhangs of 0.5m depth account for reduction in the illuminance intensity by 93.5% from the base case, which is considered the largest contribution to the reduction of the illuminance intensity, while increasing the depth to 1m provide a further reduction of 1% only, meanwhile, increasing the depth to 1.5m provides a very minute reduction of 1.3%. In addition, the percentage of glare is slightly reduced by 1.3%.

Regarding the east façade, in summer, the implementation of 0.5m overhang provides a reduction of 91.8% which is considered a very high percentage, while, increasing its depth to 1m records a slight reduction of 1% only from the 0.5m, which remains constant in case of any further increase in the overhang depth. In addition, the percentage of glare possibility is reduced by 1.3%. In winter, integrating 0.5m overhang provides a reduction of 87.4%, while, increasing its depth to 1m records a reduction of 2.7% from the 0.5m, meanwhile, increasing the depth to 1.5m indicated a further reduction of 5.1%. Moreover, the percentage of glare is slightly reduced by 1.2%.

As for the west orientation, integrating 0.5m overhangs achieved the same reduction value of 92.2% from the base case in both summer and winter seasons. In summer, increasing the overhang depth to 1m results in a very slight reduction of 1%, however integrating 1.5m overhangs provides a reduction of 2.1% from the 1m depth. In addition, the percentage of glare possibility is reduced by 1.3%. In winter, overhangs of 1m depth reduces the illuminance intensity by 5.1% from the 0.5m, while, integrating the 1.5m overhang accounts for a further reduction of 1.8%. In addition, the percentage of glare is slightly reduced by 1.2%.

Side-fins

As for vertical side-fins, there is a variation between the space’s average illumination resulting from the increase in the overhang depth on the four orientations. As for the north orientation, in summer, integrating overhangs of 0.5m depth account for a reduction in the illuminance intensity by 80% from the base case. While increasing the depth to 1m provide a further reduction of 7%, meanwhile, a further increase in the depth resulted in a 2% reduction for the 1.5m depth. In addition, the percentage of glare possibility is reduced by 0.6% only. In winter the façades does not receive any direct sunlight, while the percentage of glare is reduced by 1.9% which is considered a small reduction.

As for the south orientation, in summer, integrating side-fins of 0.5m depth account for reduction in the illuminance intensity by 93.4% from the base case, while any further increase in the depth does not provide any reduction in the illuminance intensity. In addition, the percentage of glare possibility is reduced by 0.6%. In winter, implementing side-fins of 0.5m depth account for reduction in the illuminance intensity by 93% from the base case, while increasing the depth to 1m provides a further reduction of 5.5%, meanwhile, increasing the depth to 1.5m provides a very minute reduction of 5.2%. Moreover, the percentage of glare is slightly reduced by 5.4%.

Regarding the east façade, in summer, the implementation of 0.5m side-fins provides a large reduction of 96.7%, while increasing its depth to 1m records almost the same value of the 0.5m, while, increasing the depth to 1.5m also accounts for a very minute reduction. In addition, the percentage of glare possibility is reduced by 0.6% only. In winter, integrating 0.5m overhang provides a reduction of 87%, while, increasing its depth to 1m records a reduction of 5.9% from the 0.5m, meanwhile, increasing the depth to 1.5m indicated a further reduction of 4.3%. Also, the percentage of glare is slightly reduced by 5.4%.

As for the west orientation, in summer, integrating 0.5m side-fins achieved a reduction value of 96.8% from the base case, while, increasing the side-fin depth to 1m results in a very slight reduction of 1.1%, however, integrating 1.5m overhangs provides a reduction of only 1% from the 1m depth. In addition, the percentage of glare possibility is reduced by 0.5% only. In winter, 0.5m side-fins contribute to a reduction of 89.1% from the base case, meanwhile, increasing the depth to 1m reduces the illuminance intensity by 6% from the 0.5m, while integrating the 1.5m side-fin accounts for a further reduction of 4.5%. Also, the percentage of glare is slightly reduced by 1% only.

Combined overhangs and side-fins

As for combined overhangs and side-fins, there is a variation between the space's average illumination levels resulting from the increase in the shading device depth on the four orientations. As for the north orientation, in summer, integrating overhangs of 0.5m depth account for reduction in the illuminance intensity by 72% from the base case, while, increasing the depth to 1m provide a further reduction of 9.4%, meanwhile, a further increase in the depth resulted in a 2.5% reduction for the 1.5m depth. In addition, the percentage of glare possibility is reduced by 1.8% only. In winter, the façades does not receive any direct sunlight, while the percentage of glare is reduced by 1.9%.

As for the south orientation, in summer, integrating combined overhangs and side-fins of 0.5m depth account for reduction in the illuminance intensity by 78.5% from the base case, while, any further increase in the depth does not provide any reduction in the illuminance intensity. In addition, the percentage of glare possibility is reduced by 1.8%. In winter, implementing combined overhangs and side-fins of 0.5m depth account for reduction in the illuminance intensity by 86.7% from the base case, while increasing the depth to 1m provides a further reduction of 6.2%, meanwhile, increasing the depth to 1.5m provides a very minute reduction of 6%. Also, the percentage of glare is slightly reduced by 1.9%.

Regarding the east façade, in summer, the implementation of 0.5m combined overhangs and side-fins provides a reduction of 89.2%, while increasing its depth to 1m records a reduction of 2.7% from the 0.5m depth, meanwhile, increasing the depth to 1.5m also accounts for a 1.2% reduction. In addition, the percentage of glare possibility is reduced by 1.8%. In winter, integrating 0.5m overhang provides a reduction of 80%, while, increasing its depth to 1m records a reduction of 6.9% from the 0.5m, meanwhile, increasing the depth to 1.5m indicated a further reduction of 5.2%. Also, the percentage of glare is slightly reduced by 1.9%.

As for the west orientation, in summer, integrating 0.5m combined overhangs and side-fins achieved a reduction value of 89.5% from the base case, while, increasing the side-fin depth to 1m results in a reduction of 1.5%, however integrating 1.5m overhangs provides a reduction of 2.8% from the 1m depth. In addition, the percentage of glare possibility is reduced by 1.8% only. In winter, 0.5m depth contribute to a 82.6% reduction from the base case, meanwhile, increasing the depth to 1m reduces the illuminance intensity by 7.5% from the 0.5m, while integrating the 1.5m side-fin accounts for a further reduction of 5.1%. Also, the percentage of glare is slightly reduced by 1.9% only.

6.2.3 Energy Consumption

In order to discuss the energy performance of the office sample, values for office annual cooling plant sensible load and total system energy were recorded. In general total system energy values are directly proportional with the cooling sensible load, which sounds logic. As for the base case, north façade annual cooling load is 10.9 MWh, which is considered the least annual cooling load value among the four orientations because north façades tends to receive the least amount of solar radiations throughout the year, on the other hand south façades account for a 17.1 MWh, which is the highest value. Meanwhile, east and west orientations records moderate cooling load values of 16.4 MWh and 16.5 MWh respectively, which indicates a are very close scenario. Datta (2001) ensured that integrating horizontal shading devices to south oriented façades results in a significant reduction in the building's cooling loads. In general, Kima (2012) stated the direct proportion between the depth of the shading device and the percentage of energy saving. Meanwhile, Carbonari (2001) preferred orienting the building on the North-South direction rather than the East-West direction since north and south owns the minimum and the maximum daylight availability, which creates a balance in terms of energy consumption. In addition, book 5

Overhangs

Concerning horizontal overhangs in the north orientation, the 0.5m depth overhang achieves a reduction of 0.9% from the base case, which is a low influence. Moreover, any increase in the overhang depth provides a further reduction of the same percentage. Therefore, 2.8% is considered the maximum reduction from the base case obtained when implementing 1.5m overhangs, which ensures the limited effect of overhangs on the north façade. On the other hand, in the south orientation, the 0.5m depth overhang achieves a reduction of 6.4% from the base case, which is a significant variation due to the high solar gain, while, increasing the depth to 1m provide a further reduction of 6.3%. Meanwhile, a further increase in the depth resulted in a 5.4% reduction for the 1.5m depth. Hence, the maximum reduction provided by overhangs is

17%, which shows the positive effect of integrating overhangs to the south façade, in addition, any increase in the overhang depth provide a significant difference.

As for the east and west orientations, the 0.5m depth overhangs achieves a reduction of 4.9% and 4.2% respectively, while, increasing the depth to 1m provide a further reduction of 5.1% in both orientations. Meanwhile, a further increase in the depth resulted in a 4.1% and 3.3% reduction respectively for the 1.5m depth. Therefore, the maximum reduction considered when implementing overhangs is 13.4% on the east façade and 12.1% on the west façade, which are considered moderate reductions compared to those of the north and south orientations.

Side-fins

Concerning vertical side-fins in the north orientation, the 0.5m depth side-fin achieves a reduction of 0.9% from the base case, which is a low influence. Moreover, any increasing the depth to 1m provides the same reduction percentage. Meanwhile, enlarging the side-fin to 1.5m provides a higher percentage of 4.7% due to the relation between the shading device and the sun position. Therefore, 6.4% is considered the maximum reduction from the base case obtained when implementing 1.5m overhangs, which shows the low influence of side-fins on the north façade. On the other hand, in the south orientation, the 0.5m depth side-fin achieves a reduction of 3.5% from the base case, while, increasing the depth to 1m provide a further reduction of 2.4%. Meanwhile, a further increase in the depth resulted in a 7.1% reduction for the 1.5m depth, due to the solar altitude. Hence, the maximum reduction provided by side-fins is 12.9%, which shows the good impact of integrating side-fins to the south façade.

As for the east and west orientations, the 0.5m depth overhangs achieves a reduction of 2.4% in both orientations, while, increasing the depth to 1m provide a further reduction of 1.3% and 1.2% respectively. Meanwhile, a further increase in the side-fin depth to 1.5m on both façades resulted in a 7%. Therefore, the maximum reduction considered when implementing side-fins is 10.4% on the east façade and 10.3% on the west façade, which explains an average influence compared to those of the north and south orientations.

Combined overhangs and side-fins

Regarding combined overhangs and side-fins, they provide the best results in terms of energy saving as more shading is provided to any building apertures, as more energy its operation system could save. However, other parameters such as the average illuminance in the space should influence the selection of the appropriate device as not to compromise with required illumination levels and occupant's visual comfort. As for the north oriented façades integrating combined overhangs and side-fins of depth 1.5m could contribute to a reduction of 8.3% of the cooling loads required, while south orientation account for a 27.5% reduction from the base case, which is considered the optimum performance among all cases. When integrating 1.5m combined overhangs and side-fins to east and west orientations, the reductions obtained were 22.6% and 21.2% respectively, which also shows a good influence of shading devices on east and west façades.

CHAPTER 7: ECONOMICAL ANALYSIS

7.1 Introduction

Building cost is a very complicated issue, which is affected by many aspects. The building design will determine the path of the life time building cost, which is majorly influenced by its energy behavior which comes at the first place, therefore, Morrissey (2011) ensured that there are still a lot of complains towards implementing strict guidelines for energy consumption, however, these measures are the key to lower life-time costs for the building, in addition, utilizing passive design strategies help to achieve reasonable building costs.

7.2 Capital costs

Capita costs are the initial costs spend in the construction till the building starts operating which could be direct costs such as construction materials and their installation as well as mechanical systems or indirect costs such as; building permit fees and licences.

7.3 Life cycle costing

The life cycle costing of a building includes all costs related to the construction materials, their installation, operation costs including electricity costs from lighting and HVAC system, which is affected majorly by the cooling load demand as well as its peak load frequency (Mayhoub, 2011). Meanwhile, any regulations in the energy performance would highly affect the whole life cycle costing.

The formula used in calculating the payback period is $EPP = PEC_{energy}/E_{sav}$ as per Chan (2010).

EPP = Payback period

PEC_{energy} = Primary energy consumption

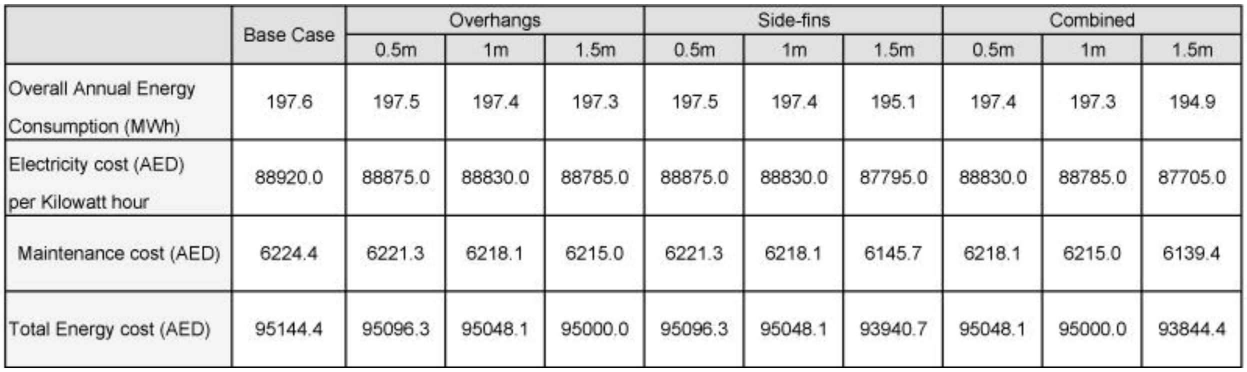
E_{saving} = Amount of energy savings

7.4 Economical Analysis:

In order to perform an economic analysis, three parameters have to be considered; the construction costs, the energy costs and the payback period. Payback periods is the period at which the investor gets a return income from the building equal to the capital cost that was invested in the project (Mayhoub, 2011). In order to compare the various options of shading elements economically, the annual energy costs would be affected by the operation profiles of the building in terms of operating times, frequency and peak loads. The annual consumption was calculated roughly taking into consideration the electricity rate in Dubai, which is 0.45 KW/h as per Dubai Electricity and Water Authority “DEWA”. In addition, a 7% would be added as maintenance costs. As for construction costs, basic materials would be assumed, therefore construction costs would be neglected for this analysis.

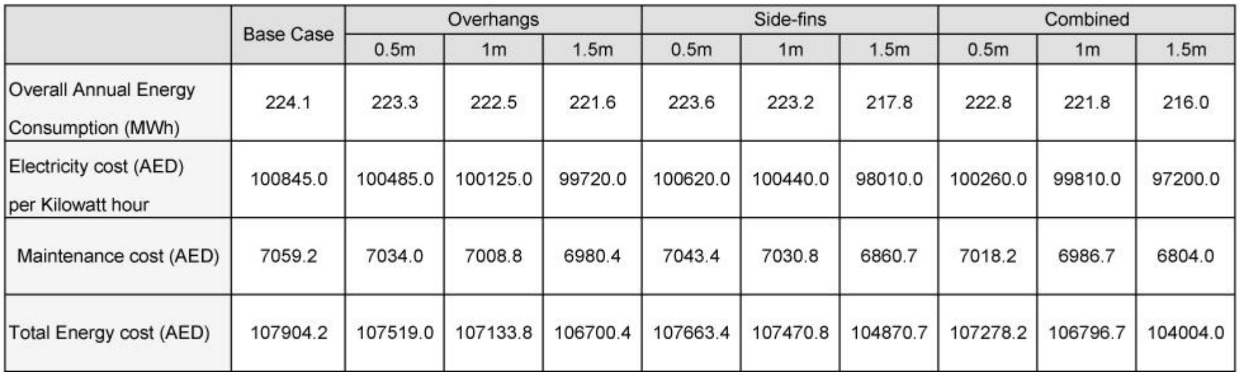
As shown in Table 7.1, energy costs for the north oriented façades are relatively close in value among all cases, which ensures the limited effect of implementing shading devices. However, on the south oriented façades; a clear variation in energy cost is noticed as shown in Table 7.2, which proves how efficient the integration of shading elements to the south façade is. As stated by Datta (2001), horizontal shading devices are significantly important, as they are the best energy saving solution for the south oriented façades.

Table 7.1: North orientation overall energy cost calculation



	Base Case	Overhangs			Side-fins			Combined		
		0.5m	1m	1.5m	0.5m	1m	1.5m	0.5m	1m	1.5m
Overall Annual Energy Consumption (MWh)	197.6	197.5	197.4	197.3	197.5	197.4	195.1	197.4	197.3	194.9
Electricity cost (AED) per Kilowatt hour	88920.0	88875.0	88830.0	88785.0	88875.0	88830.0	87795.0	88830.0	88785.0	87705.0
Maintenance cost (AED)	6224.4	6221.3	6218.1	6215.0	6221.3	6218.1	6145.7	6218.1	6215.0	6139.4
Total Energy cost (AED)	95144.4	95096.3	95048.1	95000.0	95096.3	95048.1	93940.7	95048.1	95000.0	93844.4

Table 7.2: South orientation overall energy cost calculation



	Base Case	Overhangs			Side-fins			Combined		
		0.5m	1m	1.5m	0.5m	1m	1.5m	0.5m	1m	1.5m
Overall Annual Energy Consumption (MWh)	224.1	223.3	222.5	221.6	223.6	223.2	217.8	222.8	221.8	216.0
Electricity cost (AED) per Kilowatt hour	100845.0	100485.0	100125.0	99720.0	100620.0	100440.0	98010.0	100260.0	99810.0	97200.0
Maintenance cost (AED)	7059.2	7034.0	7008.8	6980.4	7043.4	7030.8	6860.7	7018.2	6986.7	6804.0
Total Energy cost (AED)	107904.2	107519.0	107133.8	106700.4	107663.4	107470.8	104870.7	107278.2	106796.7	104004.0

Figure 7.1 and 7.2 gives an overview on the total energy saving percentage of each shading device in all orientations. In general, combined overhangs and side-fins provide the maximum saving in all orientations; however, they could have negative impacts on the illuminance levels inside the space.

As shown in Figure 7.1, the north orientation side-fins and overhangs seem to have a very small effect, even though after their depth increase. In the south orientation, overhangs seem to be more effective than side-fins due to the sun position, since they save energy up to 17 MWh annually in case of implementing 1.5m overhangs.

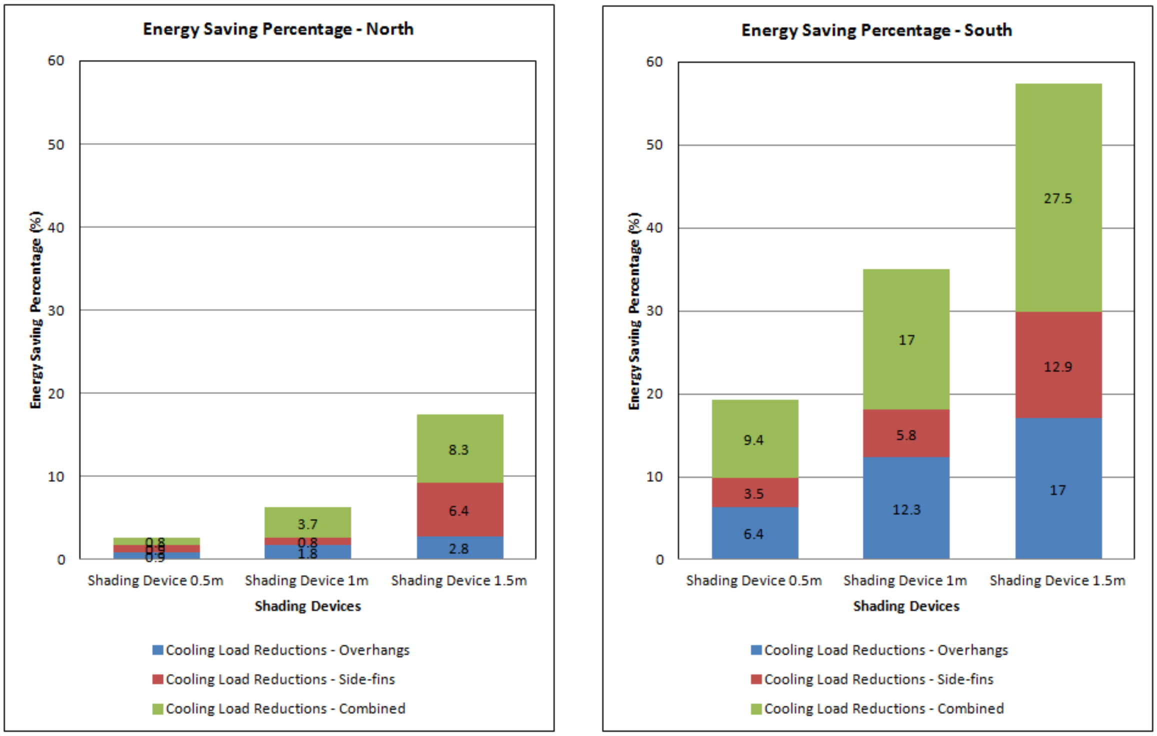


Figure 7.1: Annual energy saving in all cases for North (left) and South façades (right)

As shown in Table 7.3, and Table 7.4 energy costs for the east and west orientations show that side-fins save more money among all cases, however, in some cases overhangs gave better results depending on the sun position at certain times of the day. Meanwhile, side-fins are suitable for lower sun incidence angles found in case of east and west orientations, which could cause a raise in the space's temperature as well as visual discomfort for occupants (Lovell, 2010). Moreover, Harriman (2011), recommended small size openings in any building on the east and west façade in order to avoid most of the early morning and the afternoon sun.

Table 7.3: East orientation overall energy cost calculation

	Base Case	Overhangs			Side-fins			Combined		
		0.5m	1m	1.5m	0.5m	1m	1.5m	0.5m	1m	1.5m
Overall Annual Energy Consumption (MWh)	221.0	220.4	219.8	219.3	220.7	220.5	215.5	220.1	219.3	214.1
Electricity cost (AED) per Kilowatt hour	99450.0	99180.0	98910.0	98685.0	99315.0	99225.0	96975.0	99045.0	98685.0	96345.0
Maintenance cost (AED)	6961.5	6942.6	6923.7	6908.0	6952.1	6945.8	6788.3	6933.2	6908.0	6744.2
Total Energy cost (AED)	106411.5	106122.6	105833.7	105593.0	106267.1	106170.8	103763.3	105978.2	105593.0	103089.2

Table 7.4: West orientation overall energy cost calculation

	Base Case	Overhangs			Side-fins			Combined		
		0.5m	1m	1.5m	0.5m	1m	1.5m	0.5m	1m	1.5m
Overall Annual Energy Consumption (MWh)	221.3	220.7	220.1	219.6	221.0	220.8	215.8	220.4	219.7	214.4
Electricity cost (AED) per Kilowatt hour	99585.0	99315.0	99045.0	98820.0	99450.0	99360.0	97110.0	99180.0	98865.0	96480.0
Maintenance cost (AED)	6971.0	6952.1	6933.2	6917.4	6961.5	6955.2	6797.7	6942.6	6920.6	6753.6
Total Energy cost (AED)	106556.0	106267.1	105978.2	105737.4	106411.5	106315.2	103907.7	106122.6	105785.6	103233.6

Meanwhile, Figure 7.2 shows that overhangs could be a slightly better energy saving device than side-fins when integrated to east and west façades, however, Palmero-Marrero (2010) mentioned that in order to provide a well performing overhang for east and west façades, a problem would be faced in terms of the need for having large depths due to the sun position. Hence, vertical shading elements would be preferable in terms of visual comfort, thermal comfort and energy consumption.

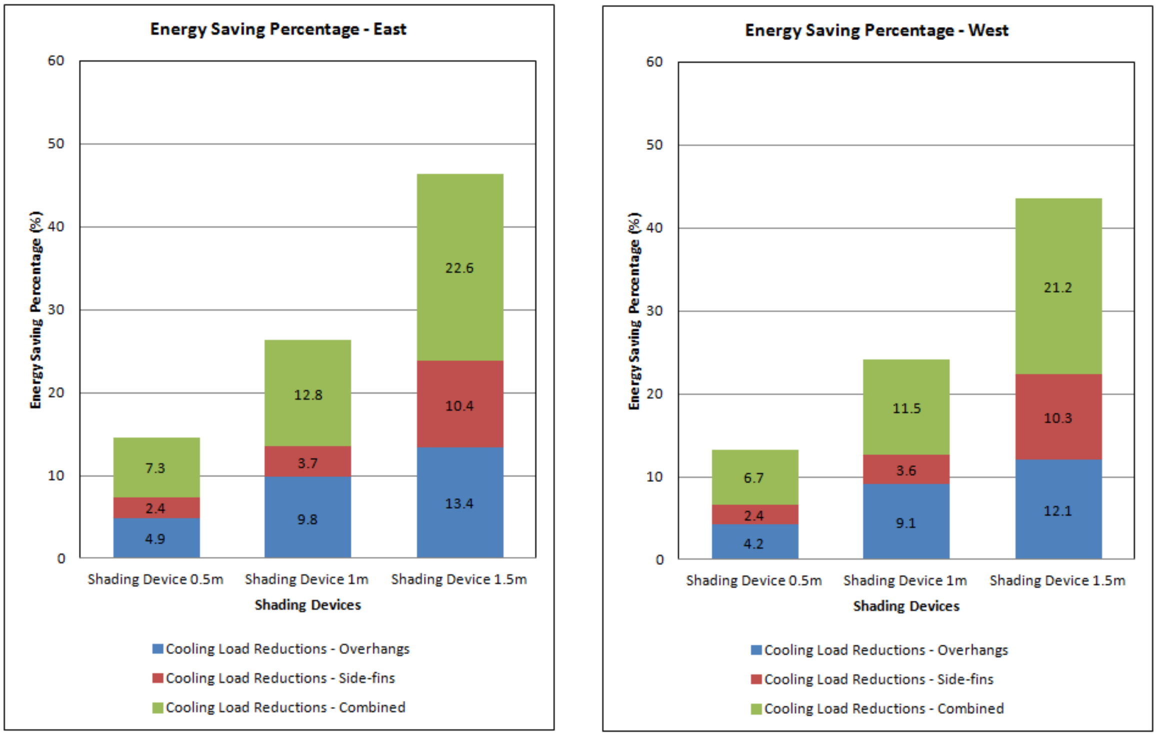


Figure 7.2: Annual energy saving in all cases for east (left) and west façades (right)

CHAPTER 8: CONCLUSION AND RECOMMENDATION

8.1 Conclusion

During the last decades, the focus has been set on reducing the use of energy sources due to its negative environmental consequences in terms of carbon dioxide emissions. Passive techniques reflect valuable benefits in terms of occupants comfort as well as contributing to great savings in energy, which could be challenging issue to meet a balance point that provide beneficial daylighting levels to the space and meanwhile avoiding discomfort glare and space overheating. This study studied integrating overhangs and side-fins to fully glazed office buildings in the tropics, which is highly recommended since mechanical ventilation is an essential, causing a major raise in the building's life cycle costs. IES-VE software was utilized to assess different cases of shading elements to a common office sample in different building orientations throughout the summer and winter seasons. Moreover, shading devices has been proved to be a major factor on changing the path of the energy profile and the building's whole life cycle costs. To conclude, the following are answers to the research questions that achieved the research aim.

Research Question (1)

- *What would be the effect of the base case at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?*

Objective (1)

- *To examine the effect of the base case at different building orientations (North, South, East, West) on thermal comfort, visual comfort and energy consumption in UAE climate.*

Concerning the base case, the north oriented base case encountered for the least illumination levels and illumination intensity, since the façade is almost fully shaded throughout the year, consequently resulting in the least solar gain amount of 5.2 MWh and the least energy consumption of 10.9 MWh annual cooling loads. While, south oriented façades account for the highest illumination levels value of 12.5 MWh due to its high solar radiation, in addition to the high discomfort glare levels. Consequently, it receives high illumination levels and consumes the highest amount of energy of 17.1 MWh. Meanwhile, east and west façades shared close solar gain values of 11.8 MWh and 12.2 MWh respectively. Moreover, moderate illumination and glare levels occur, in addition to average annual energy consumption. As for the peak solar gain, south façades recorded the highest value of 9.9 MWh, while, north façades recorded the least value of 1.8 MWh. Highest percentages of dissatisfied people in summer was observed as 27% and 26% on east and west façades respectively, due to the relatively low solar altitude. Meanwhile, in winter south orientation accounted for the highest percentage of 19% as they tend to receive much more solar radiation in winter than in summer.

Research Question (2)

- *What would be the effect of different overhangs' depths at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?*

Objective (2)

- *To examine the effect of different overhangs' depths (0.5 m, 0.75 m, 1 m) at different building orientations (North, South, East, West) on thermal comfort, visual comfort and energy consumption in UAE climate.*

Concerning the effect of overhangs on the four orientations, the maximum results showed that they seemed to be the most effective on south façades in terms of thermal comfort as they reduce the solar gain by 41.1%, which recorded 18% as the percentage of dissatisfied people in summer. However, in winter it seems to be very effective on the south oriented façades in terms of occupants' comfort reducing the percentage of dissatisfied people to 16% as well as reducing the percentage of glare significantly. Meanwhile, they achieve a maximum reduction in energy consumption of 17%, which indicates a promising impact. Concerning north façades, overhangs reduce solar gains up to 17.3%, which resulted in the lowest percentage of people dissatisfied throughout the year; however, it could have a negative impact on the illumination levels inside the space, since the façade does not receive direct solar rays. Meanwhile, 2.8% is considered the maximum reduction in energy consumption. Although implementing overhangs to east façades reduce solar gain by 34.7% and energy consumption by 13.4%, it is uncomfortable for occupants visually. As for west façades, overhangs seem to be the least effective as it achieves a maximum solar gain reduction of 4.5% only due to the accumulation of heat on the glazing throughout the day, in addition to the low solar altitude. Meanwhile the maximum reduction in energy consumption was recorded to be 12.1%.

Research Question (3)

- *What would be the effect of different side-fins' depths at different office building orientations in UAE on thermal comfort, visual comfort and energy consumption?*

Objective (3)

- *To examine the effect of different side-fins' depths (0.5 m, 0.75 m, 1 m) at different building orientations (North, South, East, West) on thermal comfort, visual comfort and energy consumption in UAE climate.*

Concerning the effect of side-fins, the results showed that they seemed to be equally effective on east and west in terms of thermal comfort, since they reduce the solar gain by 13.6% and 18.6% for east and west orientations respectively. Meanwhile, recording low percentages of people dissatisfied of 26% and 25% for east and west respectively. Moreover, they provide a better visual environment in terms of glare percentage reduction. In addition, they reduce the annual energy consumption by up to 10.4%. Although south façades records a better people dissatisfied percentage of 20% than that of east and west façades since the solar gain is reduced is equal to that achieved by the west façade, it has negative implications on the visual comfort of occupants. Meanwhile, they achieve the highest reduction in energy consumption of 12.4%. Concerning north façades, they are the least affected by implementing side-fins as they reduce solar gains up to 13.4%, meanwhile, 6.4% is considered the maximum reduction in energy consumption, which is fairly low compared to the behavior of east, west and south façades.

Research Question (4)

- *What would be the effect of combining overhangs and side-fins with different depths and different building orientations on thermal comfort, visual comfort and energy consumption in the UAE climate?*

Objective (4)

- *To examine the effect of combining overhangs and side-fins at different depths (0.5 m, 0.75 m, 1 m) and different building orientations (North, South, East, West) on thermal comfort, visual comfort and energy consumption in UAE climate.*

As for combined overhangs and side-fins, the best results belonged to south oriented façades, which succeeded in cutting off the annual solar gain by 55%, resulting in a relevant reduction in the average illumination in the space as well as the percentage of glare. In addition, the percentage of dissatisfied people was recorded to be 20% in winter. In terms of energy consumption, the south orientation account for a 27.5% reduction from the base case, which is considered the best performance among all cases. East and west orientations come at the second place orientations affected by integrating combined overhangs and side-fins since the solar gain is reduced by 44.9% and 54% for east and west façades respectively. Meanwhile, the percentages of people dissatisfied in winter were recorded to be 12% and 13% respectively. Moreover, they achieved reductions in energy consumption of 22.6% and 21.2% respectively. As for the north façade, as it is the case with overhangs and side-fins, it seemed to be the least affected by integrating combined overhangs and side-fins resulting in a reduction of 26.9% in the annual solar gain. In addition, north orientations achieved the least energy saving progress of 8.3%.

Research Question (5)

- *What would be the most economical shading element suitable for each façade orientation?*

Objective (5)

- *To examine the most economical shading method to be implemented to each façade orientation through an economic analysis based on the simulation outputs.*

Economically, it has been proved implementing shading devices to north oriented façades is not economical since the façade receives adequate daylight levels and the least solar gains throughout the year. Meanwhile, implementing shading elements results in a maximum reduction of 26.9% from the base case, however this will encounter the need for artificial daylighting, which would compensate reduction in the costs related to cooling loads. On the other hand, overhangs or combined overhangs and side-fins seemed to be highly economical when integrated to south façades due to the extremely high solar radiation. They tend to achieve a maximum reduction of 27.5% and at the same time having a positive impact on the occupants' thermal comfort in terms of solar gains and percentage of dissatisfied people as well as visual comfort in terms of illuminance and glare levels. As for Side-fins, they have proved to be the best economical solution for east and west façades as they reduce the energy costs by 22.6% and 21.6% respectively. In addition, they provide the best results in terms of occupants’ thermal and visual comfort.

8.2 Recommendation and Future Research

This study addressed a certain type of passive techniques which are shading devices and specifically horizontal overhangs and vertical side-fins, however, the author recommends to perform further research on other shading elements parameters such as assessing the impact of changing the color and the material of the shading device as well as changing its inclination. In addition, different types of glazing could be investigated such as double-glazing and low emissivity glazing. Moreover, the implication of the shading elements could be investigated when changing the building’s construction and finishing materials. Also, further research could be done on the effect of integrating those shading devices on the occupants’ performance in the office. Meanwhile, the simulation process could be performed more detailed by observing all cases during the four seasons of the year instead of summer and winter only, which was due to the time restrictions, especially, that there are no financial restrictions for further studies using computer simulation programs.

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APPENDICES

Figure 1: United Arab Emirates map *[http://www.archtrophy.com]*

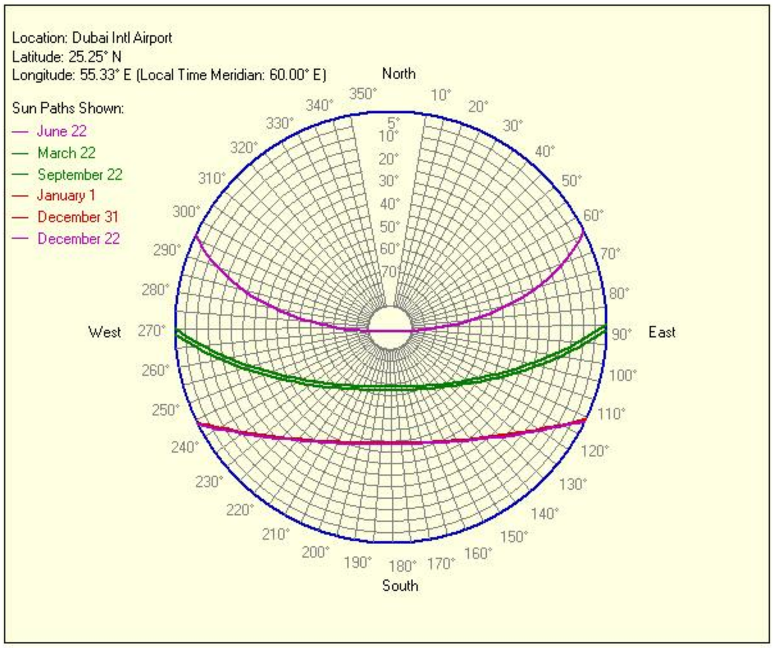

Figure 2: Dubai sun path *[IES-VE, location and site data]*

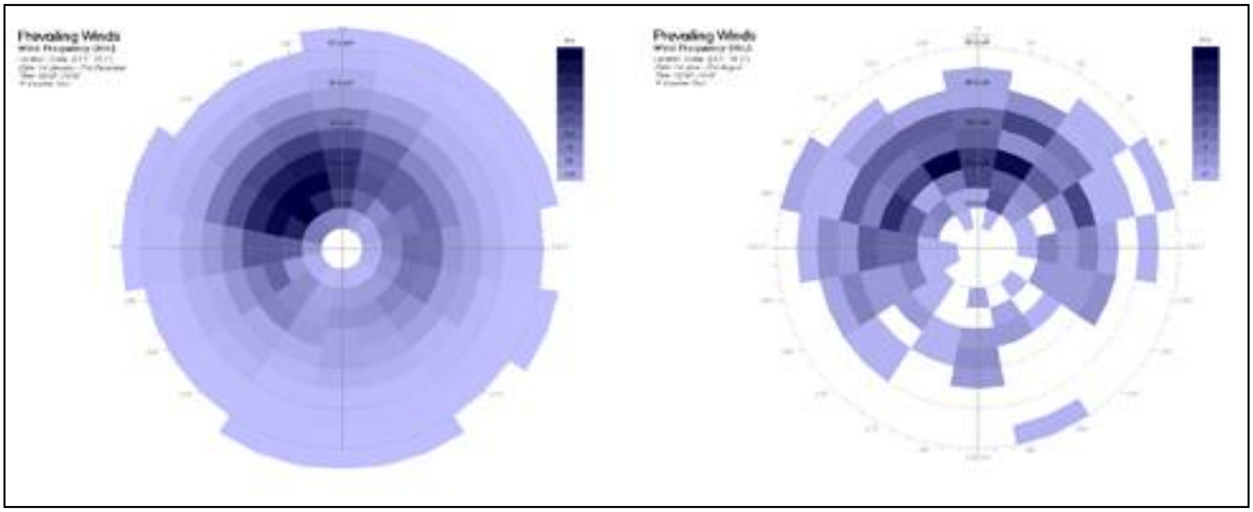

Figure 3: Dubai summer and winter prevailing winds *[Weather tool]*

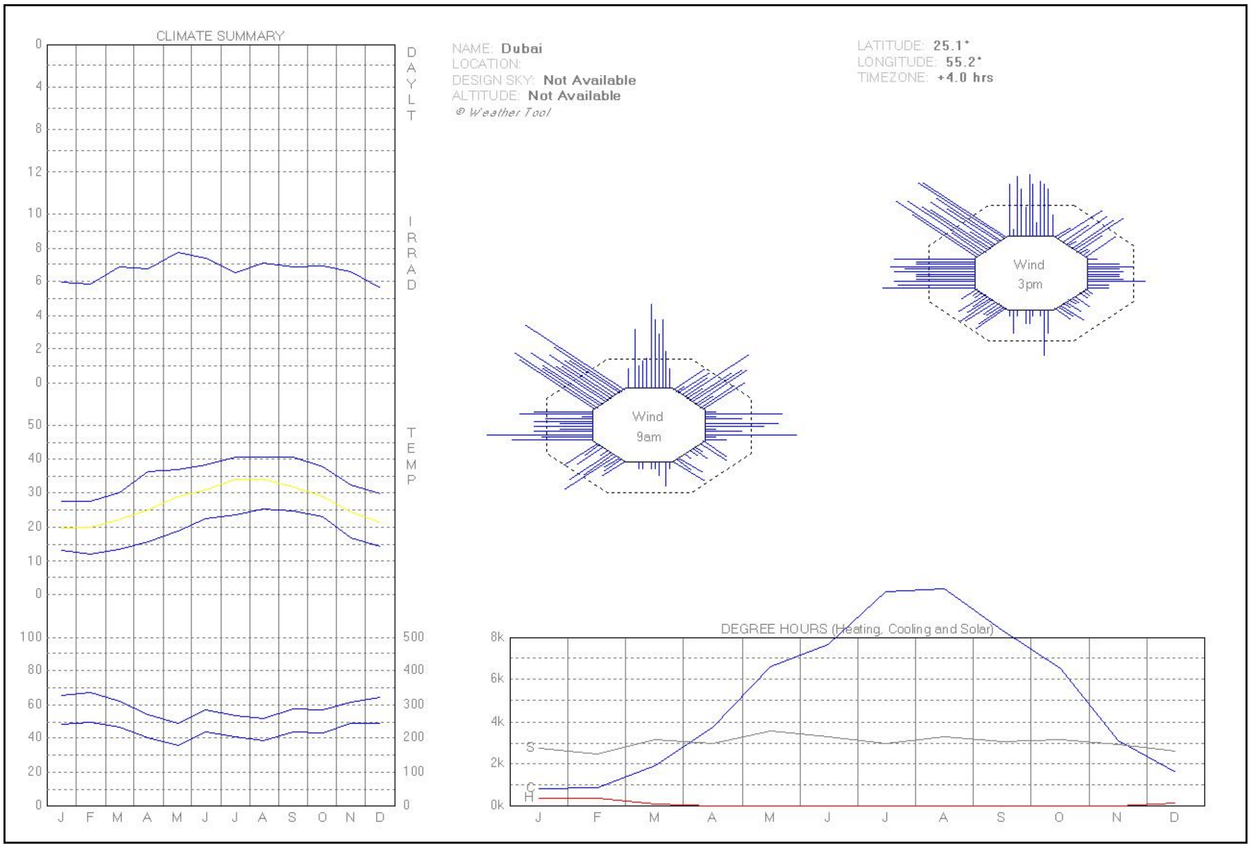

Figure 4: Dubai climatic summary *[Weather tool]*